# China: 40-Year Experience in Renewable Energy Development

*Policies, Achievements, and Lessons Learned*

WORLD BANK GROUP

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***Policies, Achievements, and Lessons Learned***

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# Abbreviations

| | |
|---|---|
| ABC | Agricultural Bank of China |
| APAC | Asia-Pacific |
| ASEAN | Association of Southeast Asian Nations |
| BOS | Balance of System |
| CCICED | China Council for International Cooperation on Environment and Development |
| CDM | Clean Development Mechanism |
| CFB | Circulating Fluidized Bed |
| CHP | Combined Heat and Power |
| CIGS | Copper Indium Gallium Selenide |
| CIWRHR | China Institute of Water Resources and Hydropower Research |
| CMA | China Meteorological Administration |
| CNCA | Certification and Accreditation Administration of the People's Republic of China |
| CNREC | China National Renewable Energy Center |
| COD | Chemical Oxygen Demand |
| CPC | Communist Party of China |
| CPIA | China Photovoltaic Industry Association |
| CRESP | China Renewable Energy Scale-Up Program |
| CSIC | China Shipbuilding Industry Company |
| CSP | Concentrated Solar Power |
| CWEA | Chinese Wind Energy Association |
| EMCA | China Association of Energy Management Companies |
| ESCO | Energy Saving Services Company |
| FiT | Feed-In Tariff |
| FYP | Five-Year Plan |
| GDP | Gross Domestic Product |
| GEF | Global Environment Facility |
| GHG | Greenhouse Gas |
| GIZ | German Agency for International Cooperation (*Deutsche Gesellschaft für Internationale Zusammenarbeit*) |
| HJT | Heterojunction Technology |
| HVDC | High-Voltage Direct Current |
| ICSHP | International Small Hydropower Center |
| IEC | International Electrotechnical Commission |
| IFC | International Finance Corporation |
| IPP | Independent Power Producer |
| MoA | Ministry of Agriculture |
| MoALF | Ministry of Agriculture, Livestock, and Fisheries |

| | |
|---|---|
| MoARA | Ministry of Agriculture and Rural Affairs |
| MoF | Ministry of Finance |
| MoIIT | Ministry of Industry and Information Technology |
| MoST | Ministry of Science and Technology |
| MoWRE | Ministry of Water Resources and Electricity |
| MSW | Municipal Solid Waste |
| NDC | Nationally Determined Contribution |
| NDRC | National Development and Reform Commission |
| NEA | National Energy Administration |
| NEC | National Economic Commission |
| NPB | National Price Bureau |
| NPC | National People's Congress |
| NSTC | National Science and Technology Commission |
| PERC | Passivated Emitter and Rear Cell |
| PPA | Power Purchase Agreement |
| PV | Photovoltaic |
| R&D | Research and Development |
| RE | Renewable Energy |
| REDP | Renewable Energy Development Project |
| RPS | Renewable Portfolio Standards |
| SDGs | Sustainable Development Goals |
| SEMI | Semiconductor Equipment and Materials International |
| SETC | State Economic and Trade Commission |
| SEZ | Special Economic Zone |
| SMEs | Small and Medium Enterprises |
| SOE | State-Owned Enterprise |
| SPC | State Planning Commission |
| UASB | Up-flow Anaerobic Sludge Bed |
| UNDP | United Nations Development Programme |
| UNESCO | United Nations Educational, Scientific, and Cultural Organization |
| UNIDO | United Nations Industrial Development |
| VAT | Value Added Tax |
| WED | Wind Energy Development |
| WTO | World Trade Organization |

# Preface

The journey that China started a few decades ago to develop renewable energy (RE) led to impressive results. In less than 40 years, China has moved from a lagger to a global leader status. While the energy demand has steadily grown at an unprecedented pace, frequently at a double-digit growth rate, the share of renewable in the total primary energy consumption ramped up from 4 percent in 1980 to about 13.1 percent in 2019, delivering considerable benefits in terms of avoiding local pollution and global greenhouse gas (GHG) emissions.

The installed capacity of RE power generation increased from slightly more than 20 gigawatts (GW) in 1980, mostly from hydropower, to nearly 795 GW in 2019, the largest capacity in the world, accounting for more than 31 percent of the global installed capacity. It surpassed the combined capacity installed in the United States, Brazil, and Germany by 44 percent.[1] By 2019, installed hydropower capacity had reached more than 358 GW, followed by wind with 210 GW, solar with 204 GW, and others combining for 22 GW. The total accounted for 39.5 percent of China's generation capacity, with hydro totaling 17.8 percent, wind 10.4 percent, solar 10.2 percent, and other technologies (mainly biomass) slightly more than 1.1 percent. In terms of energy generated, renewables accounted for about 27.9 percent of the country's total power generation in 2019.

With the support of the China-World Bank Partnership Facility, a team composed of Chinese experts and World Bank energy specialists, directed by the World Bank-China Energy Unit coordination, explored the considerable experience that China has accumulated over the last 40 years. In doing so, it looked for the lessons that could be learned from that experience and then shared with other developing countries engaged in the same challenge of ramping up their own production and consumption of renewable energy. This report, prepared by the World Bank, therefore presents the findings that the World Bank found the most interesting and relevant for dissemination to other countries where it also supports the development of renewable energy.

While the Chinese experience is country specific in many aspects, still, the diversity of contexts, in terms of both natural resources regional endowment and economic development, and the multiple successive stages of development of the renewable industry China went through, regarding the manufacturing and the project industries, offer multiple opportunities for smaller developing countries to identify similarities with their own present challenges.

The purpose of this report is thus to unveil the most valuable aspects of the Chinese experience along that long journey that can be useful today to other developing countries, particularly with respect to policy design and implementation.

To facilitate the identification of and the access to the lessons that are the most relevant to each of these countries, the team organized the development of renewables in China in successive stages. These stages can vary from one RE source to the other, and thus the overall analysis of RE policies in China in the four last decades (Chapters 3 to 5) is complemented by four chapters focusing specifically on the four major RE sources: hydropower, wind energy, solar photovoltaic (PV), and biomass (Chapters 6 to 9).

This report offers several levels of reading. Chapter 1 offers the overall view of this long journey 'from lagger to leader' and guides the reader into the rest of the report. This introduction can be read as an executive summary. Then, depending on the main interest of the reader, either for the overall national renewable policy framework or for more technology-specific lessons, he or she can delve into the corresponding two sets of chapters.

1 Source: Renewable Energy Statistics 2019, IRENA.

Still the breadth of the undertaking was considerable, covering four industries that have become world leaders, over an exceptionally long period of four decades, since the very birth of these industries in China. Thus, there is a delicate balance between granularity and conciseness to containing the size of this report to around 100 pages. In many cases, entering into more granular details, would have inflated the text with more Chinese context-specific additions, which might have diluted the relevance of the report for an audience looking for lessons that could be translated into their own contexts.

Therefore, the hope of the World Bank and the Chinese experts who worked arduously on this report, many of whom have directly participated in the journey of several decades, is that this report has produced enough value for practitioners engaged in developing renewable energy in other countries to pursue a direct South-South knowledge exchange with Chinese counterparts and thus further learn from them, including by establishing a fruitful cooperation.

The World Bank has been supporting this successful development of the renewable energies in China since the beginning, financing projects and producing analytical works to support its Chinese counterparts in shaping and revising successive policies and programs. Multiple assessments of these supports, not only by the internal assessment department of the World Bank but, more importantly by the Chinese authorities themselves, have confirmed the catalytical role of the partnership. Therefore, this main report is accompanied by a separate paper,[2] which focuses more on this partnership along the same period. This companion paper will hopefully also inspire and provide ideas to practitioners, from the World Bank itself and other international cooperation institutions working on renewable energy in other countries as well as their national counterparts, to develop their own partnerships for t further development of renewable energy across the developing world.

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2 Renewable Energy Development in China: A 40-year China-World Bank Partnership.

# Acknowledgments

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It was produced by a team of Chinese and international experts led by Christophe de Gouvello, Coordinator of the World Bank-China Energy Team, and Yanqin Song, World Bank Senior Energy Specialist.

The main international expert and international contributor was Noureddine Berrah, who worked for more than 30 years with the World Bank and the China energy sector authorities on the development of the China energy sector and in particular on the development of renewable energy in China.

The Chinese experts team consisted of Mr. LI Jufeng, First Director and Chairman of Academic Committee of National Center for Climate Change Strategy and International Cooperation (NCSC); Mr. WANG Weiquan, Secretary General, Energy & Environment Committee of China Energy Research Society; Ms. Li Dan, Executive Secretary General, Chinese Renewable Energy Industries Association(CREIA); Mr. YUAN Xiaoyang, Project Specialist, Chinese Renewable Energy Industries Association; Ms. WANG Qian, Project Specialist, Chinese Renewable Energy Industries Association; Ms. MA Lifang, Policy Research Director, Chinese Renewable Energy Industries Association; Mr. YU Yang, Project Specialist, Chinese Renewable Energy Industries Association.

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# Chapter 1. Introduction

**Key Messages**

China leapfrogged from a laggard to a leader in renewable energy (RE) development in less than four decades: (a) installed RE power generation capacity increased from about 20 GW in 1980 to nearly 795 GW in 2019, the largest capacity in the world, accounting for more than 31 percent of the global RE generation installed capacity and (b) total commercial renewable energy utilization increased from about 24 million tons of coal equivalent (tce) in 1980, about 4 percent of the total primary energy consumption, to 637 million tce in 2019, about 13.1 percent of the country's primary energy consumption.

Up to 2017, China's RE development can be divided into three stages, marked by two major policies:

- **The first stage titled 'The Early Years' extends up to 1994,** the year of the adoption of China's 'Agenda 21', which identified RE as an independent energy subsector. This marked an uptick in hydropower development, reaching 49 GW, and during this stage, China initiated several international cooperation and pilot projects for wind and solar, reaching 29 MW of wind and 5 MW of solar photovoltaic (PV). The use of RE began to extend from rural areas to the entire energy system in China. The non-power RE utilization also increased significantly with the installation of 2.9 million $m^2$ of solar heaters and the 1.3 billion $m^2$ of biogas production per year. **Main lessons from this period:** balance top-down with decentralized approach, engage volunteers from the local population, establish strong research and development (R&D) institutions to build knowledge base and provide decision-makers with sound objective information, ensure demonstration pilots before scale-up, learn from international experience, and seek cooperation.

- **The second stage titled 'The Takeoff' covers the period from 1995 to the adoption of the 'Renewable Energy Law' in December 2005.** During this stage, China moved from small and modest demonstration projects, especially wind, to commercial projects supported by bilateral and multilateral institutions to introduce advanced technologies and industry best practices in project preparation and operation and build technical capacity. During that stage, RE power installed capacity increased significantly, except for PV, reaching 117 GW of hydropower, 2 GW of biomass, 1.26 GW of wind, and 70 MW only of PV. Non-power RE utilization also increased noticeably with the installation of 80 million $m^2$ of solar heaters, the equivalent of 2 million tce per year of geothermal heating, and production of 8 billion $m^3$ of biogas per year. **Main lessons from this period:** strong commitment and subsidization are necessary, but not sufficient, conditions for large-scale RE development; clear mid- and long-term ambitious goals are prerequisites to develop sustainable RE development; a sound bid evaluation methodology is essential to the success of competition; and continued international cooperation is important to improve knowledge and build capacity.

- **The third stage titled 'From Lagger to Leader' covers 2006 to 2017.** After the issuance of the Renewable Energy Law, China committed to ambitious RE development targets, which were always achieved or surpassed, except for biomass. During successive Five-Year Plans (FYPs) (2006 to 2020), the development was supported by several policies and fiscal and financial incentives, which included feed-in tariffs, state and provincial capital subsidies, and specific initiatives such as the 'Top Runner' and 'Golden Sun' PV programs. These propelled China to a leading position in RE development and reach by 2017 hydropower of 341 GW, wind power of 164 GW, and solar PV of 130 GW. **Main lessons from this period:** feed-in tariffs are effective in building capacity but could lead to inacceptable levels of subsidies in case of a dramatic drop of actual investment costs; aggressive RE development programs can lead to inefficiency, including curtailment; and fast development allowed China to quickly develop a globally competitive wind and PV industry.

**The period from 2018 to present is titled 'The Way Forward'.** Major changes have been undertaken by the government to address the ballooning subsidies stemming from the momentous increase in capacity and electricity production of wind at the beginning of the third stage followed by PV as the prices began to decrease in the late 2000s. It is expected that (a) the development of renewable energy will be more market oriented and the auction approach will be streamlined and regulated; (b) renewable energy would be deployed at a faster pace following the issuance of the Quota Policy in 2019, imposing RE obligations on distributors and large consumers (Chinese version of renewable portfolio standards [RPS]); (c) the emergence of battery and other means of power storage and their decreasing costs would make intermittent technologies, mainly PV, more prominent in China's energy growth; and (d) the enactment of the new Energy Law, under consultation, would address the inconsistencies among the different laws governing the sector and adapt the legal framework for a future characterized by the increased dominance of RE.

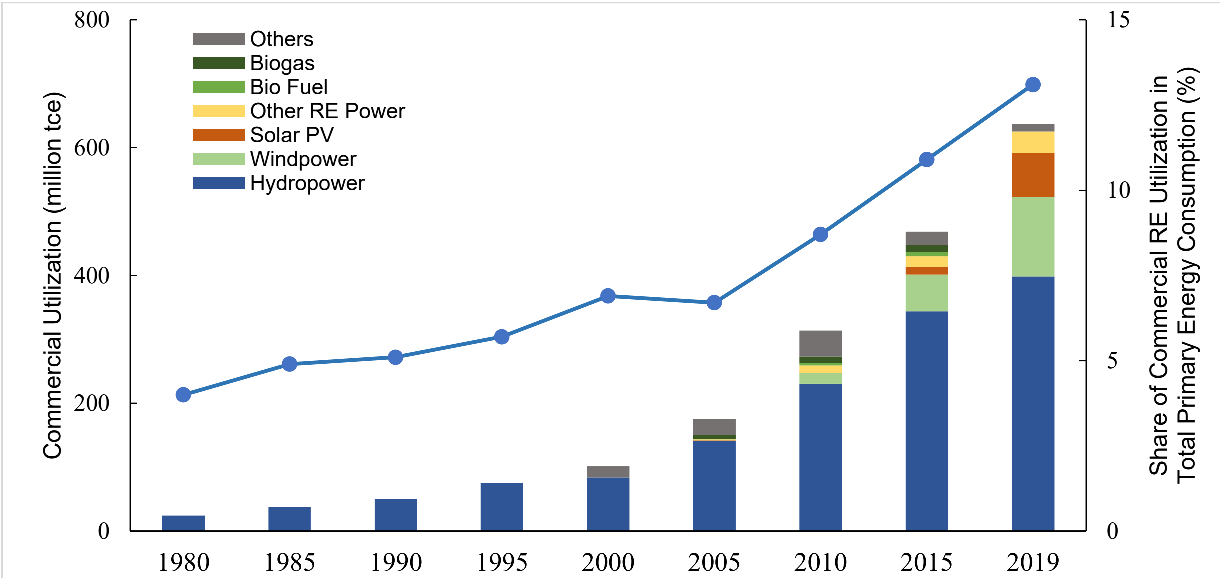
1. China made impressive progress in developing renewable energy to provide access to clean energy and electricity to its predominantly rural population before the economic boom that followed the 'open door policy',[3] by improving energy supply to the economy as the country industrialized and urbanized at an extremely fast pace and finally by fighting debilitating local pollution and mitigating the impact of climate change. Through that journey, China has accumulated a considerable amount of experience and learned many lessons. Its evolution from a low-income to a middle-high income country and its wide geographical diversity brought about extensive challenges, many of which are similar to those facing a wide range of developing countries who are willing to further rely on renewable energy to address their own energy needs. This report attempts to present the Chinese rich and diversified experience and draw the lessons learned that might inform decision-making in these countries.

## A. From Lagger to Leader

2. The total commercial RE utilization increased from about 24 million tce in 1980, about 4 percent of the total primary energy consumption, mainly from small hydropower and biogas, to 637 million tce in 2019, about 13.1 percent of the country's primary energy consumption (see Figure 1.1). This progress contributed to achieving the 15 percent of non-fossil fuel (nuclear and RE) share in the primary energy consumption target set for 2020 by the middle of the 13th FYP (2016–2020), more than one year ahead of schedule.

3 In China's modern economic history, the open door policy refers to the new policy announced by Deng Xiaoping in December 1978 to 'open the door' to foreign businesses that wanted to set up in China. Special economic zones (SEZs) were set up in 1980 to attract foreign direct investment, which was deemed necessary to modernize China's industry and boost its economy.

**Figure 1.1: Commercial Renewable Energy Utilization and Share of Primary Energy Consumption**




Source: Study team[4].

3. The installed capacity of RE power generation increased from slightly more than 20 GW[5] in 1980 to nearly 795 GW in 2019, the largest capacity in the world, accounting for more than 31 percent of the global installed capacity. It surpassed the combined capacity installed in the United States, Brazil, and Germany by 44 percent.[6]

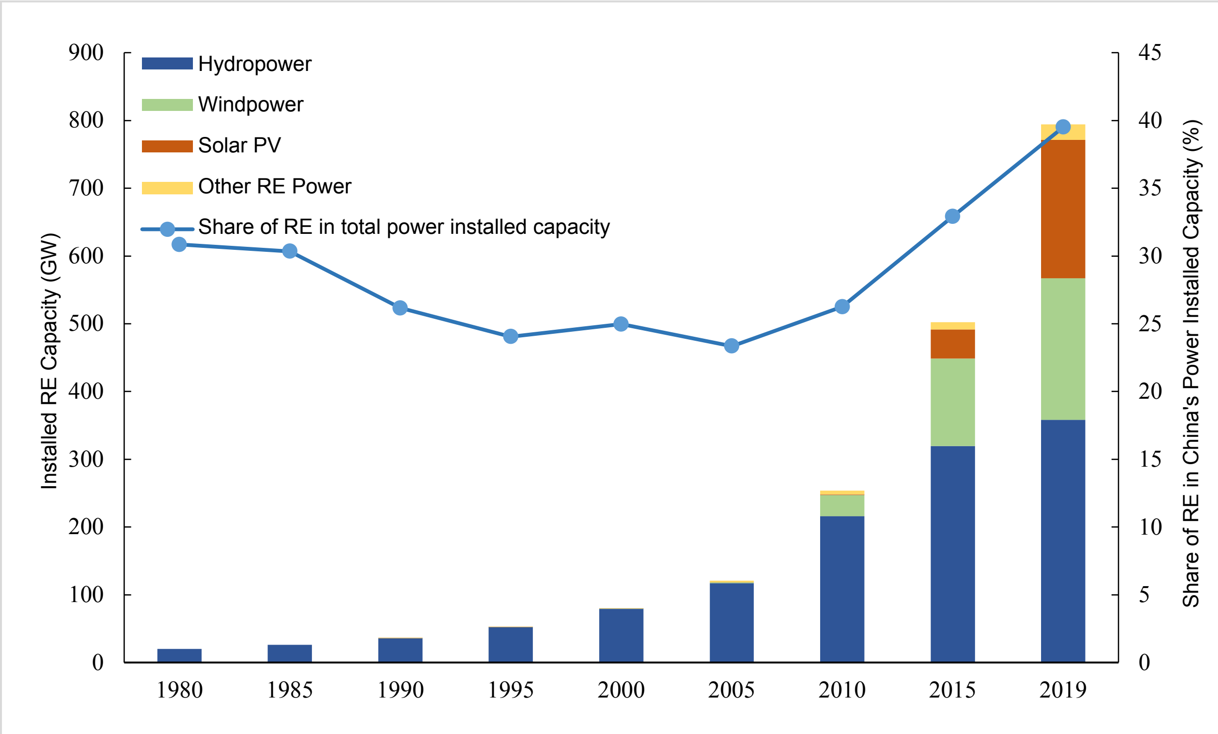
4. Hydropower plants, large and small, amounted to 20 GW in 1980, about 30 percent of China's installed power generation capacity. By 2019, installed hydropower capacity had reached more than 358 GW, followed by wind with 210 GW, solar with 204 GW, and others combining for 22 GW. The total accounted for 39.5 percent of China's generation capacity, with hydro totaling 17.8 percent, wind 10.4 percent, solar 10.2 percent, and other technologies (mainly biomass) slightly more than 1.1 percent (see Figure 1.2).

4 Based on China Energy Statistical Yearbook 2018, China Renewable Energy Data Book 2012 and 2019. The 2019 data of biofuel and bio gas are not published yet.

5 This important number is indicative of the efforts deployed by China to develop RE to provide its huge rural population with modern energy. However, it remains modest compared to the size of the population, and the installed capacity per capita at the time was about 20.4 W.

6 Source: Renewable Energy Statistics 2019, IRENA.

**Figure 1.2:** RE Installed Capacity and Share in Total Installed Capacity in China

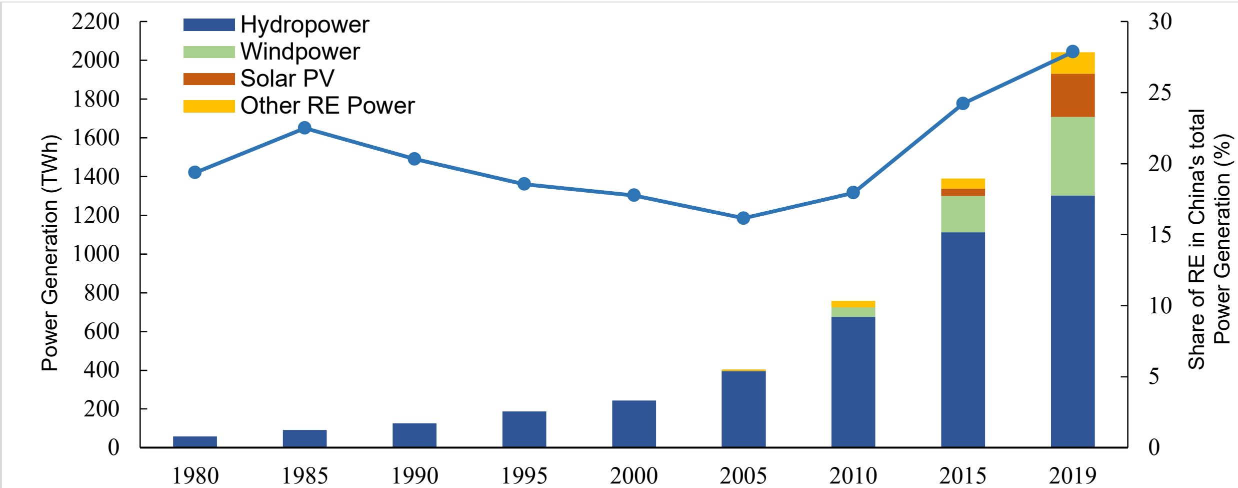



Source: Study team.[7]

5. RE power generation increased from 58 terawatt-hours (TWh) in 1980, mainly from hydropower, to 2,042 TWh in 2019, when it accounted for about 27.9 percent of the country's total power generation. In 2019, hydropower accounted for 17.8 percent of China's power generation, followed by wind for 5.5 percent, solar for 3.1 percent, and other technologies combining for 1.5 percent (see Figure 1.3). In 2018, it exceeded the combined RE power generation of the United States, Brazil, and Canada by about 15 percent.[8]

7 Based on China Electricity Council's Statistical List of Power Basic Data.
8 Source: Renewable Energy Statistics 2019, IRENA.

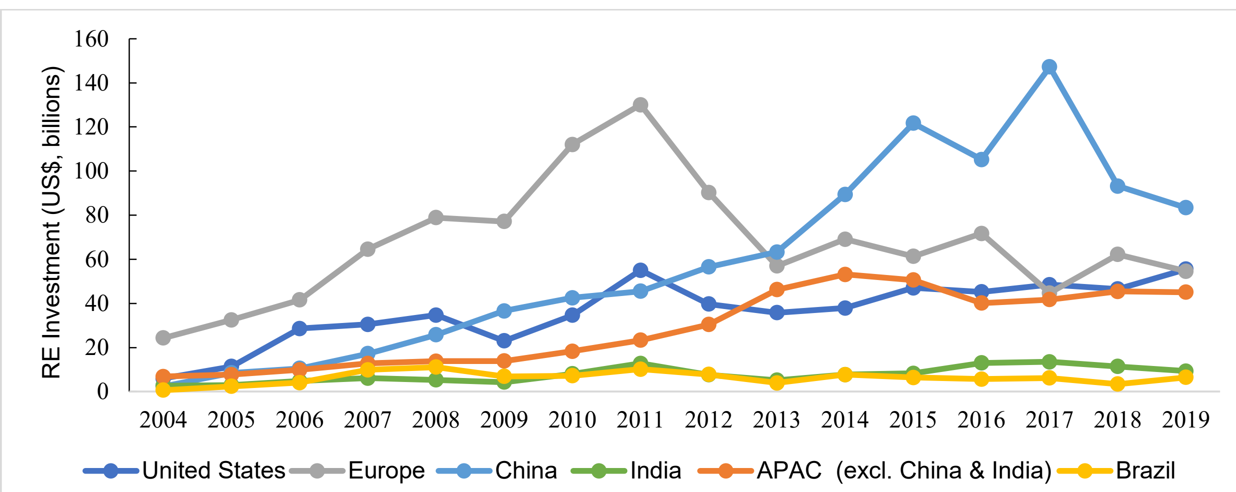
**Figure 1.3:** RE Power Generation and Share in Total Power Generation in China




Source: Study team.[9]

6. Moreover, China's RE investment (excluding large hydro) soared in 2017 to US$147.2 billion, only slightly lower than combined investments in Europe, the United States, and other Asia-Pacific (APAC) countries. Although China's RE investment dropped to US$83.4 billion in 2019, it remained the largest RE investment in the world (see Figure 1.4).

**Figure 1.4:** RE Investment in Selected Countries and Regions




Source: The study team, based on data from Frankfurt School and UNEP (United Nations Environment Programme) Center/BNEF. *Global Trends in Renewable Energy Investment(2020 and 2019.*

7. RE development brought about significant social, economic, and environmental benefits:

- By 2016, the country's entire population had access to electricity. In recent years, 'PV poverty alleviation' programs increased the annual income of 4.15 million poor households by at least CNY 3,000 (equivalent to US$435). China's RE industry is currently among the global leaders, especially in wind and solar PV, providing about 5 million jobs.

9 China Electricity Council's Statistical List of Power Basic Data.

- It contributed significantly to curbing the momentous air pollution of the early 2010s and mitigating climate change impacts by avoiding annual $SO_2$ emissions of 2.24 million tons, ash emissions of 224 million tons, and $CO_2$ emissions of 1.53 billion tons in 2018.[10]

## B. The Long Journey

8. China's RE development can be divided into three stages marked by two major milestones (Figure 1.5), which help identify successive challenges and policies undertaken to address them and thus relevant lessons for other countries facing challenges that are similar to the ones China faced and addressed at each of these stages.

   (a) China's 'Agenda 21', adopted in 1994, identified RE as an independent energy subsector[11] and one of China's main development anchors for the first time. This marked the beginning of China's planned implementation and development of emerging RE, mainly wind power and solar.

   (b) The issuance of the 2005 Renewable Energy Law established five basic measures to promote the development of non-hydro RE in China:

   - The announcement of ambitious overall, and later technology-specific, RE targets for the medium and long term which provided clear signals to developers, investors, and other market players about the expected growth of the RE market

   - The legal requirement that all power grid companies purchase the full amount of on-grid RE electricity and ease access of RE electricity to the power systems

   - The assurance that the 'on-grid prices' of RE electricity would provide investors and developers adequate returns on investment for the development and utilization of RE. The prices were differentiated by region and evolved over time to sustain the unprecedented development of RE in the country.[12]

   - The surcharge levied on each kWh of electricity consumption that shared the financial burden among all electricity consumers and supported pilot and R&D projects

   - The establishment of a Special Fund,[13] funded by consumer fees and state budget, to provide subsidies that made RE electricity more attractive to investors.

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10 The avoided emissions were calculated comparing the actual emissions to a hypothetical case where RE consumption is replaced by standard coal consumption (commercial RE consumption in tce times standard coal's emission factors). Source: Chinese Academy of Engineering, Renewable Energy Law Implementation Assessment Report 2018.

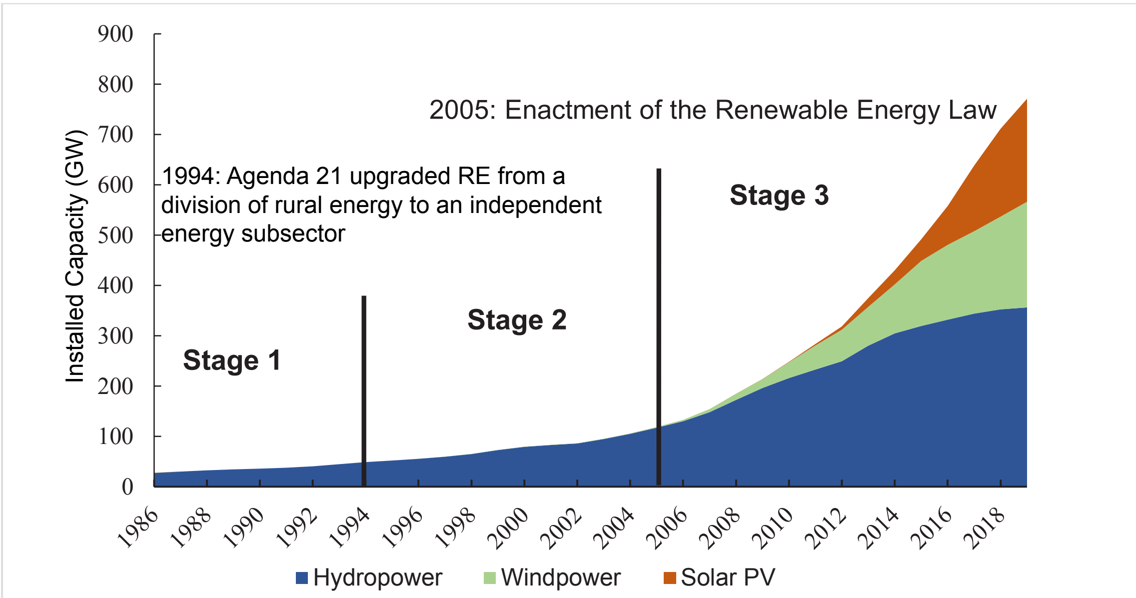
11 Before the adoption of Agenda 21, RE developed was supervised by rural energy departments at different administrative levels.

12 "The success of China's renewable energy drive fully illustrates the effectiveness of China's on-grid tariff subsidies. The advantage of the on-grid tariff policy - through which the government can make renewable energy production more competitive and attractive to businesses and investors - is that it anchors the revenue of power generation throughout the entire life cycle. In this way, it conveys a clear price signal to investors, and can effectively support the early stages of renewable energy development." Source: Boquiang, Lin. 2018. "China Is a Renewable Energy Champion. But It's Time for a New Approach", China Center for Energy Economics Research, World Economic Forum. May 22, 2018.

13 Before 2010, the Special Fund, managed by the Ministry of Finance (MoF), was fully endowed by budget resources and dedicated to demonstration projects, R&D programs, resource evaluation projects, standard development projects, and remote area electrification projects, and consumer fees to compensate RE developers for costs not covered in electricity prices were collected and allocated by the National Development and Reform Commission (NDRC). After 2010, consumer fees were also incorporated in the RE Fund to unify the management of RE financial resources. However, the management of the two sources of funds remained separate.

(c) The ‘Notice on matters related to photovoltaic power generation’ in 2018 was issued following the unprecedented decrease in the cost of PV systems. It initiated a new era in China’s RE development characterized by the phasing out of subsidies, increased market orientation, and increased efficiency of PV installed capacities.

**Figure 1.5: Major Renewable Energy Installed Capacity and Milestones**




Source: Study team.

## C. Structure of the Report

9. This report was prepared by the World Bank energy team based on a comprehensive data collection and extensive analytical work by senior Chinese consultants. It is dedicated to the evolution of RE development in China paralleling the triple transition—from command-and-control to increased market orientation, from a rural to an urban society, and from a medium-size, deficient energy sector to the largest energy sector in the world.

10. The report consists of two parts. Part 1 comprises Chapters 2 to 4 which are dedicated to the three stages of RE development and the main events, policies, and triggers that led to the deployment of RE technologies at a large scale and Chapter 5 which highlights the initiatives and policies to address the problems that emerged at the end of the third stage and put RE development on a sustainable path. Part 2 covering Chapter 6 to 9 focuses on the four main technologies—biomass, hydropower, wind, and solar energy—detailing the technical policies and regulations that led to the development of competitive industries that accompanied, promoted, and facilitated the important contribution of these RE sources in meeting the country’s primary energy needs.

11. The two parts assess the RE development in China from two different but intertwined perspectives:

- On the one hand, the commitment of China’s decision-makers to develop policies and initiate bilateral and multilateral international cooperation programs that (a) at the outset, mostly benefitted state-owned enterprises (SOEs) and led to momentous scale-up of wind and hydropower that triggered and sustained the development of RE manufacturing—all the SOEs were partially or totally reformed through listing in domestic and international markets; (b) allowed the return of Chinese entrepreneurs and allowed them to create privately owned companies that triggered the development of solid, innovative, and technologically advanced companies that created the backbone of the country's PV manufacturing; and (c) provided ad hoc and differentiated support to biomass, especially biogas and biofuels.

- On the other hand, the quality improvement and cost reductions achieved by the industry for each of the four main RE technologies triggered government policies and support that extended the market of the technologies and contributed to accelerating the growth of RE utilization.

12. The two parts tell the interlinked stories that propelled China to the forefront of RE development and manufacturing.

**Part 1: The Quest for Sustainability**

13. Part 1 is dedicated to the development and use of RE, which in the first stage evolved from small hydropower and biomass (mainly biogas and firewood) focusing predominantly on the rural population until the early 1980s to large hydropower to ease power shortages that constrained the economic boom following the 'open door policy'. During the second stage, the government focused on testing emerging wind and solar technologies, improving the design and management of large hydropower projects, and building institutions to expand the use of renewable energy. The enactment of the Renewable Energy Law in 2005 opened the door for the unprecedent boom of wind and solar technologies during the third stage. Finally, in the next stage of RE development, the Chinese government focused on measures to phase out subsidies and increase the market orientation of the RE subsector to progressively and aggressively increase the share of RE in the energy.

14. Chapter 2 focuses on the first stage (up to 1994) during which China managed to maintain a quasi-energy autarky and faced acute insufficiency of energy supply, especially in rural areas. This led to increased deforestation and indoor pollution stemming from the extensive use of coal and wood. To address these issues, China mainly focused its efforts on developing RE to address the energy needs of rural areas and build the foundation for more ambitious RE development. The development of renewable resources was limited, except for hydropower, given the size and the population of the country. By the end of 1994,

- Hydropower, wind power, and solar PV amounted to 49 GW, 29 MW, and 5 MW, respectively, which is less than 25 percent (for hydropower) and less than 0.1 percent (for wind and solar) of total installed generation capacity and

- A total of 5.4 million biogas digesters produced about 1.3 billion $m^3$ of gas annually, and 2.3 million $m^2$ of water heaters were installed nationwide.

The government focused on coordinating the efforts of the concerned ministries and establishing research and technical institutes to promote and support the development of renewable energy.

15. Chapter 3 examines the second stage of RE development (1995–2005). During this period, the development of RE was promoted as an essential part of improving energy security, environmental protection, and sustainable development. In line with the 'Agenda 21', the use of RE began to extend from rural areas to the entire energy system in China, and its development was emphasized for the first time in the 10th FYP (2001 to 2005). By end of 2005,

- RE power installed capacity increased to 117 GW hydropower, 2,000 MW biomass, 1,270 MW wind, and 70 MW solar PV.

- Non-power RE utilization also increased significantly with the installation of 80 million $m^2$ of solar heaters, 2 million tce of geothermal heating per year, and 8 billion $m^3$ of biogas production.

16. Major new players emerged as the 1995 Electricity Law transformed incumbent national and provincial power utilities from monopoly holders to single buyers and allowed the entry of nonutility generators to ease the financial constraints facing the power sector. This mainly favored the development of hydropower during this stage but opened the door to future development of wind and PV bases. Wind power took off owing to a series of demonstration programs supported by the State Economic and Trade Commission (SETC) and State Planning Commission (SPC), now the NDRC, and after China ratified the Kyoto Protocol and committed to its development at the 2004 Bonn Renewable Energy Conference, thus generating an additional momentum for RE development. The SPC launched a program of 'supplying power to townships', which promoted RE to address power supply problems and provide access to electricity in rural areas.

17. During this stage, international aid and cooperation also began to extend from demonstration to commercial projects and introduction of industry best practice. For example, in 2004, the Fujian provincial government requested a World Bank loan to develop one of the first 100 MW commercial wind farms in Pingtan. The project was based on a full year of resource assessment, state-of-the-art design and micro siting, and detailed preparatory works before construction. The equipment was procured through international competitive bidding that led to use of foreign turbines, with subcontracting of the construction of the foundation and many assembly activities to Chinese companies to reduce the project cost.

18. Chapter 4 focuses on the third stage (2006–2017) and the development of renewable sources after the issuance of the Renewable Energy Law. China embarked on momentous scale-up of hydropower, wind, and solar and by 2017

- Hydropower capacity reached about 341 GW, wind power capacity about 164 GW, PV capacity 130 GW, and biomass capacity about 15 GW and

- Biogas production increased to about 14.5 billion $m^3$, and bioethanol production amounted to more than 2.6 million tons. RE heating also increased with the installation of 478 million $m^2$ of solar heaters and geothermal heating systems displacing 20 million tce of coal use per year.

19. This unpresented surge stemmed from the commitment to ambitious RE development targets that, with the exception of biomass power, were always achieved or surpassed. In the 11th, 12th, and 13th FYPs, the development was supported by several policies and provision of fiscal and financial incentives, which included feed-in tariffs for several RE technologies, state and provincial capital subsidies, and specific initiatives such as the 'Top Runner' and 'Golden Sun' PV programs. To address quality and operational/ curtailment issues, [14] China (a) adjusted policies and incentives to overcome the resistance of incumbent utilities through the adoption of quality standards and improved grid codes to reduce disturbances on the grid; (b) stepped up R&D to adapt turbines to China's wind characteristics and bring their quality up to international standards; and (c) built capacity in the design and operation of wind and solar bases. As

14 Onshore wind energy resources and solar energy resources are mostly located in the 'Three North' area, far from load centers. The fast development of wind power and solar PV in the area resulted in serious problems of wind power evacuation and system balancing because local electricity markets were incapable of absorbing all generated electricity. Delivering electricity to the load center in east and south coastal areas is a requisite to address the issue. However, due to transmission capacity constraints and fiscal disincentives, electricity generated in the 'Three North' area was curtailed.

RE generation increased dramatically, a major challenge emerged in this stage as subsidies ballooned, surpassing the amount collected from consumers to support RE development and imposing a huge burden on the state budget. [15] Following the quality improvement and significant cost reduction of wind and PV, the National Energy Administration (NEA) initiated several pilot wind and PV auctions, which resulted in lower prices than the benchmark price issued by the NDRC.

20. Chapter 5 assesses the major changes undertaken or considered by the government to gradually eliminate subsidies as manufacturing prices continue to decrease and auction became the primary method to set RE-based power generation prices. It is expected that (a) the development of renewable energy will be more market oriented and the auction approach will be streamlined and regulated; (b) renewable energy would be deployed at a faster pace following the issuance of the quota policy in 2019, imposing RE obligations on distributors and large consumers; (c) the emergence of battery and other means of energy storage and their decreasing costs would make intermittent technologies, mainly PV, more prominent in China's energy growth; and (d) the enactment of the Energy Law, under preparation, would address the inconsistencies among the different laws governing the sector and adapt the legal framework for a future characterized by the increased dominance of RE.

### Part 2: The Technological and Industrial RE Leap Forward

21. Part 2 is dedicated to the technological and industrial development that propelled China's RE manufacturing industry, especially wind and PV, to leadership status. It describes the major institutions involved and the policies and standards issued to bring equipment quality to recognized international standards.

22. Chapter 6 describes the development of the hydropower industry. The early years of RE development were not conducive to manufacturing large hydropower turbines. However, several companies at different administrative levels manufactured small turbines (from 0.5 to 5 MW) that in most cases did not meet international standards but met the need of rural electrification efforts. With the Soviet Union's technical assistance, China gradually developed hydropower standards, which benefitted the nascent industry. By the 1970s, China had mastered the manufacturing of several hundred megawatts turbines and managed to meet the needs of larger projects initiated during the decade. After the open door policy, China launched several large pilot hydropower projects in collaboration with foreign partners. These contributed significantly to the development of the Chinese power industry. Technology transfer; improved design, construction, and management of large projects; and the development of quality standards improved China's hydropower and laid the base for its strength in a short time: For example, the first unit of the Three Gorges Project—Unit No.2 with an installed capacity of 700MW, was purchased through international bidding. The equipment was supplied by VGS, a multinational group, that consisting of Voith, Siemens and General Electric, and the installation was carried out by the Eighth Bureau of China Hydropower. While 8 units out of the total 12 units of the Right Bank Power Station are produced by Chinese manufactures.

23. In 2018, China's domestic hydropower industry had a manufacturing capability of over 30 GW but its production was limited to 7.6 GW as domestic and international demand significantly decreased.[16] Currently, two of the largest Chinese companies have the capability to manufacture 1 GW hydraulic turbines, 350 MW pumped storage units with 500 meter level heads, and other equipment. China's dam engineering and technology performance, acquired from the construction of more than 100,000 large-scale dams, is largely recognized, especially in underground engineering, flood discharge, and earthquake prevention.

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15 China's renewable surcharge was CNY 0.015 per kWh in 2012 and rose to CNY 0.019 per kWh in 2016. There was a surplus of CNY 15 billion in the account of China's 'renewable energy subsidy' in 2012, but by 2018 it had turned into a large deficit of about 230 billion yuan. Source: Energy Research Institute of NDRC

16 Source: China Society for Hydropower and China Electricity Council.

24. Chapter 7 introduces the experience and lessons of the modern utilization of biomass in China. China has a long history of biomass energy utilization, mainly household biogas, which was used to meet the energy demand in rural areas. However, before 1980, the development of China's biomass utilization experienced ups and downs brought about by low technical capabilities. More than 10 million household biogas digesters were decommissioned and removed few years after they were built. Following the open door policy, China embarked on a large program to provide clean energy access to its dominant rural population and sought cooperation from several multi- and bilateral institutions. Use of biomass energy increased rapidly. Biogas played a major role in meeting the rural population's energy needs and the design and manufacturing of anaerobic digestion equipment grew rapidly. About 8,700 large and medium biogas projects (more than 500 $m^3$ biogas per day) have been undertaken in China with local equipment.

25. Biomass power generation also grew exponentially, especially after the enactment of the Renewable Energy Law. Multiple power projects related to direct combustion of agricultural residues and forestry biomass power projects and municipal solid waste (MSW) incineration power projects were launched. Many faced teething problems because of low-quality equipment, and initial biomass power targets were the only ones that have not been achieved in the RE power sector. Subsequently, the supply chain improved and by the end of 2018, 18 GW of biomass power units, designed and manufactured in China, were satisfactorily operating. Since the 2017 promulgation of the Winter Clean Heating Plan in Northern China (2017–2021), biomass heating has regained popularity, boosting the development of China's biomass industry. By the end of 2018, China's biomass technology and manufacturing had improved and was able to meet the needs of increased biomass use. About 49,000 biomass patents had been submitted for approval, the thermal efficiency of MSW incinerator and steam turbine had reached 85 and 35 percent, respectively, and bioethanol fuel production amounted to nearly 3 million tons, used in more than 15 provinces.

26. Chapter 8 focuses on the development of the wind power industry. Until 1994, the industry was nascent and fragmented as a large number of companies were created at the state, provincial, and even lower administrative levels to manufacture micro and small turbines under 250 kW. The manufacturing industry benefitted from a series of national engineering programs, international cooperation, and multiple international projects that set the foundation of the industry. It also benefitted from the accumulation of knowledge stemming from scientific programs, technology transfer from leading foreign manufacturers involved in early large wind projects, the establishment of joint ventures with recognized manufacturers, the acquisition of international companies holding licenses of large wind turbines, and bilateral and multilateral cooperation programs.

27. The industry expanded as the market developed and major SOEs and private companies gradually began manufacturing larger turbines from 1 to 5 MW to meet the momentous demand that followed the launch of the concession and wind base programs.[17] A report published jointly by the NEA and the World Bank noted that the increase in installed capacity has been accompanied by significant development of the Chinese industry, which accounted for about 62 percent of the total market share (cumulative up to 2008): (a) five large-scale domestic firms manufacturing turbines certified by the International Electrotechnical Commission (IEC), (b) five joint venture firms manufacturing in China, and (c) more than 10 domestic firms with prototype testing under way.

28. The strength of the wind industry laid a solid foundation for the development of offshore wind power in China. The 100 MW Shanghai Donghai Bridge demonstration wind power project, launched in 2010, was China's first attempt in developing offshore wind. The equipment provider was a Chinese company,

17 Source: National Energy Administration and World Bank. 2010. *China - Meeting the Challenges of Offshore and Large-Scale Wind Power.*

listed on the Shanghai stock market, that assembled the turbines from different parts (nacelles, blades, tower, and so on) procured from both publicly and privately owned Chinese manufacturers. By the end of 2013, 17 test projects had been undertaken from shallow water to intertidal zones, testing 1 to 5 MW offshore wind turbines to corrosion and typhoon resistance. In 2018, at the 80 MW Xinghua Bay offshore wind farm, all turbines ranging from 5 to 6.7 MW and manufactured by seven SOEs and Chinese and foreign private companies successfully withstood the strong typhoon 'Maria', demonstrating the quality and soundness of China's offshore wind power equipment and its suitability to the Chinese wind regime.

29. To bring equipment quality to international standards, China initiated several cooperation programs with wind standard institutions, especially the IEC. This stimulated technological and industrial progress and led to significant cost reduction and quality improvement, which in turn led to increased development of wind.

30. Chapter 9 focuses on the development of the PV industry. The manufacturing of PV systems was initiated as demand increased due to government efforts to provide electricity access to poor remote areas and nomadic populations, mainly in the northwest region of the country. Several technical institutes were incorporated and began manufacturing PV systems. Private enterprises and joint ventures have also entered the market. Seven solar cell production lines were installed in cooperation with the United States, Canada, and other countries and the annual production capacity of solar cells reached 4.5 MW by the end of 1994. But, at that time, no efforts were deployed for R&D. As climate change concerns emerged and installation of PV systems increased in developed countries and in China, the PV industry developed at a fast pace to reach a production capacity of 1 GW by the end of 2007 with special focus on improved quality, international certification of the systems, and issuance of standards on par with developed countries. China contributed to the decrease of system costs and prices and became one of the global industry leaders in the industry; currently six of the top ten PV manufacturing companies are Chinese.

# Part 1: The Quest for Sustainability

# Chapter 2. The Early Years (Stage 1: Up to 1994)

**Key Messages**

During the 1960s and 1970s, hydropower, mainly small, and biogas contributed significantly to improving clean energy supply to the rural population, which accounted for more than 80 percent of the total. Major efforts deployed after the open door policy led to significant progress in research and demonstration projects in line with China's prudent and gradual approach to test policies and development approaches before deploying them at a large scale.

After China's opening to the world, its hydropower industry sought and benefitted immensely from extensive cooperation with and technical and financial support from multi- and bilateral institutions. By 1994, hydropower capacity reached 49 GW. The World Bank Lubuge (Yunan) and Ertan (Sichuan) and the Asian Development Bank Lingjintan (Hunan) hydropower projects are illustrative cases. Regarding other renewables, installed capacity started to increase modestly; wind power amounted to 26 MW and solar PV started to be deployed in remote and nomadic areas with about 5 MW installed capacity.

These results were achieved through the establishment of a 'Renewable Energy Management System' and a 'Study and Research Base', leading to a coordinated and comprehensive RE development, an accumulation of knowledge, and the building of a strong construction and operation capacity.

It took China four years to upgrade its Renewable Energy Management System from a single Hydropower Management Department to a comprehensive Renewable Energy Management Department affiliated with the national economic authority.

- In 1982, the government established the Department of Rural Electricity in the Ministry of Water Resources and Electricity (MoWRE) to manage and plan the development of rural hydropower.

- In 1984, the government established the Rural Energy Leading Group to coordinate several national ministries and commissions.

- In 1986, the government established the Rural Energy Management Division under the National Economic Commission (NEC), now the NEA's Department of New Energy and Renewable Energy, as a permanent agency to promote rural energy pilot demonstrations, technology improvement and deployment, and industrial manufacturing.

To build a strong knowledge and research base, the Chinese government created several research institutes to study and identify challenges related to development of China's energy sector with special focus on renewable energy. In the field of scientific research, the State Scientific and Technological Commission (now the Ministry of Science and Technology [MoST]) began providing support to R&D programs relating to RE science and technologies in 1981. The State High-Tech Development Plan provided a stable and long-term research environment for the development of advanced RE technologies.

Three major policies contributed to the RE achievements in this first stage:

(a) The 'Notice on Opinions on Strengthening Rural Energy Construction' was issued in 1986 by the NEC, to guide the development of renewable energy and build the foundation for the development and utilization of RE at a larger scale: long-term planning; international cooperation to access state-of-the-art knowledge; train and strengthen human resources; and pilot, test, and demonstrate.

(b) The 'Notice on Actively Supporting Rural Energy Development Loans' was issued in 1986 by several ministries. It entrusted local governments with providing financial support to rural RE development through provincial loans provided by the Agricultural Bank of China (ABC) and financial support from provincial budgets and/or collection of local fees/surcharges.

(c) The 'Notice on Several Regulations on the Price of Small Hydropower' was issued in 1986 by the NEC, Ministry of Agriculture, Livestock, and Fisheries (MoALF), and the National Price Bureau (NPB), which promoted the local self-reliance principle for 'self-construction, self-management, self-operation, and self-utilization' of small hydropower projects.

The lessons learned during this period can be summarized as follows: (a) adequate planning, decentralized approaches, and engagement of the local population could lead to successful outcomes; (b) establishment of strong research and study institutions is essential to build a knowledge base; (c) pilot and demonstration projects are essential to assess new technologies before large-scale development; and (d) learning from international experiences and seeking cooperation with more advanced countries are paramount to improving outcomes by facilitating knowledge, technology transfer, and access to advanced management systems.

30. RE development focused first on meeting the rural population's needs for clean energy and its expansion and was largely integrated with rural development, with the exception of large power projects. However, following the opening of the Chinese economy to the world, energy shortages, especially inadequate power supply, constrained the development of emerging large industries and thriving businesses. Subsequently, RE, particularly hydropower, significantly contributed to easing the energy and power shortages that slowed the pace of economic growth after the launch of far-reaching reforms.

31. Former US Secretary of State Henry Kissinger, citing Sun Tzu, noted that "China seeks its objectives by careful study, patience, and the accumulation of nuances."[18] This observation was validated by China's approach during the first stage that laid the foundation for the RE booms experienced in the second and third stages. The approach carefully and methodically built a strong base for the development of RE, allowing for the study, research, and testing of technologies and modern management and construction methods before adopting them.

32. China's approach to change has always been pragmatic and gradual and illustrated by the Chinese saying, "Crossing the river by feeling the stones." Before the deployment of RE technologies at a large scale, several demonstration and pilot projects were undertaken which allowed the country to build a leading RE industry. China also set up a new institutional framework, called the Renewable Energy Management System, designed and adopted a series of coordinated policies focusing first on rural areas, and built a Study and Research Base. Before detailing below these different elements which characterize the first stage, we are briefly presenting the main results of RE development.

18 Kissinger, Henry A. 2005. "China: Containment Won't Work." Washington Post. June 13, 2015.

## A. Modest RE Development

33. The development of small hydropower, biogas, and the deployment of efficient stoves and, to a lesser extent, wind and PV contributed significantly to increasing energy supply to rural areas. By the end of the first stage,

- More than half of rural households used biomass energy-saving stoves, which can save one-third to half of fuel consumption.
- 5.4 million biogas digesters were built nationwide to produce 1.3 billion $m^3$ of biogas annually.
- 60,000 small hydropower stations, amounting to about 16 GW, were constructed and most of them were managed at the county or prefecture level.

34. While development of wind and PV was still very modest, hydropower and biogas development contributed significantly to improving clean energy supply in the 1960s and 1970s. Major efforts deployed after the open door policy, especially during three FYPs,[19] covering the end of the first stage, led to

- Significant progress in research and demonstration projects in line with China's prudent and gradual approach to test policies and development approaches before deploying them at a large scale and
- A good foundation for RE development and utilization at a larger scale.

35. By 1994, China's RE capacity increased relatively modestly as detailed below:

- Hydropower installed capacity reached 49 GW,[20] two-thirds of which was derived from large hydropower.
- Wind power installed capacity amounted to 26 MW and solar PV started to be deployed in remote and nomadic areas with about 5 MW installed capacity.

36. These results were achieved through the establishment of the Renewable Energy Management System and a Study and Research Base, leading to accumulation of knowledge and capacity.

37. Four main successful pilot and demonstration projects were undertaken during this first stage with regard to biomass, hydropower, wind, and comprehensive use of RE technologies. These pilot and demonstration projects focused on (a) testing new technologies and modern management methods and (b) assessing successful foreign experiences and adapting them to Chinese conditions. They generally resulted in capacity building and accumulation of experience by the Chinese personnel involved in RE development. They also provided objective assessments to allow decision-makers to make informed decisions about deployment of technologies and needed technology transfer. These fours pilots and programs were the following:

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19 Sixth, seventh, and eighth FYPs (1981–1995).

20 The sizable numbers of RE achievements in this chapter are characterized as modest because of China's population and size. Per capita numbers are modest (see footnote 2).

(a) Learning from the unsuccessful development of biogas during the 1960s and 1970s that damaged the reputation of digesters among rural households,[21] the Ministries of Water Resources and Agriculture cooperated to launch pilot projects in 1983 for comprehensive rural energy planning and the development of local energy systems to provide cleaner energy to rural population in 100 counties (extended to 200 counties in 1991). These pilot programs were successful and replicated in other counties and contributed to the deployment of small hydropower in 1,500 counties which provided cleaner energy for cooking and heating and increased access to electricity. By the end of 1994, 87 percent of the rural population had basic access to electricity. These pilot programs also improved project designs, construction methods, and equipment production of small hydropower units, efficient stoves, and biogas digesters.

(b) During the three decades preceding the open door policy in the 1980s, several large-scale hydropower special projects were launched and contributed to (i) strengthening hydropower station design, construction, and equipment manufacturing and (ii) building the technical and engineering capacity of personnel involved in these projects. However, these projects suffered from insufficient government financing and experienced extended construction periods due to inefficient use of resources and inadequate project management. After China's opening to the world, its hydropower industry sought and benefitted from extensive support provided by the international community, including developed countries such as the European Union, Japan, Australia, and Canada and international organizations such as the United Nations Development Programme (UNDP), Global Environment Facility (GEF), and World Bank. The Yunnan Lubuge hydropower project, the first World Bank loan to China, and the Ertan hydropower project, the largest in China in the twentieth century, are illustrative of such an approach (see Box 2.1 and Box 2.2).

(c) The establishment of demonstration wind power test farms. The Badaling test farm (4 to 50 kW) in Beijing Municipality and the Pingtan farm (55 to 200 kW) in Fujian allowed the assessment of the strengths and weaknesses of turbines designed by domestic research institutions and strengthening of construction and operation capabilities of concerned parties.

21 In the 1960s, China launched an important program to meet rural energy needs with biogas in a short time and installed a large number of digesters, which all had to be scrapped after few years of operation and some even before commissioning. In the 1970s, history repeated itself and China installed 7 million digesters in rural households but 3 million failed to operate adequately. These failures are mostly caused by low quality of the digesters; due to the shortage of cement, many digesters were built with the so-called 'three-in-one soil' (clay, lime, and big sand) instead of cement. As a consequence, these biogas digesters would last only for a few years. https://pubs.iied.org/sites/default/files/pdfs/migrate/16553CIIED.pdf (XIA Zuzhang).

**Box 2.1: The 600 MW Lubuge Hydropower Project**

In 1984, China signed the 'Agreement on the use of a US$154 million loan from the World Bank for the Lubuge Hydropower Station'. In line with this agreement, China conducted an international tender for the construction of the required diversion tunnel. The Japanese company, which won the bid, completed the project in October 1986, five months ahead of the expected schedule, based on prior Chinese experience. The 'project-based schedule management' method surprised Chinese experts and Vice Premier Li Peng demanded that construction companies start trial implementation of advanced foreign management methods.

With the support of the World Bank, the Lubuge project also raised grants from the Governments of Norway, Australia, and Canada to purchase advanced equipment, hire consulting teams to assist the Chinese project team, and conduct theoretical and on-the-job and in-project design and management.

The success of the Lubuge project led to further use of foreign loans and advanced project management methods for five other 1,000 MW+ hydropower projects in the late 1980s and early 1990s that significantly contributed to reduce power shortages.

**Box 2.2: The 3,300 MW Ertan Hydropower Project**

The Ertan Hydropower Station was the largest station built in China in the twentieth century. Its total installed capacity is 3.3 GW (6 × 550 MW), with an annual average generation capacity of 17 TWh. The 240-meter-high concrete double-curved arch dam ranks first in Asia and third in the world. The total investment of the project is US$3.2 billion, out of which US$780 million IBRD loan, US$150 million guarantee, and IDA US$2.5 million are from the World Bank Group; the Norwegian government also provided a US$5 million grant. Chinese experts commented in many publications that the project introduced international best practice of project design, construction, and management. It promoted the reform of corporate management systems, strengthened the protection of the ecological environment in hydropower construction, and successfully implemented large-scale resettlement. It also triggered the power sector reform.

- It was the first project that fully aligned with international competitive bidding and introduced modern and computerized project construction management to achieve full compliance with International Federation of Consulting Engineers (FIDIC) terms (Norwegian grant financed the training program and allowed transfer of software for power system optimization). Experts from 47 countries have participated in the construction of the project and for the first time in China, a panel of international experts was established to (a) arbitrate in cases of disputes between the project owner and participating foreign companies, which were participating for the first time in the construction of an hydropower project in China, and (b) supervise the implementation of the environmental and resettlement plans.

- In 1998, it was granted the 'National Honorable Collective for Flood Fighting' award and in June 2006, it became one of the first 10 construction projects to win the award of the 'National Environment Friendly Project', the highest environmental protection award in China.

- The project started the long process of corporatization and commercialization of Ertan Hydropower Development Company (EHDC) to become one of the largest hydropower developers and independent power producers (IPPs) operating in the single power scheme and currently in a more market-oriented environment based on contracts and rules and from old style government control to modern light-handed regulation.

The international cooperation left Ertan Hydropower (now Yalong Jiang Company) with long-lasting benefits across the sector. According to Wu Shiyong, Deputy General Manager of Yalong Jiang Company, experiences gained from the development of Ertan were fully used in the development of subsequent hydropower projects by Yalong Jiang Company, such as the Xiluodu Hydropower Project with the dam height of 285.5 m and the Jinping Hydropower Project with the dam height of 305 m, the highest arch dam in the world.

(d) China and Germany initiated the Beijing Daxing New Energy Demonstration Village in 1980. The project is one of the first scientific and technological cooperation agreements between the two countries. This demonstration village focused on comprehensive use of RE technologies, such as solar thermal utilization, solar PV, solar houses, and biogas, among others, to meet social energy needs. It succeeded in showing the potential contribution of RE potential to meet China's fast-growing energy needs. It also contributed to setting the pace for the development of solar water heaters and PV applications in China.

## B. Establishment of the Renewable Energy Management System

38. In the 1970s and especially the 1980s, after the launch of the open door policy, China's rural energy shortages exacerbated as the rural economy boomed. This economic expansion caused an increase in incomes, which in turn led to an improvement in the rural population's living conditions. To meet the rural population's increasing modern energy needs, the Chinese government established several departments to manage and boost rural energy development. Since modern rural energy was dominated by renewable energy at that time, this also laid the foundation for what can be called the China's Renewable Energy Management System as described in the following paragraphs.

39. In 1982, the Department of Rural Electricity（农村电力司）was established under the MoWRE, to manage and plan the development of rural hydropower. It was China's first state-level department to focus on the management of one of China's RE technologies and continues to supervise it to date.

40. In 1984, the State Council established the Rural Energy Leading Group（农村能源领导小组）. This group coordinated the efforts of the Ministry of Agriculture (MoA), the SPC, the National Science and Technology Commission (NSTC), and the MoWRE. The group has been tasked with consolidating rural energy development plans, issuing guidelines and policies for rural energy development, and supervising their implementation.

41. One of the major achievements of the Rural Energy Leading Group is the establishment of the Rural Energy Management Division（农村能源管理处）under the NEC as a permanent agency by the State Council in 1986. The Rural Energy Management Division was entrusted with the promotion of rural energy pilot demonstrations, technology improvement and deployment, industrial manufacturing, and other operational tasks. The establishment of the division marked the beginning of China's comprehensive deployment of renewable energy at a larger scale. This division is the predecessor of the current NEA's Department of New Energy and Renewable Energy.

42. It took China four years to upgrade its Renewable Energy Management System from a single Hydropower Management Department to a comprehensive Renewable Energy Management Department affiliated with the national economic authority. Although this group faced various challenges in its daily operation, it managed to coordinate and rationalize the various departments' efforts and provided an impetus for

the setup of guidelines that led to a flexible approach to RE development. This approach was beneficial insofar as it is adaptable to unique local conditions and take advantage of the synergy and complementarity of various technologies to achieve an optimal use of resources and maximize economic benefits.

43. Until 1994, the Renewable Energy Management System led the efforts to develop policies that promoted the development of small hydropower and biogas in rural areas and later variable renewable energy, especially wind and PV, in China.

## C. Major RE Policies of Stage 1

44. Although the policies formulated at the first stage mainly targeted hydropower and biomass, they can be seen as the demonstration policies, which built the foundation for several important RE measures that were eventually expanded to the whole renewable energy sector. Three major policies were developed during this early stage of RE development.

- The 'Notice on Opinions on Strengthening Rural Energy Construction' was issued in 1986 by the NEC to guide the development of renewable energy in the first stage. It mainly (a) required the preparation of long-term rural energy development plans, (b) initiated studies to formulate technical and economic regulation for rural energy, (c) promoted the strengthening of rural energy technology R&D of demonstration projects, (c) initiated the development of rural energy industries, and (d) improved the capacity of staff involved in all stages of the deployment of RE technologies. Its implementation promoted the establishment of rural energy management institutions at all administrative levels and improved the efficiency of rural energy management and utilization. Moreover, it raised the rural population's awareness about the use of RE and environmental protection.

- The 'Notice on Actively Supporting Rural Energy Development Loans' was issued in 1986 by the Ministry of Agriculture, Livestock, and Fisheries (currently renamed the Ministry of Agriculture and Rural Affairs [MoARA), SPC, and ABC. It entrusted local governments with providing financial support to rural RE development through provincial loans provided by the ABC and financial support from provincial budgets and/or collection of local fees/surcharges, allowed by the notice. The RE technologies eligible for support included biogas digesters, PV systems, energy-saving stoves, geothermal utilization, and biomass gasification. This notice preceded the 2005 Renewable Energy Law, which created a compensation system based on sharing financial costs of RE development among all electricity consumers, preferential loans from sate banks, and state budget. It also launched the decentralized development model of renewable energy in China, which is based on meeting the national RE targets through obligations on provinces and ultimately on local enterprises and consumers. The decentralized development model relies greatly on local governments, local private initiatives, and the engagement of citizens. It successfully promoted the rapid development of renewable energy, especially small hydropower at this stage without burdening the strained state budget.

- The 'Notice on Several Regulations on the Price of Small Hydropower', issued in 1986 by the NEC, MoALF, and NPB, promoted the local self-reliance principle for 'self-construction, self-management, self-operation, and self-utilization' of small hydropower projects. It set a floor price and entrusted local governments to regulate electricity prices to adapt them to local conditions and provide developers reasonable profits. This is one of the first attempts to depart from uniform pricing systems based on tariffs imposed by higher administrative levels and the first attempt at determining differential price by region, which also was one of the basic pricing measures adopted in the future 2005 Renewable Energy Law. It greatly contributed to the development of RE in rural counties.

## D. Building a Study and Research Base

45. The 1973 oil crisis raised concerns in several countries about energy security and many nations began to attach importance to local energy supply, increasing focus on RE resources. In China, several energy research institutes were established in the 1970s and 1980s, the most important of which include the Energy Research Institute of the Chinese Academy of Sciences (now affiliates with the NDRC), the International Small Hydropower Center (Hangzhou), the Chengdu Biogas Research Institute, the Guangzhou Institute of Natural Energy, the Beijing Energy Research Institute, the Gansu Solar Energy Research Institute, and the Liaoning Energy Research Institute. These institutes were tasked with studying and identifying future challenges facing the development of China's energy sector with special focus on RE issues. International organizations helped establish and manage these institutions in the early years. For example, UNDP and United Nations Industrial Development (UNIDO) supported the establishment of the Hangzhou International Small Hydropower Center (ICSHP)[22] and the Guangzhou Institute of Natural Energy.

46. The research and work objectives of these institutions included, but were not limited to, the following aspects:

- Studying the path and measures related to the development of the RE industry in China and abroad to allow the government to make informed decisions about RE development and to formulate mid- and long-term development plans and industrial policies

- Carrying out research programs to improve energy efficiency and production processes

- Disseminating information on the commercialization of renewable energy and providing technical consulting services for RE companies

- Establishing cooperation programs with recognized international institutions, organizations, and countries to develop policy information exchange and technology transfer.

47. In the field of scientific research, the State Scientific and Technological Commission (now the MoST) began providing support to R&D programs relating to RE science and technologies during the 6th FYP (1981–1985). The State High-Tech Development Plan (also known as 863 program) provided a stable and long-term research environment for the development of advanced RE technologies.[23] Although no world-leading results have yet been achieved at this stage, these programs trained a generation of high-level scientific and technological talents and laid the foundation for the momentous development of renewable energy in the next stages:

- The China National Shipbuilding Corporation factory undertook a research program on 100 W wind turbines during the 6th FYP (1981–1985), which resulted in the development of the first wind power

22 The ICSHP was promoted five years after its establishment to a UNIDO-affiliated institution to promote small hydropower development in developing countries and South-South cooperation for 'the social, economic, and environmental development of rural areas'. The institute focuses on research and information exchange on small hydropower development and provides training and advice and encourages South-South 'horizontal investment flows'.

23 The 'National Basic Research Program of China (973 Program)' was the third program launched in 1997.

products based on national design standards and specifications and indicated China's ambitions to develop R&D and complete the manufacturing of modern wind turbines.

- The Beijing Solar Energy Research Institute developed the copper-aluminum vacuum tube heat collector under the UNDP international technical cooperation project with Canada and Germany during the 7th FYP (1986–1990). The program explored a development path for absorbing advanced foreign technologies and greatly promoted the utilization and widespread dissemination of solar water heaters in China.

## E. Lessons Learned

48. Several lessons learned during this stage are worth considering by countries struggling to meet the Sustainable Development Goals (SDGs), especially SDG 7 aiming at "ensuring access to affordable, reliable, sustainable, and modern energy for all."

    - The approaches adopted to deploy biogas at a large scale during the 1960s and 70s not only failed to meet their objectives but, more importantly, undermined the credibility of the technology among the rural population. Therefore, before scaling up, conducting bottom-up pilots to demonstrate the technical feasibility, implementation supporting system, as well as financial mechanism is important to avoid large scale failure.

    - Adequate planning, decentralized approaches, and engagement of the local population could lead to successful outcomes. The deployment of small hydropower at a large scale to provide access to electricity for the rural population in 1,500 counties was financed locally and benefited from voluntary participation in the construction and the collection of fees and surcharges borne by the population. Decision-making related to prices of electricity generated by the small hydropower stations has been delegated to the local government and fully accepted by local communities.

    - The establishment of strong research and study institutions is essential to build a knowledge base, overcome technical hurdles, and provide decision-makers the needed information to make informed decisions.

    - Pilot and demonstration projects are useful, and even necessary, to assess new technologies before large-scale development.

    - Learning from international experiences and seeking cooperation with more advanced countries are paramount to improving outcomes by facilitating knowledge, technology transfer, and access to advanced management systems.

49. These lessons are essential to build the foundation and enable the environment for the effective deployment of renewable energy at a large scale. However, they need to be complemented by the removal of market, institutional, and legislative barriers to allow for the fast-track development of renewable energy.

# Chapter 3. The Takeoff (Stage 2: 1995–2005)

**Key Messages**

China committed to develop RE sources to help alleviate acute energy shortages, ease growing energy security concerns, and mitigate local and environmental impact.

By 2005, the total amount of RE development and utilization reached 166 million tce, accounting for about 7.5 percent of the total primary energy consumption: (a) the installed capacity of hydropower reached 117 GW, including about 7 GW of pumped storage; (b) annual utilization of biogas reached about 8 billion $m^3$, providing cleaner fuel for nearly 70 million rural people; (c) total installed capacity of biomass power generation amounted to about 2 GW; (d) more than 60 grid-connected wind farms were commissioned, with a total installed capacity of 1.26 GW; (e) total capacity of PV power generation reached 70 MW; (f) total number of installed solar water heaters covered 80 million $m^2$; and (g) geothermal deployed for heating replaced about 2 million tce of coal per year.

The surge in RE development experienced during this stage was triggered by the issuance of the Electricity Law in 1995, which contributed significantly to opening the sector to RE investors. It was followed by the New Energy and Renewable Energy Development Plan (2001–2015), which supported the development of the knowledge base and the assessment of resources, guided the localization of RE manufacturing, and finally, established technology and market development goals as well as targets for RE consumption level and per technology.

The 10th FYP (2001–2005) for new energy and RE industry was issued in 2001 and focused, for the first time, on RE development separately. The plan focused on (a) research activities and development of adequate policies; (b) promotion of technological progress and improvement of equipment quality; (c) implementation of demonstration projects; (d) development and regulation of the market; (e) awareness, training, and information dissemination; and (f) international cooperation. Furthermore, the plan set quantitative RE targets, one for overall development and a specific target for each technology. All targets were achieved and surpassed, except that of biomass power.

As the implementation of the Kyoto Protocol progressed, China intensified its cooperation with the countries at the forefront of RE development and was supported further by several countries, such as Denmark, Germany, the United Kingdom, Japan, and Canada, and by multilateral organizations, such as the World Bank, GEF, and UNDP.

Two World Bank/GEF projects in particular contributed to laying the ground for PV and wind development at a large scale:

- **The China Renewable Energy Development Project (REDP)** was developed by the SETC to support wind power through a US$13 million wind power investment loan and a US$27 million GEF grant to develop PV markets in northwestern provinces. It essentially supported public and private integrators to improve the quality of their products, develop PV technical standards, and improve quality control and testing capacity.

- **The China Renewable Energy Scale-Up Program Phase I (CRESP I),** initiated in 2000, established a long-term three-phase cooperation program to sustain RE development. Its first phase contributed to (a) developing a legal, regulatory, and institutional environment conducive to large-scale, renewable-based electricity generation; (b) financing some of the first large wind and biomass projects; (c) improving the local equipment and designs through technical standards.

RE resources were thoroughly assessed. Regarding hydropower, more than 12 GW of hydropower stations were commissioned during the 10th FYP (2001–2005) and 80 GW started construction. Regarding wind energy, the concession program, launched by the SPC in 2002, initiated the development of large wind farms and ultimately led to GW wind bases, mainly in north and northwestern China.

**The lessons learned** are as follows:

(a) Strong commitment and subsidization are not the only prerequisites for large-scale RE development. Successful and sustained programs also require a stable policy and regulatory framework, availability of skilled personnel, and clear mid- and long-term ambitious goals.

(b) A sound bid evaluation methodology is essential to the success of competition evaluation, bid criteria should not over-rely on pricing, and multicriteria evaluation should also ensure the strength of the financial standing of the bidding companies, the soundness of technical characteristics, and appropriate financial returns based on proposed bid prices.

50. "From the early 1980s to the mid-1990s, China managed to achieve high economic growth with near self-sufficiency in energy supply. However, during the second half of the 1990s, China gradually emerged as a net importer of energy, and by 2005, its dependence on oil imports had soared to about 45 percent of consumption." [24] To address the growing sense of energy dependency and fuel its highly growing economy, China relied heavily on domestic coal, which led, by the early 2000s, to serious environment pollution and increased GHG emissions. After completing the required internal procedures, China approved the Kyoto Protocol, which it signed in 1998. This opened the door to the development of renewable energy as a potential option to help alleviate acute energy shortages, ease growing energy security concerns, and mitigate environmental impacts, especially to meet growing rural energy demand in a sustainable way. However, deployment of renewable energy at a large scale was hindered by the following:

- Lack of a national strategy and lack of mid- and long-term plans, prerequisites to development activities in a 'command and control' economy
- Lack of the appropriate legal framework
- Lack of expertise and know-how about RE, lagging behind Germany, the United States, Demark, and the United Kingdom and thus still depending on other countries' expertise
- Inadequate incentives to promote investments in RE development in an environment characterized by scarcity of capital at the national and lower administrative levels
- Nascent markets and weak industrialization base.

24 Berrah, Noureddine, et al. 2006. *Sustainable Energy in China: The Closing Window of Opportunity.* World Bank.

51. To address these issues, China initiated the preparation of mid- and long-term planning procedures, enacted an Electricity Law that abolished the monopoly on electricity generation, thus opening the door to independent RE-based generation, and actively cooperated with other countries, in particular within the Kyoto Protocol framework to create an enabling environment for the takeoff of development of renewable energy.

## A. Achievements in Stage 2

52. During 1995–2005, renewable energy in China developed rapidly. Significant progress has been made in the utilization of hydropower, biogas, bioliquid fuel, wind power, and solar energy. The role of renewable energy, especially hydropower, made a remarkable contribution to the country's energy supply. By 2005, the total amount of RE development and utilization (excluding the traditional way of using biomass energy) reached 166 million tce, accounting for about 7.5 percent of the total primary energy consumption, including the following:

- The installed capacity of hydropower reached 117 GW (including about 7 GW of pumped storage power stations), accounting for 23 percent of the total installed capacity of power generation. In 2005, electricity generation amounted to about 395 TWh, accounting for 16 percent of the total electricity generation.

- More than 18 million household biogas digesters had been installed, and about 1,500 large-scale livestock and poultry farm biogas projects have been completed. The annual utilization of biogas reached about 8 billion $m^3$, providing cleaner fuel for nearly 70 million rural people. The total installed capacity of biomass power generation in China amounted to about 2 GW, including 1,700 MW of bagasse power generation capacity, 200 MW of MSW power generation capacity, and about 100 MW of power generation capacity fueled by gasified agricultural and forestry wastes, such as rice husk and biogas. Production of bioethanol slightly exceeded 1 million tons and utilization of biodiesel amounted to about 500,000 tons.

- More than 60 grid-connected wind farms were commissioned, with a total installed capacity of 1,260 MW, laying the foundation for the large-scale development of wind power. In addition, there were about 250,000 small independently operated wind turbines in remote areas, with a total capacity of about 50 MW.

- The total capacity of PV power generation reached 70 MW. Non-grid-connected PV stations were built in 12 counties and more than 700 towns, and more than 500,000 household PV systems were installed to provide access to electricity to poor population in remote areas.

- The total number of installed solar water heaters covered 80 million $m^2$.

- The geothermal deployed for heating was about 2 million tce.

## B. Policies Paving the Way to RE Development

53. During this stage, the government formulated a series of policies setting a total target for RE development and defining key tasks required to achieve it: scientific R&D, improved market access, safeguard measures,

and so on. These top-down policies formed a first-level layer promoting and regulating RE development in the country. The main policies and measures formulated during this stage can be presented under three broad categories: (a) energy sector only policies and measures, which includes in particular the Electricity Law and the New Energy and Renewable Energy Development Plan; (b) energy-related policies that are part of broader national policies and planning, in particular under the 10th FYP; and (c) energy-related domestic policies that are related to international coordination to mitigate climate change, in particular China's Agenda 21 and the Kyoto Protocol:

- **The Electricity Law.** The first Electricity Law in China, approved in 1995, broke the monopoly of state-owned utilities in the sector and formalized the diversified, including private, ownership of power generation assets. It opened the door for badly needed financing sources at the time to meet the huge investment need to alleviate shortages and power the fast-growing economy. It guaranteed and promoted the development of electric power industry; safeguarded the legitimate rights and interests of electric power investors, operators, and users; and ensured the safe operation of electric power. The law contributed significantly to opening the sector to RE investors and the fast development of RE power generation.

- **The New Energy and Renewable Energy Development Plan,** issued in 2000, served as a long-term road map for RE development. It included a general plan and subsidiary technology plans encompassing solar, wind, geothermal, and biomass. The plan covered three periods: 2000–2005, 2006–2010, and 2011–2015. It included guiding principles and basic knowledge, resources, technology and market, development goals, localization of RE manufacturing, expected benefit, constraints and obstacles assessment, and finally, policy and implementation. The industrial development goals were set based on detailed analyses and evaluation of four aspects: resources, local technical knowledge and gap with advanced countries, market development and demand potential, and availability of skilled personnel in each RE technology. Its guiding principles were reflected in the 10th FYP leading to the end of the second stage of RE development.

- **The 10th FYP (2001–2005) for new energy and renewable energy industry** was issued in 2001 and focused, for the first time, on RE development separately. The plan stressed the following actions to ensure sustainable RE development: (a) research activities and development of adequate policies; (b) promotion of technological progress and improvement of equipment quality; (c) implementation of demonstration projects; (d) development and regulation of the market; (e) launch of awareness and information dissemination activities and training; and (f) widely carry out international communication and cooperation. The plan set quantitative RE targets, a general one for overall development and a specific one for each technology (See table 3.1).

**Table 3.1: RE Targets and Achieved Rate in the 10th FYP for New and Renewable Energy**

| Technology | 2000 | 2005 Target | 2005 | Annual Growth Rate (%) | Achieved Rate (%) |
|---|---|---|---|---|---|
| **Power generation** | | | | | |
| Hydropower (GW) | 79.35 | 100 | 110 | 6.7 | 110 |
| Wind power (MW) | 340 | 1,200 | 1,260 | 30 | 105 |
| Wind power (off grid) (MW) | 150 | - | 250 | 11 | n.a. |
| Solar PV (MW) | 19 | 53 | 70 | 30 | 132 |
| Biomass power (MW) | 1,700 | - | 2,000 | 3 | n.a. |
| **Gas** | | | | | |
| Biogas (billion $m^3$) | 3.5 | 4 | 8 | 18 | 200 |
| Rural household biogas (thousand households) | 8,500 | 10,000 | 18,000 | 16 | 180 |
| **Heating** | | | | | |

| Technology | 2000 | 2005 Target | 2005 | Annual Growth Rate (%) | Achieved Rate (%) |
|---|---|---|---|---|---|
| Solar water heater (million m$^2$) | 26 | 63 | 80 | 25 | 127 |
| Geothermal and others (1,000 tce per year) | 1,200 | | 2,000 | 11 | n.a. |
| Fuel | | | | | |
| Fuel ethanol (1,000 tce per year) | - | - | 1,020 | - | n.a. |
| Biodiesel (1,000 tce per year) | - | - | 50 | - | n.a. |
| **Total utilization (million tce per year)** | 120 | 136 | 166 | 6.70 | 122 |

Source: 10th FYP for new and renewable energy and 11th FYP for RE development.

- It was planned that by 2005 (a) the development and utilization of new energy and renewable energy would reach 13 million tce from 12 million tce in 2000; (b) the annual production capacity of solar heaters would reach 11 million m$^2$, with an accumulated installation of about 64 million m$^2$; (c) the production capacity of PV cells nationwide would reach 15 MW and the cumulative installed capacity would amount to 53 MW; (d) the generation installed capacity of wind power would reach 1,200 MW, and the equipment manufacturing capacity would reach about 150 to 200 MW; (e) the geothermal heated area would reach 20 million m$^2$; and (f) biogas utilization would reach 2 billion m$^3$.

- **China's Agenda 21.** This important policy was approved by the State Council in 1994 to define China's overall strategy and action plan to solve environmental and development problems. The SPC (later NDRC) and the State Science and Technology Commission (later MoST) followed up with the development of a 'priority plan' to put the policy into practice. The 'priority plan' identified the priority projects to be included in the mid- and long-term national economic plans to implement the Agenda 21 policy. RE development and utilization projects were included in the first batch of priority projects, including test and demonstration projects in three areas: thermal utilization of solar energy and PV power generation, large-scale wind turbines for power generation, and utilization of biomass. The successful implementation of these projects contributed to extending knowledge on and commercializing key RE technologies, which contributed to reducing greenhouse gas (GHG) emissions, improving environment, increasing the supply of reliable and clean energy, and promoting sustainable development.

- **Approval of the Kyoto Protocol.** The ratification of the Kyoto Protocol, almost four years after signing it, indicated, according to a ministerial announcement, "China's positive stance towards international environmental cooperation and world sustainable development."' It opened the door to increased cooperation with countries leading RE development at the time and led to the declaration of China's commitment to RE development in the 2004 RE Bonn Conference. Developers showed greater interests in RE projects as their financial returns became more attractive with the additional benefits from sales of GHG emissions through the Clean Development Mechanism (CDM).

## C. International Cooperation

54. China continued and intensified the international program with the countries at the forefront of RE development. As the implementation of the Kyoto Protocol progressed, China's renewable energy was further supported by several countries, such as Denmark, Germany, the United Kingdom, Japan, and Canada, and by multilateral organizations, such as the World Bank, GEF, and UNDP. China benefitted from numerous bilateral and multilateral international cooperation and exchanges with programs and acquired technological, financial, training, and other support. Counterparts also occasionally gained from the Chinese experience and successful programs were disseminated by multilateral institutions to other

developing countries in the context of South-South cooperation. Some of the international programs are detailed as follows:

- The **REDP** was developed by the SETC and the World Bank to support wind power through first a US$13 million wind power investment loan and a US$27 million GEF grant to develop PV markets in northwestern provinces. The impact of the project was considerable as all outputs were achieved or surpassed and the project helped establish a sustainable PV market in the targeted provinces. Technical standards developed by the project were strictly enforced: 74 component manufacturers involved in the project met them and 18 companies offered PV systems that met international standards. The testing capacity developed under the project contributed greatly to the quality of PV equipment and integrators were supported to develop better-quality and novel products. The project PV standards were adopted as national standards before the country opted for international standards.

- **CRESP I.** In 2000, The Chinese government, the World Bank, and the GEF cooperated to prepare CRESP I and launched its implementation in November 2005. The first phase of the program focused on supporting (a) the development of a legal, regulatory, and institutional environment conducive to large-scale, renewable-based electricity generation and (b) the demonstration of early success in large-scale, RE development with participating local developers in Jiangsu, Zhejiang, Fujian, and Inner Mongolia Autonomous Region. CRESP has made significant contributions to the legal, regulatory, and policy framework for scaling up renewable energy in China and catalyzed government investment in and support to RE development at a large scale during the 11th FYP. The outputs, outcomes, and achievements of CRESP are categorized in the following three key pillars: (a) CRESP played an essential role in the rapid growth and quality improvement of the domestic wind and, to a less extent, biomass manufacturing industry, through cost-shared subgrants and establishment of standards, testing, and certification facilities; (b) CRESP also supported the development of eight wind turbine standards based on best international practice; and (c) CRESP has contributed to large-scale RE investments by supporting two 100 MW wind farms in Fujian and Inner Mongolia, a 25 MW biomass power plant in Jiangsu, and 6 new and 10 existing small hydropower plants with a total installed capacity of 24 MW. The investments focused on quality, efficiency, and sustainability of the built infrastructure when many of RE projects were below par in China and exhibited low capacity factors and/or technical problems that hampered their connection to the grid. Equipment improvements, adequate designs, and technical standards developed under CRESP and financed by GEF grants were disseminated and profited numerous similar projects in China.

- **Other international cooperation programs.** The development of renewable energy in China was also supported by several bilateral cooperation programs during this stage, including with the Netherlands for the Xinjiang Silk Road Brightness Program (2002–2007), Germany for Sino-German financial cooperation program on solar energy in western area (KFW Program, 2003–2004), Germany for the Technical Assistance for Renewable Energy (2002–2004), Canada for the Solar Electrification Program in Remote Areas (2002–2005), and Japan for the Green Energy Cooperation Plan (1998–2002). These programs enabled better assimilation of RE technologies, increased awareness and built consensus among Chinese experts, and improved their understanding of determinants of successful experiences. They contributed to create an enabling environment and laid a solid foundation for the large-scale application of renewable energy in western China. Furthermore, many people were trained under these projects and programs, including government officials, entrepreneurs, technicians, scholars, and so on. They formed the core of RE champions and all of them continue to play an important role in RE development in China.

## D. Implementation of Major Nationwide Resources Assessments and Programs

55. Some important activities were carried out, before undertaking or in parallel with the investment projects, to better assess the resources and increase the number of skilled personnel in engineering, construction, and operation of large-scale projects. Some major projects and programs were undertaken to acquire knowledge on construction techniques and novel management methods, through cooperation activities with more advanced countries during the first stage, and continued to benefit from international cooperation during this second stage.

56. The major resource assessment and pilot/test projects carried out during the second stage include the following:

- **Reevaluation of water resources.** During 2001–2003, the National Leading Group Office on Water Resources Reevaluation undertook a comprehensive reevaluation of potential hydropower resources and published the results in November 2005. The theoretical hydropower capacity potential was estimated at about 700 GW and the energy generation potential at about 6,200 TWh per year. The technically exploitable installed capacity potential was estimated at about 540 GW and the annual energy generation potential at 2,470 TWh. Finally, the economically exploitable potential installed capacity was estimated at about 400 GW, with an annual energy generation potential of 1,760 TWh. This reevaluation guided the rapid development of hydropower during this and future stages.

- **Wind energy resource evaluation.** The importance of proper wind resource assessment is paramount for identifying both areas of interest to develop wind energy and for project-specific needs. In 2003, China initiated a systematic and organized national measurement program to prepare for the large-scale deployment of wind power. The regional resource and pattern evaluation was mainly based on meteorological data. It was combined with terrain characteristics, landform, traffic, and grid conditions to determine wind farm sites. According to the evaluation results of wind energy resources during 2004 and 2005, the potential wind power capacity was estimated at that time at about 300 GW. This evaluation and more sophisticated ones carried out during the next stages were instrumental in planning and developing wind power assets.

- **Bioethanol pilot projects.** China initiated ethanol pilot activities in 2000. Four pilot projects were carried out to produce about 1 million tons of ethanol, to be mainly blended with gasoline and currently used in Heilongjiang, Jilin, Liaoning, Henan, and Anhui provinces and 27 cities in Hebei, Shandong, Jiangsu, and Hubei provinces. The pilot ethanol projects vitalized the development of bioenergy, promoted cleaner and low-carbon transportation fuel, and could contribute to reducing oil imports.

57. The major projects and programs completed during this stage include the following:

- **Large hydropower.** The large hydropower stations put into operation during the 10th FYP (2001–2005) included the units of the left bank of the Three Gorges Project amounting to 9.8 GW in Hubei Province, the 1,350 MW Dachaoshan hydropower station in Yunnan Province, and the 1,500 MW Gongboxia hydropower station in Qinghai Province. Several large-scale hydropower projects were also started, including the Lancang River power station and the Xiaowan hydropower station totaling 4,200 MW in Yunnan Province and the 4,200 MW Longtan hydropower station on the Hongshui River in Guangxi Province. The total capacity of hydropower projects under construction during this stage was about 80 GW. The construction of these large-scale projects eased the power shortages and contributed to a more reliable power supply. They consolidated the experience and advanced construction methods of the early cooperation programs with advanced countries and provided experience to a large pool of hydropower experts. These led to noticeable cost reduction that allowed a faster development of hydropower in the country and built the base for future exports of engineering services.

- **Rural biogas development.** From 2003 to 2005, the National Debt Fund[25] invested CNY 1 billion annually to promote biogas. Rural biogas construction gained momentum and began to develop rapidly. By the end of 2005, 18 million households relied partly on biogas to meet their cooking needs and more than 700 biogas projects were developed in large-scale farms. The development of biogas became an important component of rural development and ecological protection. The programs were based on local expertise, manufacturing, and operation. Technical institutes gradually improved the design and manufacturing as competition increased in a thriving market. Developers accumulated vast experience in construction and training centers built local workers' skills and capacity. These actions laid a solid foundation for the Chinese biogas industry.

- **Substituting small hydropower for fossil fuel.** In 2003, the government initiated a program to substitute small hydropower for fossil fuels to address fossil fuel shortages and reduce local pollution in rural areas of the mid- and upstream of the Yangtze and the Yellow Rivers. The program was implemented in 26 counties and cities located in Sichuan, Guizhou, Yunnan, and Shanxi Provinces and Guangxi Zhuang Autonomous Region. By the end of 2005, the program benefited 200,000 people, avoided 160,000 tons of firewood consumption, and allowed transformation of 20,000 ha of farmland into forest and the protection of 104,000 ha of forest.

- **Power supply to townships program.** In 2002, the Chinese government launched the 'Power Supply to Townships Program' to provide isolated rural population with access to RE-based electricity. Off-grid solar PV power stations, wind-solar hybrid power stations, and small hydropower stations were built to meet the electricity demand of farmers and herdsmen living in remote areas. The program covered a wide area within a short period and demonstrated RE technology advantage to meet electricity needs of dispersed demand at lower cost than grid extensions. The program played an important role in promoting the development of China's PV industry. Several companies actively participated in the program and the production capacity of the PV cells increased from 4 MW in 1997 to 67 MW in 2004, and the production capacity of PV modules increased from almost 0 to 150 MW in 2004. More importantly, the quality of the systems greatly improved. All of these laid a solid foundation for the rapid development of China's PV industry. The program provided a unique opportunity to train and consolidate the experience of all technical, construction, and personnel involved.

- **Wind concession program.** In 2002, the SPC (currently NDRC) launched a 'concession program' to develop large-scale wind farms. The program was fully driven by the government as site and size selection, capacity, engineering and technical specifications, and construction conditions were defined in the calls for bids. The concession rights were granted to companies with proven operation and management experience that propose the lowest offtake price. The project company would be responsible of the maintenance and operation of the wind farm according to strict concession conditions spelled out in the agreement signed with the government. The company was granted a power purchase agreement (PPA) to sell the generated electricity to the grid company at the bid

25 The National Debt Fund refers to the Special Financial Fund established in 1998 by the Central Government and endowed by the issuance of long-term national bonds mainly for infrastructure development.

price. If the bid price was higher than the benchmark price for coal-fired generated electricity, the price gap will be passed through to end users by power grid companies. During 2003–2005, three concession tenders were conducted:

(a) In 2003, the NDRC called for bids for the first two 100 MW wind farms, the Guangdong Huilai wind power project and the Jiangsu Rudong wind power project, to test the procurement procedure. Six enterprises participated in the bidding for the two projects. The concessions were granted to the bidders 'offering the lowest price with the highest proportion of local content'. The proposed prices of the winning bids were CNY 0.4355 per kWh (US¢5.26 per kWh) and CNY 0.5013 per kWh (US¢6.06 per kWh), respectively.

(b) In 2004, the NDRC expanded the scale with a total installed capacity of 650 MW, including the 150 MW Jiangsu Rudong Phase II wind power project, the 100 MW Inner Mongolia Huitengxile wind power project, the 200 MW Jilin Tongyu Phase I wind power project, and the 200 MW Jilin Tongyu Phase II wind power project. Five enterprises participated in the bidding for these four projects. The evaluation was conducted according to the same principle and the three winning bids offered, respectively, CNY 0.382 per kWh (US¢4.62 per kWh), CNY 0.509 per kWh (US¢6.15 per kWh), and CNY 0.519 per kWh (US¢6.27 per kWh).

(c) In 2005, a third round of bids to construct three wind farms totaling 450 MW: the 200 MW Jiangsu Dongtai wind power project, the 100 MW Gansu Anxi wind power project, and the 150 MW Shandong Jimo wind power project. Ten enterprises participated in the bidding for these three projects. The evaluation methodology was changed and included several technical and financial criteria, including the bidding price with a 40 percent weigh, to ensure the technical and financial soundness of the project. The bidders with the highest scores were granted the concessions. The prices offered by the winning bidders were, respectively, CNY 0.4618 per kWh (US¢5.64 per kWh) and CNY 0.4877 per kWh (US¢5.95 per kWh).

## E. Lessons Learned

58. Four lessons can be drawn from experiences gained during this stage. The first two illustrate China's adherence to the most important drivers of successful RE development policies: strong political commitment, enabling policies with clear and ambitious targets to attract investors, and adequate incentives to address market failure to reflect local and global environmental benefits in energy and electricity prices. The third one stresses that reliance on adequate market-oriented processes and competition are essential to efficient implementation of RE policies. Finally, the sustainability of RE development requires state-of-the-art knowledge and strong capacity along the chain of RF development. Chinese experience clearly indicates that reliance on international cooperation is essential to leapfrog to the most advanced knowledge and technology.

- **Strong commitment and subsidization are necessary, but not sufficient, conditions for large-scale RE development.** Only hydropower and solar water heaters developed significantly during this stage as they also benefited from adequate knowledge of the characteristics of the resources, clear development targets, well-proven technologies, and availability of skilled personnel along the development chain of the two technologies. Other technologies struggled because of the still high costs of the emerging technologies, lack of a stable policy and regulatory framework and limited availability of skilled personnel. They even suffered from the fragmented and volatile subsidization mechanisms.

- **Clear mid- and long-term ambitious goals are prerequisites to develop sustainable RE development.** The development of clear targets in the early 2000s did not significantly benefit wind and PV expansion during this stage as market development takes time and developers enter new businesses prudently. However, the government can rely on special programs to test and demonstrate the technologies and build a skilled force to prepare for the large-scale development.

- **Sound bid evaluation methodology is essential to the success of competition.** The first two concession bidding rounds in China were successful as they indicated the Chinese government willingness to promote wind power and demonstrated the interest of developers in undertaking large-scale wind power projects. However, reliance on a predominantly price-based bidding mechanism eventually led to serious shortcomings, including delays and winning bidders failing to deliver. Main causes include the following: (a) certain winners did not manage to raise debt to finance the projects because they did not have strong financial standing and/or proposed prices did not meet the expectation of financiers and (b) as bidders were not required to do so as part of the bidding qualification process, they did not plan ahead to arrange for timely delivery of equipment to implement the project in accordance with the concession schedule. Multicriteria evaluations to ensure the strength of the financial standing of the bidding companies, the soundness of technical characteristics, and appropriate financial returns based on proposed bid prices are paramount to the success and timely completion of the projects. For example, the Inner Mongolia Huitengxile wind farm project was delayed by about four years. It finally got financed by the World Bank after securing CDM extra revenues to improve the financial return of the project.

- **Continued international cooperation is important to improve knowledge and build capacity.** As shown in Section C, China engaged in several bilateral and multilateral programs to access state-of-the-art policy and technical knowledge and train a strong core of RE experts, who are still involved in policy development and project implementation. China avoided the ‘reinventing the wheel’ syndrome and managed to catch up with most advanced countries in less than two decades and embarked on ambitious R&D and innovation programs.

# Chapter 4. From Lagger to Leader (Stage 3: 2006–2017)

**Key Messages**

The adoption of the Renewable Energy Law was indicative of China's commitment to RE development and to internalizing environmental benefits in pricing. The Renewable Energy Law was followed by policies and regulations, especially feed-in tariffs for wind in 2009 and PV in 2014, that set ambitious development targets and provided a wide range of incentives to increase investment and build a sizable market.

This led to a boom of RE development, making China the world leader by the end of 2017. During this stage (2005–2017), the installed RE power capacity increased by 16 times reaching 638 GW, accounting for almost 37 percent of the total installed power generation capacity, and the total RE power generation amounted to about 1,699 TWh, more than four times the 2005 generation, accounting for almost 26 percent of the total power generation.

This boom is the result of five edicts of the law: (a) ambitious technology-specific medium- and long-term targets, (b) legal obligation on power grid companies to ease access of RE electricity to the transmission systems and to purchase the full amount of the on-grid RE electricity, (c) assurance that RE offtake prices and other compensations would provide adequate returns to investors and developers, and (e) addition of a surcharge on each kWh consumed to finance a Special Fund to provide subsidies.

The Renewable Energy Law was followed by a series of fiscal incentives at the national and provincial levels, in particular value added tax (VAT) and land use tax exemptions, as well as access to preferential loans.

Other earlier non-energy-sector-specific policies also benefitted the development of the RE market and industry at this stage, namely, the China Company Law issued (1994), which allowed the creation of public and private companies; the 'Electricity Law' (1995), which allowed new entrants in the power generation subsector and mandated single-buyer utilities to take off their generation; and the State Council's Electric Power Sector Reform Decree No. 5 (2002) that led to the separation of generation from transmission and distribution and the creation of RE generation companies.

This stage also saw the emergence of climate change and air pollution policies, which underlined the role of RE development to protect the local and global environment. This includes the National Plan on Climate Change (2014–2020), which set a series of targets, including increasing the share of non-fossil fuels in primary energy consumption to 15 percent by 2020, achieving $CO_2$ emissions peaking by 2030 or before, and lowering $CO_2$ emissions per gross domestic product (GDP) unit by 60–65 percent from the 2005 level. With respect to local pollution, the State Council issued, on September 10, 2013, the 'Action Plan for the Prevention and Control of Air Pollution' followed by the launch of President Xi 'Energy Revolution' in 2014, which defined a series of guiding principles to promote and deploy 'green and low carbon' technologies on both supply and demand sides, mobilizing market mechanisms and international cooperation.

These principles were reflected in ensuing ministerial policies and regulations to promote clean heating and increasing the share of low carbon energy in industrial energy consumption from 10.9 percent in 2015 to 15 percent in 2020.

During this stage, with the support of international cooperation, the assessment of RE resources was greatly improved. Large wind power bases were built with capacities ranging from 7 to 36 GW, thus creating a large market for wind power in China, enabling the development of wind turbine manufacturing. Large government programs were also launched to promote the technological progress and large-scale development of solar PV, including the Golden Sun demonstration project and the Top Runner Project launched respectively in 2009 and 2015.

The two main lessons learned during this stage are as follows:

(a) **Aggressive and uncoordinated RE development programs can be effective in deploying RE at a high scale but can lead to substantial inefficiencies,** including a high level of curtailment. In 2012, the United States generated the same wind-based electricity generation as China with half of the capacity. China has since undertaken many corrective measures to better coordinate wind base development and grid development, allowing the capacity factor of existing wind assets to increase.

(b) **Feed-in tariffs are effective in building capacity but can lead to ballooning subsidies to unsustainable volume in case of a drop of investment costs.** By the end of 2017, the accumulated deficit of the Special Fund had reached more than US$14 billion.

The fast development allowed China to quickly develop a strong-performing and globally competitive wind and solar PV industries whose benefits might have compensated for the underperformance of capacity to date.

59. During the first and second stages of RE, China crafted sound policies, built a strong technological base, and assembled the talent pool to embark on a more aggressive development of wind and PV. However, many conditions required for large-scale development had still not been met in the mid-1990s:

- Policy on the role of renewable energy in the future mix was not clearly defined.
- The environmental benefits were not reflected in the pricing system and the subsidies deemed necessary to address this market failure were not yet in place.
- The market size was limited and developers lacked experience in large-scale project construction and operation.
- The potential and characteristics of RE resources were not yet confirmed.

60. To address these issues under this next stage, following the assessment of the potential and characteristics of RE resources, China adopted a Renewable Energy Law that clarified the status of the role of renewable energy and set ambitious development targets. The law was followed by the implementation of policies and regulations that provided a wide range of incentives to increase investment and build a sizable market, namely, feed-in tariffs for wind in 2009 and PV in 2014. The manufacturing industry was strengthened through international cooperation programs with more advanced counties and later with the development of a stronger domestic R&D base, which became capable of innovation. These

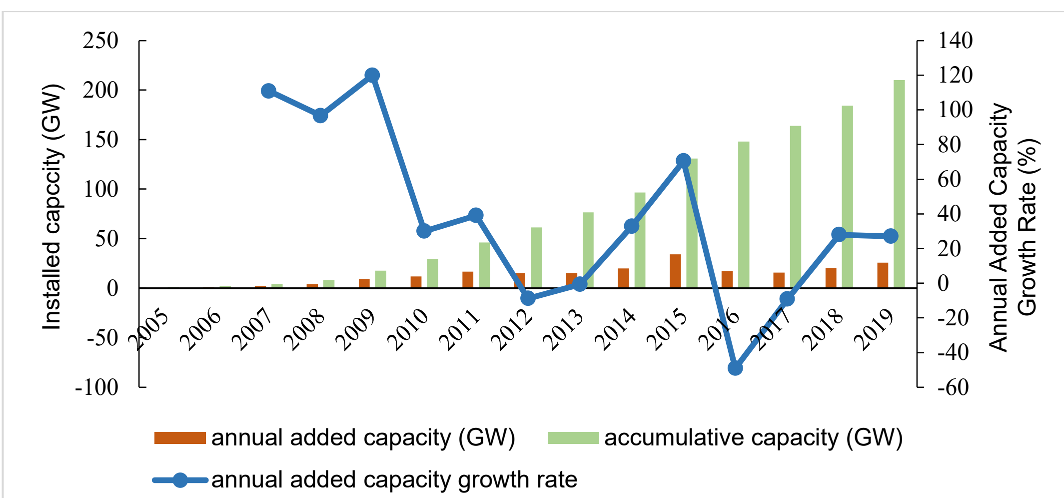
measures put RE development on a fast track and China was propelled to a leadership position in the field.

## A. RE Development Boom

61. During this stage, the proportion of RE in the energy mix increased constantly, making a significant dent in coal's long-reigning supremacy and contributing to the expansion of China's industrial base and economic development. By the end of 2017, China was the world leader in RE development:

- During this stage (2005–2017), the installed RE power capacity increased by 16 times reaching 638 GW, accounting for almost 37 percent of the total installed power generation capacity. The total RE power generation amounted to about 1,699 TWh, more than four times the 2005 generation, accounting for almost 26 percent of the total power generation: (a) the cumulative installed wind capacity increased from 1 GW to 164 GW, including about 3 GW in offshore wind power with a record annual capacity increase of more than 34 GW in 2015 (see Figure 4.1), and the single unit capacity of wind turbine reached more than 6 MW; (b) the cumulative installed PV capacity grew from 70 MW to slightly more than 130 GW, including 30 GW of distributed PV power; (c) the cumulative installed hydro capacity almost tripled from 117 GW to more 344 GW, including 29 GW of pump storage; (d) the cumulative installed biomass capacity reached increased 7.5 times from 2 GW to 15 GW, including 7 GW of straw-fired power, 7 GW in MSW incineration power, and about 450 MW in biogas power; and (e) the cumulative installed solar thermal power capacity reached 24 MW, geothermal power reached 27 MW, geothermal heated area amounted to 650 million m$^2$, and bioethanol and biodiesel consumptions reached 2.6 million tons and 600,000 tons, respectively.

**Figure 4.1: China On-Grid Wind Power Installed Capacity**




Source: Study team.[26]

- Commercial RE utilization amounted to 540 million tce (more than three times higher than the utilization in 2005) and accounted for 12 percent of the national primary energy consumption (about 60 percent higher than the share in 2005).

26 Renewable Energy Data Book published by the China National Renewable Energy Center (CNERC), 2019.

## B. Strengthening the Policy Framework

62. On February 28, 2005, the Standing Committee of the National People's Congress (NPC) adopted the Renewable Energy Law of the People's Republic of China (referred to as 'Renewable Energy Law'), which officially took effect on January 1, 2006, and was amended on December 26, 2009. The law included five key institutional arrangements:[27]

- The announcement of ambitious overall, and later technology-specific, RE targets for the medium and long term, providing clear signals to developers, investors, and other market players about the expected size of the RE market.

- The legal obligation on all power grid companies to purchase the full amount of the on-grid RE electricity and ease access of RE electricity to the transmission systems.

- The assurance that the 'on-grid price'[28] of RE electricity would provide investors and developers adequate return on investments for the development and utilization of RE. The prices were differentiated by region and evolved over time (see Figure 4.2 and Figure 4.3) but supported the unprecedented development experience in the country.

- The surcharge added to each kWh shared the burden among electricity consumers. Beginning in 2006, all categories of customers, except electricity for agricultural production, are charged CNY 0.001 per kWh (equivalent to US¢0.0125 per kWh) in 2006. The charge was increased to CNY 0.019 per kWh (equivalent to US¢0.29 per kWh) in 2016. The charge amounted to about 0.25 percent of total electricity price in 2006 and to 3.96 percent from 2016 for residents, 0.14 percent in 2006 and 2.24 percent from 2016 for general industrial and commercial consumers, and 0.18 percent in 2006 and 2.9 percent from 2016 for the large-scale industry.[29] However, the fee for residents and consumers with captive power plants is not fully levied in practice.

- The establishment of a Special Fund funded by consumer fees and state budget to make RE electricity more attractive to investors. Customer fees are mainly used to cover RE incremental financial costs and state budget funds are dedicated to support demonstration projects, R&D programs, resource assessment, and electrification projects in remote areas.

63. The Renewable Energy Law also introduced preferential tax and funding policies. In addition, the law entrusted relevant government departments with the issuance and implementation of rules and regulations.

- The competitiveness of wind and solar energy consistently increased during this stage as the installation cost of wind turbines and PV systems decreased significantly. Regarding wind, this was in part because the operational efficiency of wind farms improved considerably with the development of high-precision wind pattern prediction models. These gains were reflected in the slight reduction in wind and PV feed-in prices in all four wind and PV classes (see Figures 4.2 and 4.3).

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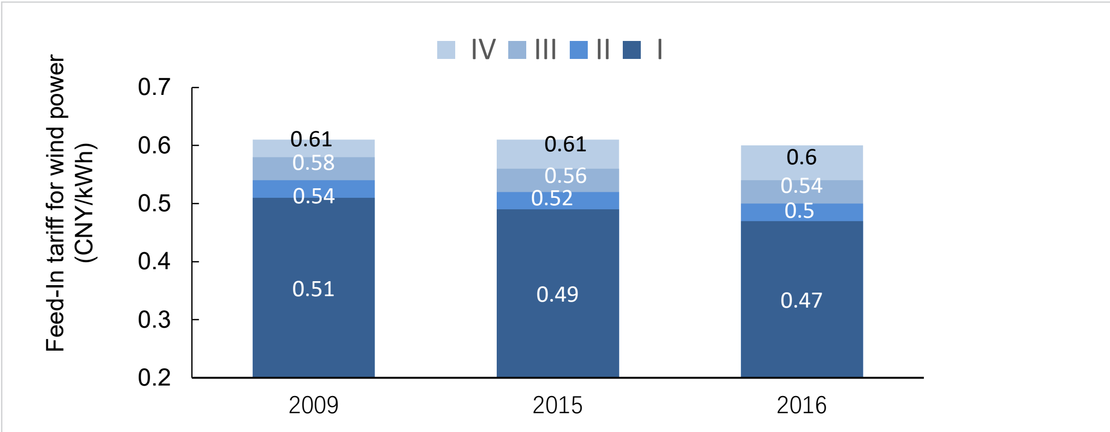
27 While this report focuses only on laws and policies directly related to RE development, it should be noted that such development would not have been possible without important reforms and laws such as the 'Company Law' (1994), the 'Power Law' (1995), the 'State Council Decree No. 5' (2002) that separated power generation from transmission and distribution

28 On January 1, 2006, when the Renewable Energy Law was implemented, the feed-in tariff did not exist. The on-grid price here refers to the price of electricity sold by the power plant to the grid, which was approved by the NDRC on a case-by-case basis. The on-grid price replaced feed-in tariffs for biomass in 2006, for wind in 2009, and for solar PV in 2014.

29 The electricity prices are different in different cities and regions. Beijing electricity prices have been used above as an example.

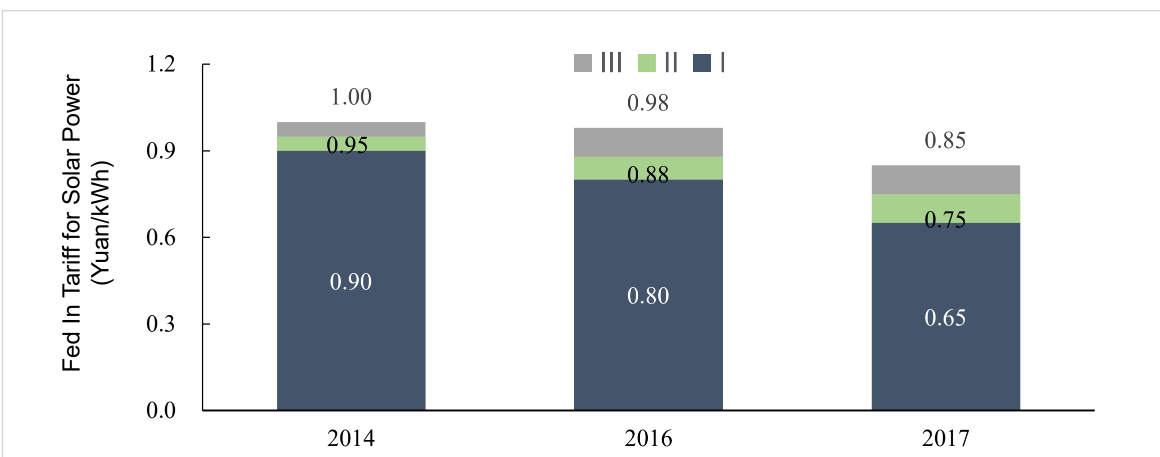
**Figure 4.2: Feed-In Tariff for Onshore Wind Power**[30]




Source: Study team.

64. Before 2009, the price of wind kWh was set competitively after several rounds of concession bidding. Before 2014, the price for solar PV-generated kWh was approved on a case-by-case basis. As the price of PV-generated electricity decreased from CNY 4 per kWh in 2008 to CNY 1.15 per kWh in 2011, Chinese authorities published a PV feed-in tariff to stimulate PV growth in 2014. The PV developers rushed to take advantage of the cash windfall as PV system costs fell dramatically. The PV feed-in tariff was adjusted slightly in 2015 and 2016 (see Figure 4.2), but too little and too late to contain the rush, which put a heavy burden on the RE Fund as discussed in the next chapter.

**Figure 4.3: Feed-In Tariff for Solar PV Electricity**




Source: Study team.
Note: See footnote 33.

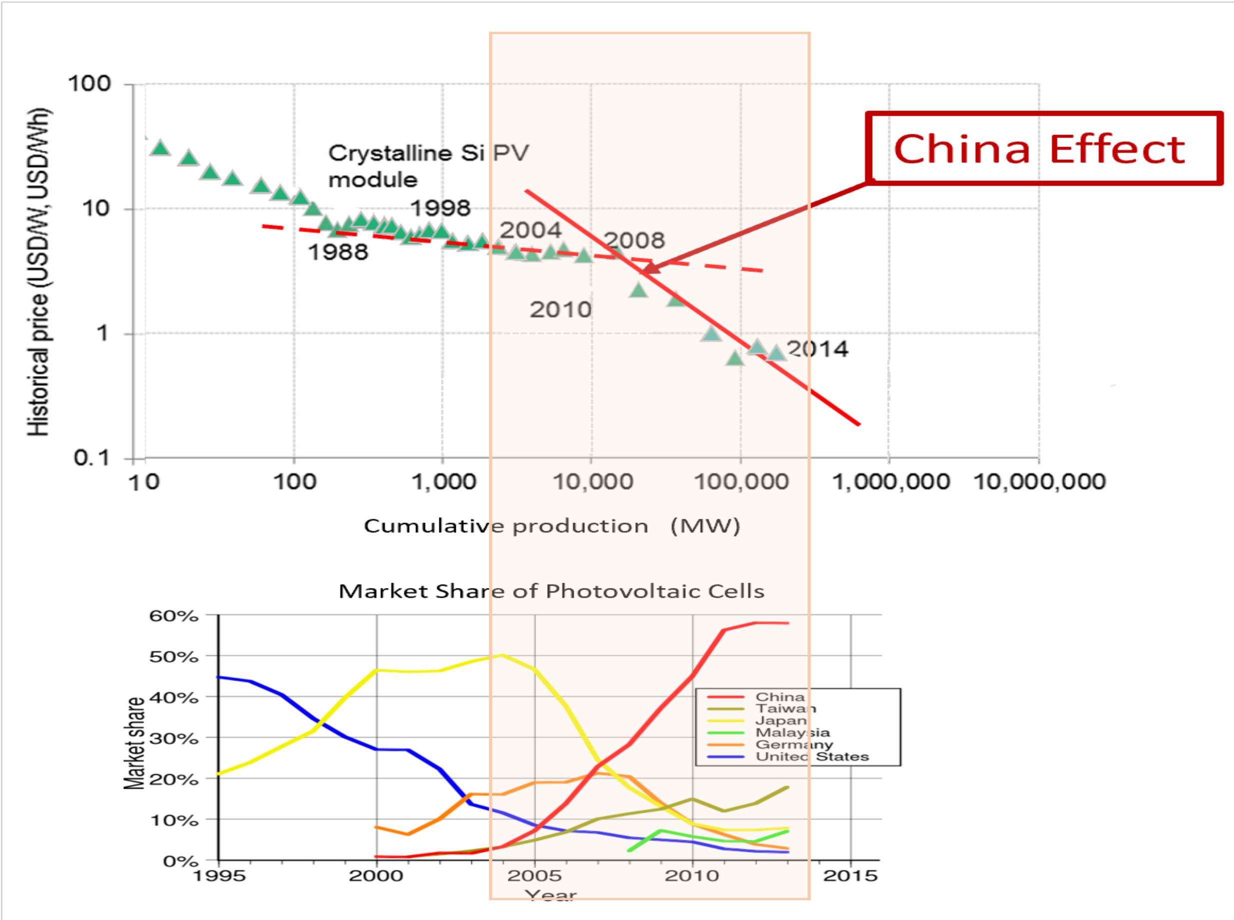
30 The wind resources were divided in four classes with quality of resources declining from Class I to Class IV. Wind resources are evaluated at the city level and one province may include more than one class of wind resources. The NDRC set higher feed-in tariffs for lower resource classes to increase the attractiveness of wind development. The same approach was followed for PV.

65. Since the promulgation and implementation of the renewable energy law in 2006, the relevant central government departments have issued multiple policies and notices relating to RE strategic planning, regulation, pricing, and so on. All provincial and autonomous region governments have also formulated special RE development or energy plans integrating renewable energy. This opened the door for the large-scale, diversified development and utilization of renewable energy and led to unprecedented market expansion. The cost of renewable energy, especially wind and PV, dropped significantly while the quality and reliability of the equipment increased. The scale of the Chinese market and low-cost production capacity of PV cells and modules led to an acceleration of the cost reduction globally and a quick increase of China's share of global market from 2006 onward (see Figure 4.4). To a lesser extent, a similar impact of the China wind energy industry development was observed on the evolution of the global price of wind turbines. Moreover, the industrial system gradually improved, forming a solid foundation for sustaining RE development in the country and participating in the global RE market.

66. In 2007, the NDRC issued the Medium- and Long-Term Development Plan for Renewable Energy indicating that RE development in China during from 2007–2020 would rely on hydro, biomass, wind, and solar energy. It stressed the need not only to accelerate the development of solar power but also to encourage solar heat utilization. The plan laid out guiding principles, main measures, focus areas, and safeguard measures and, most importantly, set the specific target of achieving a 15 percent RE share in the primary energy consumption by 2020. This established the foundation for the formulation of the 11th, 12th, and 13th FYPs:

- The national 11th FYP, prepared before the creation of the NEA on August 8, 2008, defined, for the first time, specific goals and targets not only for the overall RE development but also for all technologies defined in the Renewable Energy Law.

**Figure 4.4: Joint Evolution of Global PV Price and China's Share of Global PV Market**




Source: Study team, based on Bloomberg New Energy Finance, Maycock, Battery University, MIT.

- During the preparation of the 12th FYP, the NEA formulated four special plans for hydropower, wind power, solar, and biomass energy, to accelerate RE development as all of these technologies were gaining momentum in China and globally. The 12th FYP went beyond national goals and targets and promoted decentralized development through 'New Energy Cities' and green county pilots. It also promoted, for the first time, the development of emerging RE such as geothermal energy and ocean energy.

- At the outset of the 13th FYP, China's RE development was at its peak. During this stage, this momentous, and sometimes hasty, development led to subsidy amounts that heavily burdened the national budget and threatened the sector's sustainability. The 13th FYP attempted, for the first time, to coordinate the development of the power grid and huge wind and solar bases in the northwestern regions. Most of its RE targets have been, or are nearly, achieved.

67. The Renewable Energy Law devised diversified incentives to boost the development of renewable energy.

- Fiscal incentives. Wind power, PV, and other renewable energy equipment benefitted from VAT and income tax deductions (see Table 4.1). The 2008 'Notice of the Ministry of Finance and the State Administration of Taxation on the Comprehensive Utilization of Resources and Other Products' and follow-up provisions issued in 2015 as well as the 2014 'Notice on the Tax Policy for Non-grain Based Fuel Ethanol' provided significant VAT reductions to wind, PV, and biomass power generation as well as biomass heating and biofuels. Tax income deductions or exemptions were applied only to emerging advanced technologies and products or to infrastructure projects in poor and/or regions without access to electricity and clean energy. Few biomass power generation projects were eligible for the latter policies.

**Table 4.1: Summary of RE Tax Deduction**

| Category | Standard Tax Rate | Deduction Rate |
|---|---|---|
| VAT | From 17% to 13% | Solar PV and wind power are 50% exempted from VAT.[31] Biomass power generation and biomass heating benefitted from a 100 percent rebate on VAT. |
| | | Non-grain bioethanol has 100% VAT exemption. |
| | | Biodiesel had 100% VAT exemption in 2008, which was reduced to 70% in 2015 |
| Income tax | 25% | RE power generation projects are exempted from income tax in the first three years and pay only half from the fourth to the sixth year. |
| | | Non-grain bioethanol is exempted from income tax. |
| Land use tax | CNY 0.6–30 per $m^2$ (equivalent to US$0.09–4.5 per $m^2$) | Hydropower stations and transmission lines are exempted from land use tax. |
| | | Non-hydro RE power plants are exempted from land use tax if the project is built on unused land such as the Gobi desert and grassland. |

- **Land use tax exemptions.** In 2013, the Inner Mongolia Autonomous Region temporarily exempted electric power lines linking wind and hydropower projects to the grid from land use taxes as long as they did not alter the farming and husbandry patterns of the land. In 2017, the Letter of the National Energy Administration on Soliciting Opinions on the Notice on Reducing Tax Burdens on Enterprises in the Renewable Energy Sector proposed that RE power generation should be exempted from farmland occupancy, land use, and other taxes on the alteration of the purposes of concerned land uses. The 2015 "Opinions of the Ministry of Land and Resources, National Development and Reform Commission, Ministry of Science and Technology, Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development, and Ministry of Commerce on Land Use for Supporting the Development of New Industries and New Business Types and Promoting Mass Entrepreneurship and Innovation" prescribed that unused land such as the Gobi desert and wastelands leased to develop PV and wind power projects could still be declared, if the land surface is not changed, as unused/unchanged land in the annual national land change survey, and therefore not be subject to land use taxes. However, if the land was to be permanently occupied it would be regarded as used land and subject to land acquisition rules and taxation according to prevalent legal and regulatory procedures.

- **Preferential loan policy.** The 2016 "Opinions of the National Development and Reform Commission and the State Council Leading Group Office of Poverty Alleviation and Development on Implementing Poverty Alleviation Work through PV Power Generation" instructed the two major development banks, the China Development Bank and Agricultural Development Bank of China, to provide preferential loans for PV poverty-alleviation projects. The loan interest would be adjusted downwards to a certain extent following the Central Bank's guidance.

- **Other policies.** While this report focuses only on the national laws and policies directly related to RE development, many other national macroeconomic and sectoral laws and policies and provincial and lower administrative-level incentives contributed to the deployment of RE at such a large scale. Some examples are provided below, although it is well beyond the present report's

31 Solar PV VAT exemption discontinued in 2019.

scope to provide a comprehensive review of all the laws and policies that made such successful development possible:

- o The China Company Law issued in 1994 and then amended several times states that “The Company Law of the People’s Republic of China has been enacted in order to standardize the organization and activities of companies, protect the lawful rights and interests of companies, shareholders and creditors, safeguard the social and economic order and promote the development of the socialist market economy.” This allowed the creation of public and private companies that developed RE projects. The “Electricity Law” (1995) allowed new entrants in the power generation subsector and mandated single-buyer utilities to take off their generation. The State Council’s Electric Power Sector Reform Decree No. 5 (2002) led years later to the separation of generation from transmission and distribution and the creation of many companies, such as EHDC and the Three Gorges Company that contributed greatly to the development of hydropower and large state-owned generation companies, which enabled the rapid development of RE possible.

- o Many provinces also issued various incentive policies at different stages to promote the development of renewable energies. For instance, Beijing issued a solar energy promotion policy in 2009 and a distributed solar PV promotion policy in 2014, which included detailed development targets, technical requirements to meet quality standards and complements to the national incentives to support RE development. For distributed solar PV, the policy added an installation subsidy of CNY 1.0 (US$0.16) per W that would be provided for three consecutive years, subject to the system performing in accordance to the required quality specifications.

68. RE development has also benefitted from policies that emphasized the role of RE development to mitigate climate change impacts and contribute to pollution prevention and control, including clean heating in the northern region, industrial transformation, and green manufacturing:

- Taking into account China’s vulnerability to the adverse effects of climate change, the NDRC issued the National Plan on Climate Change (2014–2020) in 2014. The plan, which emphasized the rapid, diversified, and sustained development of non-fossil fuels to increase their share in primary energy consumption to 15 percent by 2020, was one of the first major actions to address the control of greenhouse gas emissions. The plan stressed the need to (a) develop hydropower in an orderly and scientific way and create pumped storage power stations to ease integration of variable RE technologies into the grid; (b) vigorously develop wind power and accelerate the completion of the eight gigawatt-wind power bases[32] planned in North China, Northeast China, and Northwest China; (c) initiate the development of offshore wind farms; (d) promote the diversified utilization of solar energy by developing large-scale PV power stations, carrying out demonstration projects of ‘New Energy Cities’ and micro-grid systems based on renewable energy, and accelerate the implementation of building integrated PV (BIPV) projects; (e) prioritize and accelerate biomass-based projects including combined heat and power (CHP) biogas, MSW incineration power, landfill gas power, and the industrialization of wood pellets; and (f) improve the development and utilization of other RE sources such as geothermal energy and ocean energy. In addition, the plan encouraged large energy consumers to rely on RE to reduce their carbon footprints and proposed to undertake low carbon province and city pilots to develop diversified decentralized RE applications. In June 2015, China issued its the Nationally Determined Contribution (NDC) specifying that “Based on its national circumstances, development stage, sustainable development strategy and international

32 The gigawatt wind power bases are large-scale wind areas devoted by the government for wind power development and provided with appropriate conditions, such as special power transmission corridor.

responsibility.” China commits to the following actions by 2030: (a) achieving the peaking of $CO_2$ emissions and making best efforts to peak earlier; (b) lowering $CO_2$ emissions per unit of GDP by 60–65 percent from the 2005 level; (c) increasing the share of non-fossil fuels in primary energy consumption to around 20 percent; and (d) increasing the 2005 forest stock volume by around 4.5 billion $m^3$.

- On September 10, 2013, the State Council issued the ‘Action Plan for the Prevention and Control of Air Pollution’ as most of the country was plagued by disastrous increase of local pollutants stemming from unbridled use of coal. The action plan also stressed the need to further diversify the development of renewable energy.

- As concerns about local pollution were brought to the attention of the highest decision-making level, President Xi launched the ‘Energy Revolution’ in 2014 to (a) change energy consumption patterns by curbing unreasonable energy consumption and furthering China’s successful energy efficiency conservation efforts; (b) diversify energy supply sources by strengthening energy transmission and distribution networks and promoting energy storage; (c) promote innovation and deploy ‘green and low carbon’ technologies and adopt greener and more effective industry and business models; (d) build competitive energy markets to allow the formation of energy prices that would ensure efficient supply and optimal use of resources; (e) complete and improve the legal system governing the energy sector; and (f) effectively strengthen and transparently use international cooperation and resources to achieve energy security and sustainable development of the energy sector.[33] To achieve the Energy Revolution objectives and meet China’s climate change commitment to peak carbon emissions before 2030, decision-makers at different administrative levels are emphasizing the need for furthering RE development, rethinking current policies and regulation mechanisms, adjusting existing energy supply and consumption models, and fostering innovation and providing a ‘green and low carbon’ development model.

- By the end of 2017, 10 ministries and commissions, including the NDRC, NEA, and MoF, issued the ‘Plan for Clean Heating in Winter in the Northern Region (2017–2021)’. The plan required that the northern region maximizes clean energy use for heating in winter. Selection of appropriate heat sources was to be adapted to local conditions and could include geothermal, biomass-based clean heating. It also set strict environmental standards and requirements for biomass-based heating and promoted solar and electric heating in areas with large-scale wind and PV power generation potentials.

- The industrial sector remains the largest energy consumer. In June 2016, the Ministry of Industry and Information Technology (MoIIT) issued the Green Development Plan for the Industrial Sector (2016–2020) to accelerate the green transition of the industrial sector. According to the plan, the share of green and low carbon energy in industrial energy consumption would be increased from 10.9 percent in 2015 to 15 percent in 2020. It proposed to vigorously substitute fossil fuels with green and low carbon RE in large industrial complexes and industrial parks.

69. These policies provided direct and indirect support for RE development and the creation of a massive market for all technologies by initiating demonstration and pilot projects, setting ambitious quantified targets, and providing clear incentives to developers and market players.

33 This description is limited to the aspects directly related to the energy sector.

## C. International Cooperation

70. China intensified international cooperation activities with multi- and bilateral institutions. The following examples illustrate the efforts deployed by the Chinese government to exchange and share knowledge to promote RE development, in particular to learn from international experience with respect to policies and institutional development to scale up investment in RE:

- **CRESP II** aims to move RE development in China from the quantitative scale-up in Phase I to sustained growth under Phase II, with a focus on efficiency improvement, smooth grid integration, and cost reduction. CRESP II has provided substantial support to an integrated approach of RE planning during the preparation of the 13th FYP. In addition to supporting policy, regulatory, and technical solutions for RE grid integration, CRESP II has also supported the government in addressing emerging RE pricing and subsidy issues stemming from the important drop in RE, especially PV, prices to reduce the important deficit of the RE Fund. Furthermore, CRESP II continues to promote technology improvement for cutting-edge RE technologies such as offshore wind and concentrated solar power (CSP) to improve quality, reduce cost, and build capacity

- **The Sino Denmark Wind Energy Development (WED) Program** was officially launched in June 2006. The Danish government provided a EUR 6 million grant to finance activities to be undertaken by the project over a four-year implementation period. It mainly provided capacity building and knowledge transfer in the field of wind energy in Heilongjiang, Jilin, and Liaoning Provinces. The Sino Danish wind energy development project is the first Sino foreign government cooperation project dedicated solely to wind energy development. It introduced Denmark's leading technology and management experience in the field of wind power to China's wind power industry and adapted them to Chinese conditions.

- **The Sino Denmark Renewable Energy Development (RED) Program** is the largest cooperation project in the field of renewable energy between China and Denmark. It started in early 2009 and ended in 2014. The goal was to improve the institutional capacity of the Chinese government in developing RE and dealing with climate change and to study and formulate a clean energy development strategy and implementation roadmap. After five years of implementation, the project has successfully completed the expected objectives and established a national RE decision-making institution—the CNREC. Since its establishment in 2012, the CNREC has completed the preparation of the 12th FYP for RE development and China's 2050 Sustainable Energy Development Strategy.

- **Sino Danish biomass CDM provincial capacity-building project.** A cooperation agreement was officially signed in December 2006. The three-year project budget was funded by a Danish grant amounting to DKK 9.6 million (about US$1.43 million). The project included 7 subprojects at the national level and 10 subprojects at the provincial level. The implementation of the project improved China's technological capacity in biomass energy development and utilization.

- **The CDM and carbon trading** under the Kyoto Protocol were major financing sources in the early days of RE development in China. Several enterprises improved the financial returns of their projects by selling their emission reductions to the program. This made several RE development projects, funded locally or by multilateral banks, possible.

- **China-US RE partnership.** A memorandum of cooperation was signed during the 2009 visit of the US President to China to establish a China-US RE partnership to combat climate change. The two countries "embraced a vision of wide-scale deployment of renewable energy including wind, solar and advanced bio-fuels, with a modern electric grid, and agreed to work together to make that vision possible."[34] Four sessions of 'China US Renewable Energy Industry Forum' were held in 2010, 2011, 2013, and 2015. These allowed (a) the establishment of the China Variable-Generation Group (CVIG) and Photovoltaic Quality Assurance (PVQA) working groups, which undertook several research and cooperation activities; (b) the cooperation on Qinghai concentrated solar power generation (CSP) demonstration; and (c) the preparation of several reports on RE grid connection, distributed power and micro-grid, and 'New Energy Cities'. The partnership promoted mutual understanding and increased cooperation between the RE industries of the two countries.

## D. Key Projects

71. To meet booming market needs, several initiatives were undertaken for the momentous development of wind first and then solar in the latter years of the third stage. They included improving the assessment of wind resources; planning for the development of gigawatt wind bases, which were facing specific and unprecedent risks; and developing specific programs to promote the boom of PV development.

- **Improved the quality of wind energy and solar resources.** The China Meteorological Administration (CMA) launched a new round of wind energy resource assessment in 2014, based on the results of the 'National Wind Energy Resources Detailed Investigation and Evaluation' released in 2010. Measurements were collected from nearly 1,000 wind masts and were used to improve simulation results. The 'China Wind Energy and Solar Resources Annual Communiques', published by the CMA since 2014, provided updated information and detailed analyses about China's wind and solar resources annually and guided the development of solar PV and wind power stations. This not only raised the efficiency of power stations but also provided recognized benefits to distributed solar PV and decentralized wind power projects as the published data contributed to better site selection.

- **Biomass resources evaluation.** In 2010, the MoA began investigating and evaluating straw resources in China. In 2009, China's theoretical crop straw resources amounted to 820 million tons (air dried and 15 percent moisture content, roughly 410 million tce), including (a) 205 million tons of rice straw (roughly 107 million tce), accounting for 25 percent of the total theoretical crop straw resources; (b) 150 million tons of wheat straw (roughly 80 million tce), accounting for 18 percent of the total; (c) 265 million tons of corn straw (roughly 140 million tce), accounting for about 32 percent of the total; (d) about 26 million tons of cotton straw (roughly 13 million tce), accounting for 3.2 percent of the total; (e) 37 million tons of oil crop residues (mainly grape and peanut, roughly 19 million tce), accounting for about 5 percent of the total; (f) about 27 million tons of bean stalk (roughly 14 million tce), accounting for slightly more than 3 percent of the total; (g) 22 million tons of sweet potato straw (roughly 11 million tce), accounting for almost 3 percent of the total; and (h) about 87 million tons of other straw and residues (roughly 46 million tce), accounting for about 11 percent of the total. However, despite the comprehensive assessment and evaluation of the resources, little reliable data about their location and use are available, hindering the optimal use of the resources.

- **Development of large wind bases**. In 2009, China started the preparatory work for large wind farms and planned to build seven wind power bases in six provinces and regions: A nearly 36 GW base in Jiuquan Gansu Province; a 20 GW base in Hami Xinjiang Autonomous Region; a 20 GW base in Western Mongolia and a 30 GW base in Eastern Mongolia; a 10 GW base in the coastal

34 Fact Sheet: U.S.-China Renewable Energy Partnership November 17, 2009. https://china.usc.edu/fact-sheet-us-china-renewable-energy-partnership-november-17-2009

and northern areas of Hebei; a 10 GW base in Jiangsu (including 7 GW in intertidal areas); and a 23 GW base in western Jilin (mainly in Songyuan, Baicheng, and other cities). In 2012, two more bases were added: 15 GW in Heilongjiang and 15 GW in Shandong. These large-scale bases created a huge market for wind power in China and principally contributed to the development of wind turbine manufacturing and the ensuing technological and industrial progress. It contributed to the achievement of medium- and long-term 3 percent target contribution of non-hydropower renewable energy in the power supply. However, this progress came at a cost, as low efficiency brought about by ineffective design and wake effect [35] and important curtailments in the early years of operation, which the government began to address at the end of this stage.

- **The Golden Sun demonstration project** was developed by the MoF, MoST, and NEA in 2009. Its goal was to promote the technological progress and large-scale development of solar PV and accelerate the deployment of emerging and innovative PV applications as well as support demonstration applications of solar PV in various fields to expand the PV market and spur the manufacturing of better-quality equipment and encourage innovation. The program provided subsidies amounting to (a) 50 percent of total investment costs, including related transmission and distribution costs, to eligible PV power stations projects and (b) 70 percent of the total investment costs to eligible off-grid projects in remote and/or poor areas, especially those without access to electricity. The demonstration scheme was implemented during 2009–2013 and supported three types of projects: (a) 222 power generation projects on the user side connected to the grid, (b) 18 solar PV projects in areas without electricity, and (c) 35 large grid-connected solar PV farms. The implementation of these projects developed a significant market for China's solar PV power. It attracted a large number of developers and energy services companies (ESCOs) and contributed to the development of a thriving PV manufacturing industry.

- **The Top Runner Project** was launched by the NEA in 2015 to support the deployment of emerging and more sophisticated PV technologies to reduce their cost. The Top Runner Project was designed to support experimental and innovative PV demonstration projects and accelerate the deployment of the most promising ones. This ultimately reduced investment costs and accelerated the adoption of technical breakthroughs and innovation by the fast-growing market. The program was phased in over 2015–2017. It led to the installation of 1 GW in 2015, 5.5 GW (in 5 supported bases) in 2016, and 6.5 GW (in 13 supported bases) in 2017. More importantly, the program allowed PV manufacturing enterprises to significantly improve and introduce advanced manufacturing technologies and expand their production capabilities of state-of-the-art and high-quality systems. Further, the average of bid prices proposed by the base developers was CNY 0.2 per kWh, 20 percent lower than the PV feed-in tariff at the time. The program's average price provided early signals about the high level of the PV feed-in tariff and contributed to the slight revisions presented in paragraph 62. It should have also been considered as an early warning about the financial problems discussed in the next chapter.

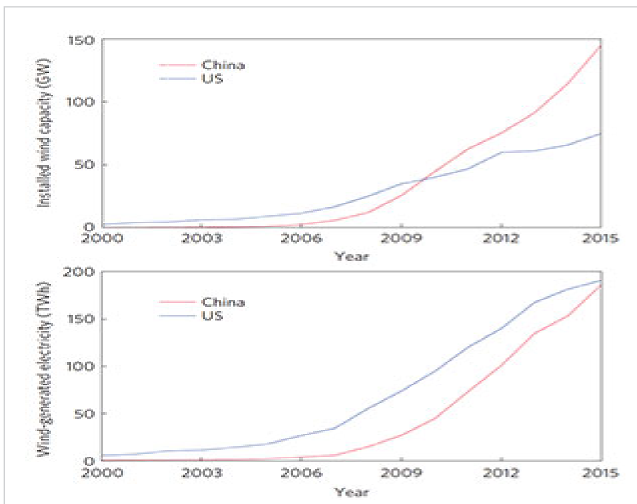
## E. Lessons Learned

72. Several lessons learned during this stage are being considered for China's future RE development and for countries embarking on ambitious RE development programs:

35 The wake effect is the aggregated influence on the energy production of the wind farm, which results from the changes in wind speed caused by the impact of the turbines on each other. Source: Wind Energy: The Facts. https://www.wind-energy-the-facts.org/wake-effect-7.html.

- **Aggressive and uncoordinated RE development programs could be disruptive, less than optimally efficient, and captured by vested interests.** The hasty launch of the wind concession program focused mainly on building capacity fast with an administratively capped price and managed to increase wind power capacity at an unprecedented and unmatched level. However, it came at a cost as, in 2012, the US generated the same wind-based electricity generation as China with half of the capacity (see Figure 4.3). The program was captured by financially and politically powerful SOEs that managed to renegotiate their bidding prices with government entities to secure higher levels of subsidies. It must however be noted that since China undertook many corrective measures to reduce wake effect, improve the program's design, and better coordinate wind base development and grid extension and reinforcement. These led to increased capacity factor of existing wind assets. In addition, the fast development allowed China to quickly develop a strong-performing and globally competitive wind industry whose benefits might have compensated for the underperformance of wind capacity to date.

**Figure 4.3: Wind Capacity and Electricity Generation in China and the United States**




Source: Image_ Tsinghua University/Harvard University. Fairley, Peter. 2016. "Why China's Wind Energy Underperforms." IEEE Spectrum. May 23, 2016.

- **Feed-in tariffs are effective in building capacity but could lead to inacceptable levels of subsidies in case of a dramatic drop of actual investment costs.** Wind power feed-in tariffs worked well in Germany and China as both countries quickly developed a sizable share of wind power capacity compared to their total power capacities. In Germany, feed-in tariff developed without disruption as wind power cost decreased gradually and slowly over time. However, in China, the feed-in PV tariff prompted a rush to build capacity as fast as possible to take advantage of the high on-grid price as the installation cost of PV systems quickly began free falling. Although small private enterprises and ESCOs contributed to the explosive growth, it was mainly led by powerful and financially powerful SOEs. The RE Special Fund then failed to compensate developers timely, with arrears extending to three years in some cases. By the end of 2017, the accumulated deficit of the Special Fund had reached more than US$14 billion. The first casualties were the small companies that borrowed excessively and did not manage to meet their debt because of the delayed compensation payments. China, along with many other countries, abandoned feed-in tariffs and embarked on auction programs to sustain its RE development program, as discussed in Chapter 5.

# Chapter 5. The Way Forward (Stage 4: 2018 to Present)

**Key Messages**

By the end of 2020, the share of China's commercial renewable energy amounted to about 13.6 percent of the national primary energy consumption, compared to 4 percent in 1980 and about 6.5 percent in 2005. The non-hydro RE installed capacity increased to 564 GW and the power generation increased to 860 TWh, both almost 300 times higher than the 2005 capacity and generation.

The success achieved is undeniable and staggering as most of the targets of the 13th FYP were extensively exceeded. However, at the end of the third stage, several issues emerged threatening the sustainability of RE development, mainly (a) low efficiency of existing wind and PV assets evidenced by very low capacity factors, (b) ballooning subsidies as feed-in tariffs remained high despite a significant decrease of wind power equipment and decrease in PV system costs, and (c) lack of interprovincial power trading leading provinces to develop their own sites even with poor resources to meet RE provincial targets.

The measures taken by decision-makers at the highest level during the first three years of the fourth stage indicate that future RE development would rely more on market-oriented and decentralized approaches to improve cost-effectiveness and put the country on a greener and sustainable path.

In 2017, three years after the launch of the 'Energy Revolution', the NDRC and NEA published the 'Energy Production and Consumption Revolution Strategy (2016–2030)' to guide all government departments and the whole society to align their practices with the principles of the 'Energy Revolution' strategy, including the following:

- **Forming a unified and open energy market with orderly competition.** The market will play the decisive role in allocating resources and price formation.

- **Establishing, improving, and completing the legal framework governing the energy sector, especially by developing an Energy Law.** The new legal system would balance the interests of all parties, strengthen energy regulations and supervision, override obsolete laws and regulations lagging behind the rapid development of the sector, and remove loopholes and inconsistencies that plagued RE development.

- **Building the new 'green, low-carbon, secure, and efficient' energy system.** By 2030, non-fossil energy share in primary energy consumption target will increase from 20 percent in 2030 to 50 percent in 2050.

Several rounds of wind and PV auctions were initiated by the NDRC and NEA and resulted in bidding prices significantly lower than 'feed in tariffs'. The auction procedures and selection criteria improved as experience accumulated and it was decided that future wind and PV power capacities will be procured through auctions.

In 2019, the NPC carried out the 'Performance Evaluation of the Renewable Energy Law'. The evaluation group suggested revising the Renewable Energy Law to adapt its provisions to current market conditions; clarify the legal responsibilities of power grid, oil, gas, heat, and other enterprises; and set minimum efficiency standards for RE assets. On April 10, 2020, a new draft was swiftly prepared and circulated by the NEA to solicit opinions of all concerned institutions.

The draft Energy Law that has been disclosed for public consultation is more explicit about China's ambition and commitment to ensure healthy and sustainable RE development, including (a) giving a prominent role to RE in the energy structure and adjusting and optimizing the energy industry and consumption structure to align them with the Energy Revolution principles; (b) allocating, for the first time, RE production and consumption targets to provinces in the mid- and long-term social and economic development plans; (c) aligning energy development with the country's climate change commitments and local pollution reduction objectives; and (d) stressing that producers and consumers have the obligation to contribute to the country's objectives relating to local pollution and GHG emission reduction objectives and that producers have the obligation to reduce emissions and environmental impact during construction and production.

Several lessons learned during this stage, on which the Chinese authorities have been taking actions, can be useful references for other countries trying to build a well-functioning RE market: (a) abrupt policy and regulatory changes are conducive to market turmoil, (b) unclear delineation of regulation responsibilities among government agencies and uncoordinated exercise of these responsibilities can derail the implementation of sound policies, and (c) auctions based only on price lead to unfair competition and failure to deliver.

73. By the end of 2020, the share of China's commercial renewable energy amounted to about 13.6 percent of the national primary energy consumption, compared to 4 percent in 1980 and about 6.5 percent in 2005. The non-hydro RE installed capacity increased to 564 GW and the power generation increased to 860 TWh, both almost 300 times higher than the 2005 capacity and generation.

74. Hydropower, wind power, and solar PV have become the main power sources in some regions. Solar thermal utilization, geothermal energy, and biomass have become important substitutes and supplements for urban and rural clean heating and clean fuel.[36] This tremendous growth elevated the role of the new RE (PV and wind) from complementary power sources to traditional ones and they began displacing coal power plants. As an example, 120 GW of new coal power plants were cancelled in 2017 and coal overcapacity became a serious problem in many provinces. A national debate ensued about the long-term prospect of RE development.

75. The momentous growth was mainly driven by a top-down approach and national and provincial policies mandating RE use and supported by subsidies mainly from the RE Fund and special national and provincial programs. However, several issues also emerged, mainly (a) low efficiency of existing wind and PV assets evidenced by very low capacity factors (see Figure 5.1); (b) ballooning subsidies as feed-in tariffs remained high despite a significant decrease of wind power equipment and substantial decrease in PV system costs [37]; and (c) lack of inter-provincial power trading leading provinces to develop their own sites even with poor resources to meet RE provincial targets.

76. This chapter is dedicated to the policies and initiatives undertaken by Chinese authorities to address these issues and move toward a higher RE penetration in the energy mix by

36 Use of ethanol gasoline is currently mandatory in more than 15 provinces in China.
37 Recently the grid parity has gradually been introduced for PV and wind.

- Asserting the priority of RE development and defining more ambitious RE development targets in a new strategy backed by first-order legal instruments, which would contribute to mobilizing the whole society to actively promote RE development and weaken efforts by vested interests to contain it;

- Increasing the flexibility of the power system to make it able to absorb a high share of intermittent RE;

- Revising and completing current policies governing the energy sector to promote more market-oriented and decentralized RE development; and

- Rethinking existing energy supply and consumption models to realize more efficient allocation of resources.

77. The measures taken by decision-makers at the highest level during the first three years of the fourth stage indicate that future RE development would rely more on market-oriented and decentralized approaches to improve cost-effectiveness and ensure a sustainable and increased share of all RE forms to put the country on a greener and sustainable path.

## A. Rising Concerns about Sustainability of RE Development

78. The highly centralized and regulated pricing approach led to lack of competition and increased market power of powerful SOEs in China's energy system, including non-hydro RE development. More importantly, the current prevailing and slowly evolving policy system during the third stage of RE development lagged behind the fast-growing non-hydropower market, the sweeping technological advances, especially power storage, and fast decreasing RE prices, especially PV systems. These led to rising concerns about the sustainability of RE development and prompted decision-makers to twin government commitment to scale up RE development with clear objectives to deliver electricity at a minimum cost and undertake swift changes to address the following issues:

- **Unbalanced development among various subsectors.** Due to greater policy focus and financial support, the actual installed capacity of PV achieved the double of both the 11th and 12th FYPs' target, while for wind, the actual installed capacity achieved the double of the 12th FYP's target, and the 13th FYP target (2016 to 2020) was reached two years ahead of schedule. On the other hand, the biogas, RE heating, and fuel development lagged behind in almost all FYPs, by 20–70 percent (see Table 5.1).

**Table 5.1: RE Development FYP Targets and Completion by the End of 2020**

| | 11th FYP (2006–2010) | | | 12th FYP (2011–2015) | | | 13th FYP (2016–2020) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Target (a) | Completion (b) | Completion Rate (%) (b/a*100%) | Target (a) | Completion (b) | Completion Rate (%)(b/a*100%) | Target (a) | Completion (2020) (b) | Completion Rate (%)(b/a*100%) |
| **Power generation** | | | | | | | | | |
| Total installed capacity (GW) | 205.8 | 253.36 | 123 | 424 | 502.02 | 118 | 710 | 934.64 | 131 |
| Hydropower (GW) | 190 | 216.06 | 114 | 290 | 319.54 | 110 | 380 | 370.16 | 97 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wind power (GW) | 10 | 31 | 310 | 100 | 129 | 129 | 210 | 281.53 | 133 |
| Solar PV (GW) | 0.3 | 0.8 | 267 | 21 | 43.18 | 206 | 105 | 253.43 | 241 |
| Biomass power (GW) | 5.5 | 5.5 | 100 | 13 | 10.3 | 79 | 15 | 29.52 | 196 |
| Total generation (TWh) | 710 | 761 | 107 | 1200 | 1380 | 115 | 1900 | 2214 | 116 |
| **Gas** | | | | | | | | | |
| Biogas (billion $m^3$) | 19 | 14 | 74 | 22 | 19 | 86 | 8 | 0.128 | 1.6 |
| **Heating** | | | | | | | | | |
| Solar water heater (million $m^2$) | 150 | 168 | 112 | 400 | 440 | 110 | 800 | n.a. | n.a. |
| Geothermal (million tce per year) | n.a. | 4.6 | n.a. | 15 | 4.6 | 31 | 40 | n.a. | n.a. |
| **Fuel** | | | | | | | | | |
| Biomass pellet fuel (million tons) | 1 | 3 | 300 | 10 | 8 | 80 | 15 | 18 | 120 |
| Bioethanol (million tons) | 3 | 1.8 | 60 | 4 | 2.1 | 53 | 4 | 3 | 75 |
| Biodiesel (million tons) | 0.2 | 0.5 | 250 | 1 | 0.8 | 80 | 2 | 1 | 50 |
| Total commercial RE (million tce) | 250 | 255 | 102 | 400 | 436 | 109 | 578 | n.a. | n.a. |

Source: Study team.[38]
Note: n.a. means data are not published yet. The 2018 data of RE gas, heating, and fuel have been used as the alternative.

- **Serious inter-provincial trade barriers.** China's RE generation locations are far from power load center. China overproduced 27.7 TWh of wind power in 2018, mainly in Inner Mongolia and Xinjiang, and at the same time, provinces in East China have struggled to meet their RE obligations, eventually developing RE with their own, sometimes poor resource. So trade is essential to optimal and cost-effective use of the country's RE resources. However, concerned local authorities focus on developing their own resources, which are sometimes inadequate and less competitive than imports of RE electricity, because of distorted fiscal incentives and local vested interest.[39] RE electricity trade could foster competition and lead to further RE development at a lower cost for the nation. A 2010 World Bank study found that meeting the 2020 national target (at that time) could be achieved without trade but the impact on the generation cost would be significantly higher and differentiated among provinces.[40] This conclusion became more relevant during the 12th and 13th FYPs as PV prices continued to decrease significantly.

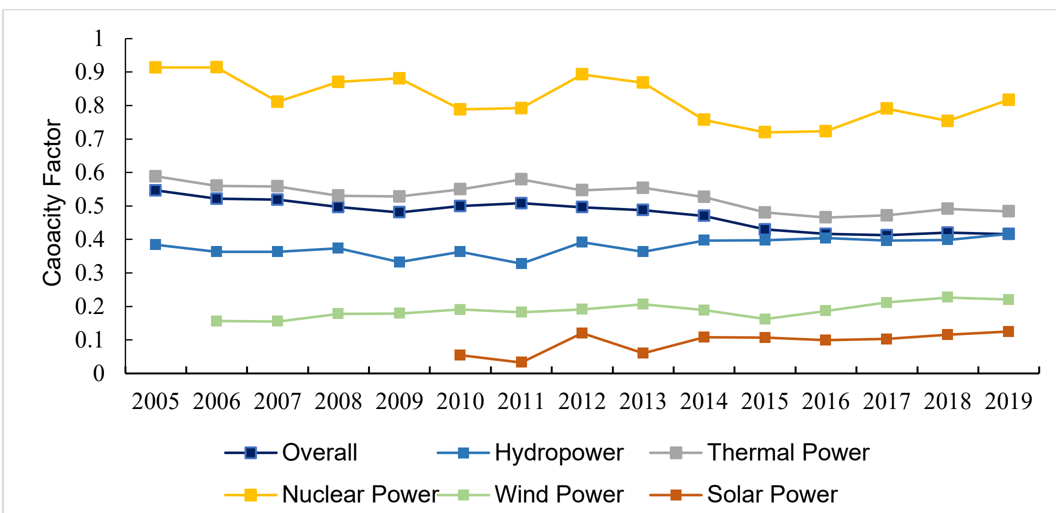
- **Very low capacity factors of RE assets (see Figure 5.2).** The generous national feed-in tariffs and other compensations at provincial and lower administrative levels triggered a 'gold rush', and wind (and later solar) developers and wind turbine (and later PV systems) manufacturers, mainly SOEs, engaged in building wind (and later solar) capacity far beyond the 11th and 12th FYP targets. The wind capacity exceeded the 11th FYP target by 210 percent, and the solar capacity exceeded the 11th, 12th, and 13th FYP targets by 167, 106, and 94 percent respectively (at the end of 2019) (See Table 5.1). During the early development years, Chinese wind farms had lower capacity factors than comparable wind farms in developed countries because of unproven turbines and the development of sites without confirmation of resources and proper micro-siting studies or development of sites with mediocre wind resources in some provinces to meet their mandatory targets. More alarming,

38 11th, 12th, and 13th FYPs for RE development, and the China Electricity Council's Statistical List of Power Basic Data
39 The VAT collected by local governments is still mostly based on electricity generated by provincial assets rather than final electricity consumption as in more advanced countries and provides fiscal incentives to develop local RE resources even at higher prices. Furthermore, provincial RE developers are shielded from more competitive RE sources in better endowed provinces.
40 World Bank. 2010. "China's Envisaged Renewable Energy Target: The Great Leap Forward" World Bank Unpublished Policy Note.

history repeated itself during the last decade of solar PV development. In 2019, the development of sites without confirmation of resources and proper micro-siting studies or development of sites with mediocre solar resources contributed to the very low efficiency of PV assets. Installed solar PV capacity amounted to 9.2 percent of the total power installed capacity, but its share in the total electricity generation accounted for only 2.5 percent of the total generation (see Figure 1.2 and Figure 1.3). The capacity factor of PV in China was, on average, about 42 percent of the PV capacity factor observed in the United States between 2014 and 2017. The low capacity factors stem not only from technical issues, such as poor design and resources, but also from external barriers: (a) inadequate operational flexibility of power systems to accommodate the variability of fast-growing wind and PV generation without electricity storage; (b) disconnect between early policy frameworks and fast-growing markets and technologies which leads to local government preventing RE power generation beyond what is guaranteed by the policy; and (c) restriction of inter-province trade that led to development of sites with poor RE resources in some provinces to meet targets assigned to them by the government.

- **Continued high subsidization despite significant price decreases of wind and PV technologies.** Although the feed-in tariff was slightly updated in 2016 and 2017, it did not reflect the fast cost drop and, as a result, subsidies ballooned to an unacceptable level and developers pocketed higher profits. This windfall led to a chaotic rush to solar PV development and the large deficit of the RE compensation fund (see Chapter 4, paragraph 62).

**Figure 5.1: Capacity Factors in China by Categories**




Source: Study team.[41]

- **Pushback of fossil fuel vested interests.** With the increased RE share in the primary energy consumption, vested interests, consisting mainly of monopoly, monopsony, and market power holders, began labelling the policy-driven RE growth as ‘unfair competition’. The criticism exacerbated as the energy consumption growth began to taper and it became obvious that by achieving the national target of 20 percent non-fossil share[42] in the primary energy consumption by 2030, renewable energy would gradually and significantly reduce fossil fuel growth. This issue is not specific to China and fossil fuel lobbyists are active in most countries. China’s ‘Energy Revolution’ is an attempt to

41 Based on China Energy Statistical Yearbooks 2014 to 2019

42 Although nonfossil energy includes nuclear energy and renewable energy, because nuclear energy will not grow rapidly within the expected range, the target of nonfossil energy is mainly borne by renewable energy.

develop innovation, new industry and business models, and development opportunities to lessen these worries and prepare the country for a 'green and low carbon future' (see Chapter 4, paragraph 66, third bullet).

## B. Toward New Consumption and Supply Models

79. In 2017, three years after the launch of the 'Energy Revolution', the NDRC and NEA published the 'Energy Production and Consumption Revolution Strategy (2016–2030)' to guide all government departments and the whole society to align their practices with the principles of the 'Energy Revolution' strategy. This strategy encompasses all aspects of energy supply and consumption with special focus on the following:

- **Forming a unified and open energy market with orderly competition.** The market will play the decisive role in allocating resources and price formation. The government will reduce its intervention in energy markets and focus on planning and regulation.

- **Establishing, improving, and completing the legal framework governing the energy sector, especially by developing an Energy Law.** The new legal system would balance the interests of all parties, strengthen energy regulations and supervision, override obsolete laws and regulations lagging behind the rapid development of the sector, and remove loopholes and inconsistencies that plagued RE development.

- **Building the new 'green, low-carbon, secure, and efficient' energy system,** optimizing the energy mix, and ensuring that the energy demand increase is mainly met by clean energy.[43] By 2030, non-fossil energy will account for 20 percent of primary energy consumption and for 50 percent by 2050.

80. Government agencies began demonstration activities and developed policies to align the development of the energy sector, especially the non-hydropower RE, with the principles of the 'Energy Revolution' as detailed in the three following sections.

## C. Increased Market Orientation

81. As wind and PV development peaked by 2015 and the RE Compensation Fund's deficit worsened, Chinese authorities launched several pilot auctions to shift away from the feed-in tariff (FiT) policy (see Box 5.1):

- From 2015 to 2017, the NEA launched three auction rounds to develop 13 GW of solar PV in nine provinces:[44]

- The wind auctions were initiated on November 11, 2018, and were conducted by the provincial governments. In April 2018, the NEA requested that provincial governments publish their auction procedures for review before they submit the projects to be auctioned for approval. Following

43 Clean energy includes nonfossil fuel energy and natural gas.
44 There are thirteen PV front-runner bases approved by NEA, including ten application Top Runner bases and three technology Top Runner bases. The applicants for "Top Runner bases" are rated in five major aspects: enterprise's investment capability, track record, technology sophistication, technical proposal and tariff level. The latter, applying for only the second and third round auctions and accounted for 35 percent of the total score. Unpublished Presentation: "Research and Formulation of Pilot Plan for Renewable Energy (Wind power and Photovoltaic) Project Auction. China Renewable Energy Engineering Institute（水电水利规划设计总院）.

proper procedures, Guangdong launched the first provincial wind auction in November 2018. Gansu published[45] the first auction results in December 2018. The lowest price proposed was CNY 0.35 per kWh (equivalent to US$0.053 per kWh), which was 30 percent lower than the FiT. The average price of winners in the same auction round was CNY 0.44 per kWh (equivalent to US$0.066 per kWh), which was 10 percent lower than the FiT.

**Box 5.1: Wind and Solar PV Auctions in China**

The momentous growth of wind power generation followed by PV during the second and third stages of RE development entailed compensation subsidies that outweighed the amount available in the RE Fund by about US$14 billion.

Several Chinese ministerial departments expressed interest in RE auctions to address the issue and started some wind auctions as early as 2003. The World Bank began supporting these efforts by (a) arranging for officials from the NEA and the NDRC Pricing Department to attend an international workshop on RE auction and (b) organizing a workshop in Beijing with the support of the International Renewable Energy Agency (IRENA) and the participation of experts from Germany, India, and the United States.

Based on China's own pilot projects and international best practices, China gradually developed its own wind and PV auction schemes.

Five rounds of wind auction were organized by the NEA between 2003 and 2009. In the first two rounds, the selection criteria were limited mainly to the offtake price and localization content. Many winners of these rounds failed to secure financing and/or did not have the technical and engineering capacity to implement the projects. Following these experiences, the NEA began working with RE experts to design auction schemes, prepare tendering documents including penalties for auction winners who failed to build their project, develop standardized long-term PPAs, and so on. These measures both ensured the quality of the bid and considerably reduced the offtake prices. During the last years, offtake prices of wind electricity significantly decreased to reach CNY 0.29 per kWh (US$0.045 per kWh), about 45 percent lower than the average FiT. Given the increasingly larger number of auctions, in April 2018, the NEA decided to decentralize wind auctions processes to local governments and requested that provincial governments publish their auction procedures under the guidance and with the support of independent experts. All future procurement of onshore wind projects will be carried out through auctions without subsidies.

Based on the wind experience, the NEA began organizing PV auctions at the central level with the assistance of Chinese experts following the procedures and using the documentation developed for wind. The progress achieved to date is significant. Three rounds of auctions were completed in nine different provinces for the installations of 13 GW of PV generation capacity:

(a) The first round included 1 GW in Shanxi Province with special focus on the technical qualification of the bidders and the efficiency of the installations. The technically sound and efficient bids were allowed to benefit from the PV FiT (CNY 0.95 per kWh, equivalent to US$0.14 per kWh).

(b) The second batch of auctions was carried out to acquire 5.5 GW of PV generation capacity in Shanxi, Inner Mongolia, Shandong, Anhui, and Hebei. The average price of these auctions was about CNY 0.21 per kWh (US$0.031 per kWh) lower than the FiT.

45 Both Guangdang and Gansu auctions are rated in five major aspects: enterprise capabilities, the advancement of equipment, declared electricity prices, preliminary work, access and consumption conditions. Guangdong also rated the intelligent and O & M solutions of projects.

(c) The third round of auctions involved the acquisition of 6.5 GW of PV generation capacity in Shanxi, Shaanxi, Hebei, Jilin, Jiangsu, Qinghai, Inner Mongolia, and Jiangxi. The lowest price achieved in this round of auctions was CNY 0.31 per kWh (US$0.046 per kWh) in Qinghai this year, about half the current PV FiT.

It is expected that the future large-scale grid-connected solar PV investments will be acquired through the solar PV auction scheme, without subsidy, to reduce offtake prices and the burden on the RE subsidy fund.

82. Due to the investment over heating and ballooning subsidy, in 2018, the NDRC, MoF, and NEA issued the ‘Notice on Matters Related to Photovoltaic Power Generation’ that stopped the approval of the investment plan of utility-scale solar PV projects. As a consequence of the policy and regulatory changes, China’s RE investment dropped 38 percent to US$88.5 billion in 2018 [46] and annual added capacity of solar PV decreased by 17 percent. Some RE companies, mostly small and medium enterprises (SMEs) and some leading companies, have been overly optimistic and invested heavily to benefit from the FiT windfall. They increased their debt ratio in some cases to more than 85 percent and then, as subsidies dried-up, they were left with stranded assets in hundreds of power stations. Their financial situations deteriorated, which led some to declare bankruptcy. [47]

83. To address the situation, concerned Chinese institutions issued several policies to remedy the dire situation and increase market orientation of the wind and solar PV development in a less abrupt manner. In 2019, the NDRC and NEA issued the ‘Notice on Matters Related to the Construction of Wind power and Photovoltaic Power Generation Projects’ to give market players a two-year relief to prepare for the cancellation of national onshore wind and PV subsidies beginning in 2022 and more market-oriented procurement processes without disruption. The notice changed the project approval process as follows:

- Projects that do not require subsidies were given the priority for construction approval and grid access.

- Projects that require subsidies would compete for a total amount of subsidies determined by the government before launching auctions, and the government first determines the total amount of available subsidies before launching auctions. Technically, for solar PV, eligible bids are ranked from the lowest subsidy requested to the highest. Approvals are provided to projects requesting the lowest subsidies up to the total amount of available subsidies. Wind power still follows the auction procedures established by the provinces, but the weight of electricity prices in the evaluation system[48] cannot be less than 40 percent.

84. In 2019, the NDRC and NEA jointly issued the ‘Notice on the Establishment and Improvement of a Renewable Energy Power Consumption Guarantee Mechanism’ close to but far more complicated than the RPS mechanism that has been successful in promoting RE development in many countries. In a nutshell, according to the notice, the NDRC and NEA will issue annually an RE obligation (RE share in the total power consumption) for each province and entrust provincial authorities to develop their own action plans and pass through the provincial obligation to grid companies, distributors, large consumers, and so on. Many provinces did not yet issue the regulations on how to transit from the current system putting RE obligations on suppliers to the more market-oriented but overly complicated system developed by the notice.

46 Source: Frankfurt School and UNEP Center/BNEF 2019, 22.
47 This situation illustrates Warren Buffett’s famous quote “You only find out who is swimming naked when the tide goes out.” Source: Berkshire's Corporate Annual Report 2001. https://www.berkshirehathaway.com/2001ar/2001letter.html
48 The evaluation system scored the technical strength and financial strength of the bidding enterprise, compliance with environmental and social regulation and the electricity price of the generated electricity.

85. In 2015, the Communist Party of China (CPC) Central Committee and the State Council issued the 'Several Opinions on Further Deepening Power System Reform' stressing the need for (a) improving the market-based trading system, (b) liberalizing electricity prices to promote pricing reform, and (c) promoting the development and utilization of new and renewable energy. Following the opinions, the NDRC and NEA issued numerous supporting policies to promote the establishment of spot power markets in eight selected pilot regions, leaving the authority for designing the markets to provincial authorities. Discussion of the implementation of power sector competitive markets is beyond the scope of the report. However, it must be noted that as experienced in many countries, the publicly available skimpy information indicates that the designs developed could be more conducive to environmental protection and sustainable development, and RE characteristics could be more reflected in market designs.

## D. Completing and Rationalizing the Legal Framework

86. In 2019, the NPC carried out the 'Performance Evaluation of the Renewable Energy Law'. The evaluation group conducted fieldwork in six provinces, entrusted 12 Provincial People's Congresses to evaluate the performance at provincial levels, and asked the NDRC, NEA, MoF, and other concerned departments to report on the implementation of the law. At the conclusion of this performance evaluation, the NPC required the following:

- Relevant departments of the State Council should enhance the coordination between RE, fossil fuel, power grid, and land use development during the preparation of the 14th FYP (2021–2025) and future mid- and long-term plans. This would ensure consistency of the objectives and their alignment with the country's climate change commitments and avoid loopholes that could be used by vested interests to derail RE development. The departments should also improve the efficiency of existing assets and establish an evaluation system of energy development based on RE utilization and an RE trading mechanism to break the inter-provincial barriers.

- The NDRC, MoF, and NEA cover the RE Fund deficit by strengthening fee collection, establishing electricity competitive markets, ensuring a sustainable and healthy development of RE assets, and increasing financial support to private enterprises.

87. More importantly, the evaluation group suggested revising the Renewable Energy Law to adapt its provisions to current market conditions, clarify the legal responsibilities of power grid, oil, gas, heat, and other enterprises, and set minimum efficiency standards for RE assets.

88. Some of the suggestions proposed by the evaluation group are beyond the scope of the Renewable Energy Law. Therefore, efforts were deployed to revive the discussion of the 2017 draft Energy Law submitted for discussion by the former Legislative Affairs Office of the State Council to address the issues flagged by the evaluation group. On April 10, 2020, a new draft was swiftly prepared and circulated by the NEA to solicit opinions of all concerned institutions. The next steps include submitting the latest draft to the Executive Meeting of the State Council for approval and initiating the legislative process of its approval by the NPC.

89. The draft Energy Law that has been disclosed for public consultation is more explicit about China's ambition and commitment to ensure healthy and sustainable RE development, including

- Giving a prominent role to RE in the energy structure and adjusting and optimizing the energy industry and consumption structure to align them with the Energy Revolution principles;

- Allocating, for the first time, RE production and consumption targets to provinces in the mid- and long-term social and economic development plans;

- Aligning energy development with the country's climate change commitments and local pollution reduction objectives; and

- Stressing that producers and consumers have the obligation to contribute to the country's objectives relating to local pollution and GHG emission reduction objectives and that producers have the obligation to reduce emissions and environmental impact during construction and production.

## E. Building the 'Green, Low-carbon, Secure, and Efficient' Energy System

90. China set the target to increase the share of non-fossil fuels to 50 percent of its primary energy consumption by 2050. While RE penetration grew to more than 12 percent of the total primary energy consumption, current trends seem to be challenging to achieve the 2060 ambitious target of net carbon neutrality. The Energy Revolution strategy focuses on bringing about transformational changes in energy supply and consumption to meet the challenges ahead of decarbonization of the energy system by the following:

- Tapping the synergies between wind power and other RE technologies development. Improve (a) the dispatching for cost-efficient renewables to displace inefficient and emissions-intensive coal power plants; (b) the integration and optimization of complementary RE technologies, such as wind, solar, large hydropower, and pumped storage plants; and (b) the ability of regional and provincial grid companies to accommodate larger integration of RE technologies without disruptions, reduce curtailments, and improve the efficiency of existing wind and PV assets.

- Enhancing the flexibility of the grid to accommodate high RE penetration through increased coal-fired power plant capability to follow load[49] and deploying energy storage, strengthening power grid construction.

- Promoting more opportunities for RE usage, such as RE power, biomass, and geothermal for heating in North China, RE power for hydrogen product, RE for charging stations of electric vehicles, promoting use of biofuel, and so on.

- Improve the digitization of the power system taking advantage of new generation and enhanced computing capability technologies to monitor, dispatch, and predict the power generation capacity of all power stations. For example, with the help of the digitization of the power system, Qinghai Province set the world record in June 2019 when it used 100 percent of RE-generated power for 15 consecutive days. The digitization also led to many promising operational aspects (see Box 5.2).

49 In 2018, the NDRC and NEA announced that, by the end of 2020, a 220 GW thermal power plant with improved flexibility can provide 46 GW space for peak-shaving.

**Box 5.2: Qinghai New Energy Data Innovation Platform**

Qinghai is located in the northwest of China, with a total area of 720,000 $km^2$ and an average elevation of 3,000 m. Qinghai has good solar energy and hydropower resources. In 2018, RE power stations generated about 80 percent of the total power generation. However, due to its vast terrain and harsh climate, the maintenance and management of RE power stations in remote areas constitutes a major challenge.

In January 2018, the Qinghai launched a New Energy Data Innovation Platform, developed by Huawei, Kunlun Data and Gold Wind, to greatly address this challenge. Almost all data related to Qinghai's RE power plants were consolidated in the platform. The data included all aspects of the operation of the plants: efficiency, operating status, and other information related to each wind turbine, solar system, and hydraulic turbine.

The platform led to promising results: (a) power plants availability increased because of preventive maintenance and reduced the need for operation and maintenance personnel by 80 percent on average; (b) the link between the platform and meteorological data improved the accuracy of the three-day-ahead and hourly generation forecasts; and (c) income of PV poverty alleviation projects (see Chapter 6 for details) can be determined online and issued directly to each household's bank card.

The improved operation brought about by the platform and increased accuracy of generation forecasts enhanced the dispatch of RE plants and the use of the interregional transmission network capacity.

## F. Lessons Learned

91. Several lessons learned during this stage can be useful references for countries trying to build a well-functioning RE market:

- **Abrupt policy changes are conducive to market turmoil.** The 2018 'Notice on Matters Related to Photovoltaic Power Generation' effectively curbed the uncontrolled development of PV deployment. However, the policy shift led to a major disruption of the PV market. Many projects under construction were suspended and companies that borrowed heavily to develop the projects defaulted when they were denied subsidy payments that they had expected under the prevailing regulations. Capital quickly fled the RE market, causing the PV stocks to plummet and affecting wind power stocks. Assurance of policy clarity and predictability is paramount to effective RE deployment.

- **Unclear delineation of regulation responsibilities among government agencies and uncoordinated exercise of these responsibilities can derail the implementation of sound policies.** In China, auctions of RE projects require inputs from the NDRC, NEA, and MoF. Uncoordinated initiatives of the three powerful institutions can lead to confusion and unintended negative effects on the process. In 2019, when the auction policy was issued, some provinces and enterprises were able to quickly adjust their investment strategy and succeeded under the new policy environment, others could not adapt quickly enough due to insufficient time and information for the preparation of the bids for the auction, some companies failing to submit materials in time, leading to mixed results. The wind auctions for the same year were successful because requested provinces were entrusted to formulate their own auction policies for 2019 and carry out the auction process according to national rules and regulations published in May 2018.

- **Auctions based only on price can be deceiving.** In 2019, solar PV auctions experienced similar problems encountered during the first and second bidding rounds of wind concession (see paragraph 58), and some PV companies proposed lower prices but could not deliver accordingly. [50]

## G. The Way Forward: The Challenges Ahead to Implement the 'Energy Revolution'

92. China pledged in September 2020 to peak its carbon emission by 2030 and achieve carbon neutrality by 2060. Carbon emission from energy production and use amounts to about 85 percent of total carbon emission in China, 42 percent of which comes from the power sector, mostly due to coal combustion. Therefore, achieving the pledge will rely mainly on actions to be taken in the energy sector, particularly in the power sector.

93. Despite the impressive development of all sources of RE described in former chapters, the share of RE in the total primary energy consumption increased from about 4 percent in 1980 to about 13.6 percent in 2020. More specifically, regarding the power sector, the share of RE-based power generation increased from around 19 percent in 1980 to 27.8 percent in 2019. Coal remains the dominant energy source both at the overall energy sector level and at the power system level.

94. **Achieving net carbon neutrality will require RE to largely replace coal.** A study by Tsinghua University indicates that the share of non-fossil fuel generation should be more than 90 percent by 2050 to fulfill China's pledge of carbon neutrality by 2060.[51] An increasing number of subsectors (for example, transport, manufacturing, and buildings) will have to switch from direct combustion of fossil fuels to using electricity, increasing the importance of achieving early net carbon neutrality in the power sector. Therefore, despite impressive absolute growth over the two last decades, the way forward cannot be the continuation of the same trend. A major acceleration, an 'Energy Revolution', as called for by leaders, including President Xi Jinping and embodied in the Energy Supply and Consumption Revolution Strategy (2016–2030[52]), is needed for elevating the role of RE from secondary to main sources.

95. **The growth of the RE capacity cannot be anymore a fraction of the total system capacity growth, with coal-based power generation continuing to also grow in absolute terms.** To achieve carbon neutrality, RE-based power generation will eventually have to displace massively coal-based generation, leading to early retirement of many coal power plants and the flexibilization of others. Over the recent years, the fast development of solar PV and wind energy has turned these energy sources competitive, meeting an essential condition for substituting massively coal. However, the current structure and regulatory framework still largely mirrors the old inefficient centralized model and favors too much local incumbent coal-based generators, maintaining a high risk of future RE curtailment in case of further accelerating their scaling-up.

96. **The 'Energy Revolution' will require a paradigm shift, from a centralized power system model, centered on large dispatchable generation plants, to a new norm of flexible integration of a variety of resources that are intermittent and decentralized.** Like other power systems in the World, the Chinese power system is still composed of largely unidirectional networks, planned and optimized to evacuate large volumes of power from giant and dispatchable power plants toward predictable consumer loads.

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50 Sina Finance. 2020. "Nan Cunhui: It Is Recommended to Extend the Grid Connection Node of the 2019 PV Auction Projects for Three Months." http://finance.sina.com.cn/jjxw/2020-05-21/doc-iirczymk2863702.shtml
51 China Low Carbon Development Strategy and Transition Pathway Study, October 2020, Tsinghua University.
52 Released by the National Development and Reform Commission and National Energy Agency in 2017

In such a model, both the locations of large central power plants and the high-voltage transmission grids are determined in accordance with the location of large consumption centers. However, PV and wind, as non-dispatchable and potentially decentralized power sources, present a challenge to this traditional model at high levels of penetration. Since the injection of non-dispatchable power from renewables needs to be accommodated at any time and at a multitude of points of the system, including behind the meter, the whole system will have to become far more flexible and the role of its parts redefined. It will have to manage multidirectional flows of energy, regulate a wider range of services, including reserve capacity, storage, and other ancillary services, and realign incentives and compensations to turn such new functions economically viable.

97. **China is at the forefront of the energy revolution, and its experience will be useful to many other countries.** China being now a leader of the RE industry, its power sector is facing challenges that other countries might face a few years later, in particular the countries which have a high share of coal in their power mix and are willing to scale up the share of RE.

98. **Increasing the flexibility of the power system and eventually phasing out coal-based generation in China requires combining a range of solutions, including the scale-up of systemic innovative technologies.** Incremental and game-changing solutions to increase flexibility include (a) improving joint planning of RE development and transmission; (b) increasing thermal plants cycling to adjust faster to the injection of non-dispatchable renewable energy; (c) improving short day-ahead variable RE forecasting to reduce uncertainties; (d) developing demand response to increase its manageability,[53] and (e) adopting technologies like utility-scale battery storage, distributed RE, and the development of new uses of electricity nearby the RE sources. These technologies are sometimes mentioned as 'disruptive' because they lead to a radical change in the way the power system is operated, from centralized and unidirectional to decentralized and multidirectional dispatch and networks management, supported by intensive use of digitalization. This is echoed by the International Energy Agency's China Power System Transformation Study, which also concluded that power system flexibility is the most important cornerstone of a transformed power system with high shares of variable Res.

99. **Enabling legal and policy environments are required to remove the market barriers for the application of these advanced technologies and measures.** Most of the advanced technologies are emerging RE applications, and there are still gaps in the legal and policy environment and in technical specifications, cost are still high, several environmental and social issues remain and business models are still to be road-tested. Therefore, building an enabling legal and policy environment is still required for these technologies to be able to access the markets, along with the establishment of the technical and environmental standards, transparent operation rules, and limiting potential market power to encourage the participation of SMEs.

100. **Immature markets of innovative Energy Revolution technologies require financial solutions to leverage private resources.** Many of the abovementioned innovative, disruptive solutions have only recently or are still about to reaching commercial stage. As a consequence, availability of capital is still limited and, with respect of debt financing, their risk profile is still less attractive than conventional solutions from the financiers' perspective. As a consequence, green energy investment is facing a shortage of financing. Although China has made remarkable strides in expanding the volume of green credit and green bonds, the green investment gap remains substantial. Estimates by the China Council for International Cooperation on Environment and Development (CCICED) indicate that until 2030, between CNY 2.3 trillion (US$320 billion) and CNY 7.2 trillion (US$1 trillion) per year would be needed to address climate and

53 Several Demand Response pilots are currently on-going in Jiangsu province, Beijing, Shanghai and Foshan (State Grid, 2017 : file:///C:/Users/wb218222/Downloads/S3-7.pdf)

environmental challenges.[54] However, due to increasingly pressing fiscal constraints, the public sector can only contribute up to 15 percent of the funding needed, leaving a significant and increasing gap of roughly US$270 billion per year that needs to be covered by private investment. Therefore, the scale-up of Energy Revolution solutions requires innovative 'green finance' solutions to kick-start business and leverage new financial resources.

101. **Interprovincial transmission and trade of RE-based electricity needs to be further developed, to counter the prevailing 'provincialism'.** Transmission bottlenecks limit interprovince power exchange from RE-resource-rich provinces to high-demand provinces, thus restricting the contribution of RE to the national energy matrix. Around 70 percent of China's current PV and wind capacity is located in the North and West where energy demand is low, far from the more populous, industrialized load centers of the East and South. To improve the channeling of growing volumes between these regions, the main grid companies need to further upgrade transmission capacity at key locations to eliminate transmission bottleneck and plan additional trans-provincial and trans-regional transmission corridors, in particular accelerating the research and application of high-voltage direct current (HVDC) transmission technologies. In addition to the lack of transmission capacity, the current transmission and distribution pricing structure also limits interprovincial trading and prevents an efficient allocation of resources. 'Provincialism' is another roadblock to a rapid decline of coal, partly driven by perverse fiscal incentives. The Chinese VAT system is production based, rather than consumption based. As a result, provinces get substantial tax if coal power plants are built within their province, while they get no VAT revenue if electricity is imported from another province, for instance, from RE-rich provinces. As a result, there has been only very limited cross-province trading.

102. **The Energy Revolution toward a high share of renewable energy will require a 'just and sustainable transition to a lower-coal economy', especially in coal dependent provinces.** For RE sources to become the dominant source of the primary energy matrix, the Energy Revolution in China will require closing a growing number of coal power plants and coal mines under a 'just and sustainable transition' process. Transitioning out of coal to renewables will affect the whole value chain of the economy of coal-dependent provinces, ranging from mining, transporting, and exporting to power generation, industrial uses, and district heating. The severity of the impact will be amplified by the high concentration of the coal production in three top coal-producing provinces of Inner Mongolia, Shanxi, and Shaanxi, which account for more than 70 percent of national coal production. A successful Energy Revolution in China will therefore require a successful Energy Revolution in the major coal-producing provinces. This will mean addressing a series of institutional and policy issues in these provinces, particularly (a) addressing social issues related to phasing out coal-based activities; (b) tackling environmental remediation and land reclamation and repurposing; and (c) develop new, non-coal activities in these coal-dependent provinces.

103. In conclusion, different from the former stages of the development of renewable energy in China, the way forward to achieve high shares of RE cannot be anymore centered on policies and incentive to develop the RE industry and its competitiveness against fossil fuels. It will not only require policies and measures that transform the whole energy sector but also economywide policies and programs that enable such a structural transformation.

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54 CCICED. 2015. *Research on Green Finance Reform and Promotion of Green Transformation.* November 2015.

# Part 2: The development of the four main renewable energy industries

# Chapter 6. Wind Industry

**Key Messages**

During the last 15 years following the enactment of the Renewable Energy Law in 2005, China built over 4,000 wind farms, including 120,000 wind turbines with unit sizes ranging from 55 kW to 6.7 MW. The total installed capacity of wind power grew from about 1.2 GW in 2005 to 281 GW in 2020, of which about 9 GW offshore. This growth created an enormous opportunity for developing a domestic manufacturing industry. Annual added capacity culminated in 2015 at 34 GW, lessened slightly to 26 GW in 2019, and jumped to 71 GW in 2020.

The wind industry's development mirrored the four stages of RE's evolution, following the same pragmatic approach of extensive piloting and association with advanced countries for knowledge transfer, with a strong focus on localization, followed by scaling-up, quality improvement and cost reduction to increase competitivity.

- The number of wind turbine manufacturers culminated at 80 (2009), consolidating then into 22 large-scale manufacturers by 2018.
- Onshore wind turbine capacity grew from 2 kW in 1983 to 5 MW in 2018; offshore reached 10 MW in 2020.
- Investment cost was reduced from CNY 20,000 per kW (US$2,457 per kW) in 1995 to CNY 7,100 per kW (US$1,059 per kW) in 2018 and CNY 5,284 per kW (US$788 per kW) in 2019.
- China graduated from an importer to exporter of turbines, reaching an exporting capacity of more than 3,500 MW.

During the first stage (up to 1994), China tried to attract leading foreign companies to manufacture turbines in China, although without success because the market was too small. To build a manufacturing industry, the government included several wind power projects in the successive FYPs and initiated several cooperation programs with leading countries. These collaborations allowed the development of 50 kW turbines.

During the second stage of 'Takeoff' (1995–2005), the government took several measures to help develop the wind power market to (a) strengthen and improve R&D and widen the industrial wind power base and (b) attract renowned wind turbine manufacturers to manufacture in China. These included the following:

- The 'Double Push Program' (1996) provided incentives and local market access to foreign manufacturers, enabling the manufacturing of 600 kW wind turbines in China.
- The 'Ride the Wind Program' (1996) allowed joint ventures with Chinese enterprises.
- The 'Wind Concession Program' (2003) created a large market, which attracted several international manufacturers.
- Two key projects were launched to develop the production of 1.2 MW turbines.

During the third stage of ‘Boom of the Wind Industry’ (2006–2017), China initiated several cooperation programs with wind standard institutions, namely, the IEC, to bring equipment quality to international standards. The China Standards Commission adopted 24 IEC 16400 standards, and IEC 16400 adopted at least one Chinese standard. To strengthen R&D and manufacturing capabilities, the government established technological institutes with the assistance of more advanced countries. At the end of this stage, Chinese manufacturers became recognized competitors to well-established foreign manufacturers.

During the fourth stage of ‘Commercialization Development’ (2018 to present), China has focused on tackling major hurdles still limiting competition of wind power with coal-fired power and on developing the offshore market. With the very fast development and highly fragmented manufacturing assets, mainly government owned, the quality of turbines was still below par. To overcome these problems, China embarked on the following initiatives:

- Making wind turbines and wind farms more friendly to the power grid. Grid disturbances were reduced by raising the power factor and using advanced fault management liability control systems.

- Developing deep offshore wind power technology. All the turbines ranging from 5 to 6.7 MW at the 80 MW Xinghua Bay offshore wind farm were jointly manufactured by seven SOEs and foreign private companies in 2018.

- Research and design on the high-capacity offshore wind turbines applied in the deep sea and associated key components supported by the MoST started in 2019.

- Developing larger-scale wind turbines. Major wind turbine manufacturers such as Goldwind, Mingyang, and Envision are working on ultra large 8–12 MW offshore wind turbines.

The positive outcome of these initiatives led to (a) the reduction of the cost of wind power to CNY 5,284 per kW (US$788 per kW) and (b) the upcoming commercialization of the 10 MW wind turbine. In parallel to its manufacturing industry, China also built a strong implementation capacity.

In the first stage (up to 1994), China lacked wind power expertise, talent, financial resources, and implementation capacity and relied on other countries to develop wind farm pilot projects financed by government funds and grants from bilateral and/or multilateral institutions.

During the second stage (1995–2005) of RE development, the generation segment of the power sector was opened to new entrants and China issued a series of policies and regulations, which enabled the emergence of a national wind project developers. The wind generation projects benefitted greatly from the expertise of the large fossil fuel and hydropower developers in construction, management, and operation and maintenance. However, their wind portfolio remained modest compared to their momentous other generation assets.

During this stage, China began borrowing from the World Bank and other financiers to build larger wind farms and introduced Chinese wind project developers to international best practices in preparing, building, and operating large wind arms.

During the third stage (2006–2017), the government set ambitious targets for the development of wind and mandated a percentage of non-hydropower renewable energy in the generation mix of all power generation companies. These two requirements led to the establishment of at least 17 key wind developers, of which 10 major generation SOEs, 2 local government-owned companies, 4 Chinese private companies, and 1 joint venture. They developed more about 230 GW of wind capacity.

**The main takeaways from the Chinese experience include the following:**

(a) Building a local competitive manufacturing industry requires a large and sustained market capacity that is only possible in large and resource-rich countries. Smaller countries, with sizable resources, need to look beyond their borders and cooperate with neighboring countries to create regional and sustainable markets.

(b) Medium- and long-term planning, cooperation with more advanced countries to build an integrated chain including testing and learning about available state-of-the-art equipment, development of a strong knowledge and R&D base, gradual development of a manufacturing industry, and cooperation with advanced country and recognized institutions to develop capacity in standards and certification.

(c) Standards, quality control, and sustained R&D are essential to increase and maintain competitivity as the technology evolves and the country embarks on offshore wind programs.

(d) Policy and regulatory measures and price and tax incentives are necessary to create a vibrant RE market and attract developers and investors and sustain RE development. Mandating minimum RE shares in total electricity generated by large and highly skilled power generation companies has been critical for China to promote a project developers' industry.

104. The development of China's wind power industry is driven by government-supported test projects and international cooperation. After 50 years of development, it is currently one of the world leaders covering a complete industrial chain from R&D to equipment manufacturing and project construction. The wind industry's development mirrored the four stages of RE's evolution. During the first stage (up to 1994), wind power developed modestly through deployment of small wind turbines in remote areas and developers were still exploring opportunities of transfer of technology and modern management systems through international cooperation. The second stage (1995–2005), known as the experimental stage, focused mainly on R&D and improving the quality of the nascent industry. The third stage (2006–2017) experienced an unprecedent boom of the local wind industries as quality improved and costs decreased and contributed to furthering the fast growth of the technology. Finally, the fourth stage (2018 to present) marks a new development era as the country began to gradually remove subsidies and increased the commercial orientation of the sector to increase RE competitivity (so-called 'grid parity') and stabilize the RE industry, mainly wind and PV, to address low efficiency and ballooning subsidies.

## A. The Achievements of the Wind Industry

105. Following the issuance of the Renewable Energy Law in 2005, China built over 4,000 wind farms, including 120,000 wind turbines ranging from 55 kW[55] to 6.7 MW each.[56] The total installed capacity of wind power grew from about 1,260 MW in 2005, all onshore, to 210 GW in 2019, of which 204 GW were generated onshore and about 6 GW offshore (see Figure 3.1).

106. During that same period, the added annual capacity fluctuated, peaking at about 34 GW in 2015, before decreasing to less than 20 GW in 2016 and 2017 and finally rebounding to 26 GW in 2019, of which 2 GW was generated offshore,. In 2019, the wind power generation amounted to 406 TWh, accounting for 5.6 percent of the country's electricity consumption (See Figure 3.1).

107. China's wind industry paralleled the growth of the power sector and made significant progress in the following aspects:

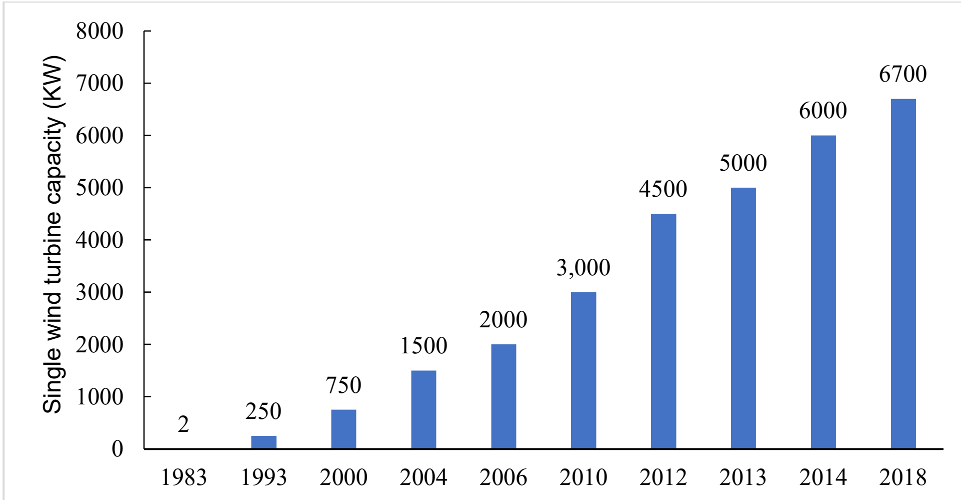
- **Increased number of wind power enterprises.** The number of wind turbine manufacturers grew to more than 80 at its peak in 2009 but fell to 22 large-scale manufacturers in 2018 after restructuring and consolidation of the industry. Wind farm development enterprises have grown to more than 90.

- **Increased single wind turbine capacity.** Onshore wind turbine capacity grew from 2 kW in 1983 to 5 MW in 2018. Offshore wind power increased from 3 MW in 2010 to 6.7 MW in 2018 (see Figure 6.3).

55 On May 1,1986, China's first demonstration wind farm was completed and integrated to the grid at Malanwan, Rongcheng (Shandong Province) with three imported Danish Vestas 55 kW wind turbines.

56 In February 2018, the largest 6.7 MW wind turbine, developed by Xinjiang Goldwind Technology Co. Ltd., was successfully installed in Xinghua Bay offshore test wind farm of Three Gorges (Fujian Province).

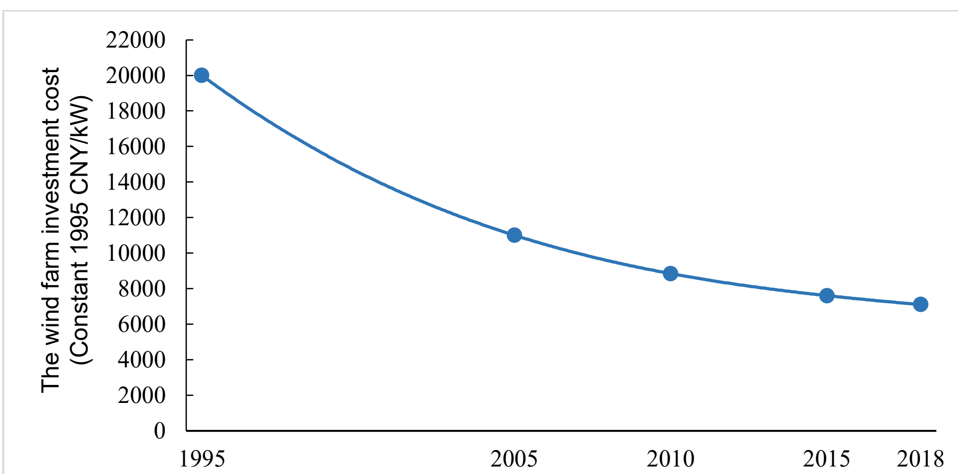
**Figure 6.3: Single Wind Turbine Capacity in China**




Source: Study team.[57]

- **Lower wind power cost.** The investment cost of wind power reduced from more than 20,000 current Yuan per kW in 1995 to 7,100 current Yuan per kW (about 3,990 constant 1995 Yuan per kW) in 2018 (see Figure 6.4 a and b).

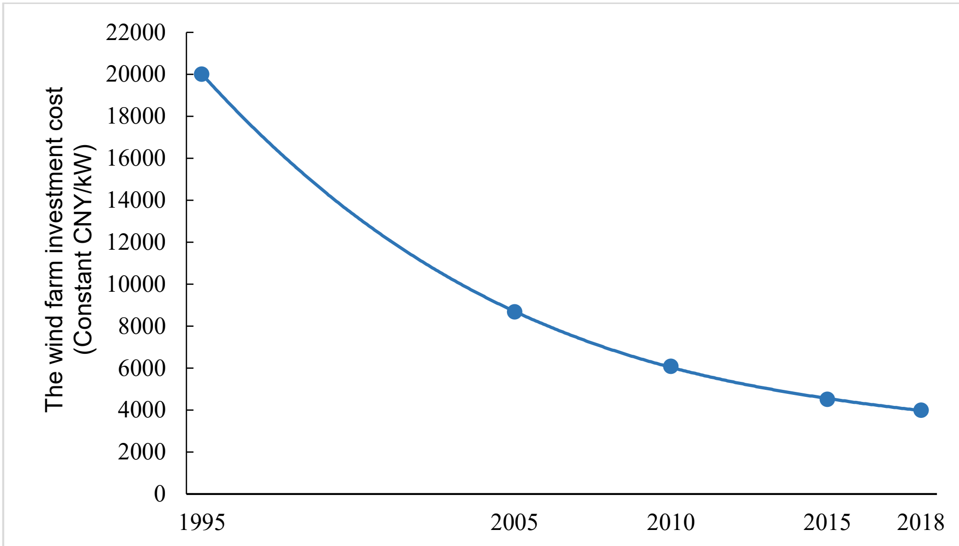
**Figure 6.4: (a) Wind Power Investment Cost Evolution (current yuan)**




Source: Study team.[58]

57 Based on data provided by the Chinese Wind Energy Association (CWEA).
58 Based on data provided by the CWEA.

**Figure 6.4:** **(b) Wind Power Investment Cost Evolution (constant yuan 1995)**




Source: Study team.[59]

- **Increased export capacity.** Given the fast development and increased quality of the wind industry, China graduated from an importer to exporter of turbines. By the end of 2018, the cumulative exported capacity of wind turbines had reached more than 3,500 MW.

108. These achievements are the result of a gradual and pragmatic approach characterized by extensive testing and knowledge transfer from developed countries during the early stages and localization and quality improvement through increased R&D, improved quality standards, and certification in the later stages.

## B. The Infancy

109. In the first stage of RE development and the early years of the second stage, wind power generation was negligible despite the significant development of wind power globally, especially in Europe and the United States.

110. At the beginning of the first stage, China lacked the robust technological and R&D base required to effectively develop local turbine manufacturing. The wind industry was limited to manufacturing of micro turbines used only for off-grid power. The few existing wind developers focused on small off-grid projects. They lacked the design, construction, and operational experience of large-scale, grid-connected wind power projects.

111. To address these problems, the government undertook the following measures to promote the development of a local wind power industry:

- It included several wind power projects in the 6th, 7th, and 8th FYPs to create a market for the development of a local industry as some of the leading foreign companies announced that localizing manufacturing in China would require an annual production capacity of at least 400 MW.

59 Based on data provided by the CWEA.

- It also initiated several cooperation programs with countries leading the wind industry at that time to broaden scientific knowledge and build an R&D base for the wind industry. For example, the China-Sweden wind energy science and technology cooperation project was among the first initiated in 1986 and lasted until 1992. One of the major undertakings during the implementation of this program is that China's Aerodynamics Research and Development Center and the Swedish Aeronautical Research Institute jointly carried out a fundamental research on 'Yawing characteristics of wind turbines and corresponding three-dimensional flow phenomenon on blades'. The research results were essential to designing and testing wind turbines in China.

112. Several measures were implemented to build the capacity of wind developers in construction and operation of large-scale wind power and test commercial turbines:

- Several test stations were established: Pingtan (Fujian Province) in 1976 and Shengsi Island (Zhejiang Province) and Badaling (Beijing Municipality) in 1979. The Badaling wind power test station, established by the former Ministry of Water Resources and Power, consisted of 26 wind turbines of various types installed successively to reach a total capacity of 120 kW. Most of the turbines were small and operated off-grid. They included a 1.5 kW turbine jointly developed by US EnerTech company and Tsinghua University, a 7.5 kW turbine produced by Baoding Repair and Construction Plant, a 1 kW turbine produced by Zhejiang Power Repair and Construction Plant, and a 5 kW unit produced by Inner Mongolia Power Plant Group. Two grid-connected wind turbines were also tested: a 50 kW unit produced by the Baoding Repair and Construction Plant and a 25 kW unit manufactured by Erzhong (Deyang) Heavy Equipment Company Ltd., an SOE located in Sichuan Province.

- In May 1986, the first demonstration wind farm connected to the grid was built in Malan Bay Rongcheng County (Shandong Province), indicating the government's intention to move from off-grid wind usage to the on-grid wind power stage. The wind farm was funded by the Shandong provincial government and the Ministry of Aviation and consisted of three 55 kW wind turbines imported from Denmark.

- In October 1989, Dabancheng Wind Farm Phase I was commissioned, and with the capacity of 2,050 kW it was the largest wind farm in Asia at that time. It consisted of 13 Danish Bonus 150 kW stall type wind turbines and one Danish Wincon 100 kW wind turbine.

- The Zhu Rihe Wind Farm in Inner Mongolia was commissioned in December 1989, comprising five US-made wind power 56–100 kW wind turbines. In April 1991, six more identical wind turbines were installed. In September 1993, four German-made HSM-250T were installed after being donated by the German government. These demonstration application projects significantly increased the scale and wind power experience in China.

113. These collaborations and test projects allowed China to build a basic scientific and R&D knowledge base that allowed the local wind industry to make modest progress, namely, the development of 18 kW, 20 kW, 30 kW, and 50 kW turbines. By the end of 1993, the last year of the first stage of RE development, the total installed wind power capacity was 14.5 MW and the maximum capacity of a single turbine was 250 kW.[60] Several companies began manufacturing wind turbines and developing small-scale wind farms. As quality varied, the importance of standards and certification was gradually recognized. All these accomplishments laid the foundation for further progress in the second stage.

60 The type is HSM-250T from Germany Husumer Company.

## C. The Takeoff (1995–2005)

114. While China gained some experience during the first stage, by the mid-1990s, its wind industry was still far behind the leading countries, for example, Denmark, Germany, and Spain. It lacked the technical knowledge, industrial infrastructure, and human resources to build a competitive industry mostly due to

- Nascent R&D, an outdated industrial base, and a limited and fragmented market as multiple efforts were deployed at the provincial level with limited coordination and knowledge sharing;
- No quality standards and certification systems leading to spotty quality of the locally manufactured turbines;
- Higher cost of locally manufactured turbines, ineffective assessment of wind resources, and subpar design of wind farms which led to high investment costs (CNY 20,000 per kW at 1995, equivalent to US$2,457 per kW) and poor returns on investments;
- Lack of wind power technology professionals in R&D, turbine manufacturing, standards development, and certification; and
- The wind power industry's reliance on grants and loans from foreign governments for many years.

115. To address these problems, the government took several measures to create a wind power market that would strengthen and improve R&D, reinforce and widen the industrial wind power base, attract high caliber technical and management talents, develop quality standards gaps, and reach local mass production scale.

116. Several initiatives were undertaken to achieve these objectives:

- In 1996, the SETC launched the 'Investment and Reform Program', dubbed 'Double Push', to select the best-performing enterprises in three years. The selected companies were given access to low-interest preferential loans to widen the breadth of the wind power market. In three years, the program led to (a) the refurbishment of four wind farms with a total of capacity of 80 MW in the north of the country; (b) the construction of new wind farms totaling 120 MW; and (c) the localization of 200 kW, 300 kW, and 600 kW wind turbines.
- In March 1996, the former SPC launched the 'Ride the Wind Program'. Through the program, the Chinese government provided 240 MW wind farm development opportunities to entice foreign wind turbine enterprises to enter Chinese market through joint ventures. In exchange for partial ownership of the wind farms, these foreign ventures were required to contribute the design of wind and manufacturing of wind turbines by Chinese enterprises. The program aimed to develop the ability to design and manufacture large-scale wind turbines locally. The commission adopted a tender process to select the foreign partners to form a joint venture with the Xi'an Aero-Engine (Group) Ltd. and the China Yituo Group Co. Ltd. to develop general assembly plants of large-scale wind turbines. This led to the formation of two joint ventures in 1998: 'the Xi'an Weide Turbine Company, Ltd.', between Xi'an Aero-Engine (Group) Ltd. and Nordex GmbH of Germany, and the 'Yituo-MADE (Luoyang) Wind Turbine Company. Ltd.' between the China Yituo Group Company Ltd. and MADE Technologies Renewable S.A. of Spain.

- In 2003, the former SPC's 'Concession Bidding Program' implemented minimum local component rates for wind turbine manufacturing in the successive call for bids. The required local component rate of wind turbines proposed to developers was fixed at no less than 50 percent in the first round (2003) and no less than 70 percent in the second round (2007). It continued to increase reaching 75 percent in the fifth round (2007) and sixth round (2008). Given the potential size of the market, this requirement provided strong incentives to foreign wind turbine manufacturers to increase their equipment manufacturing in China. In 2005, the GE Energy Group's first wind turbine assembly plant in China was established in Shenyang, focusing mainly on the production of 1.5 MW wind turbines. Vestas began the production of wind power equipment in Tianjin and later in Inner Mongolia. In September 2006, the first wind power plant funded by Gamesa, Spain's largest wind power equipment manufacturer, was put into operation in Tianjin. The establishment of these factories broadened technological knowledge and vitalized China's wind power manufacturing.

- During the last three years of the 9th FYP (1995–2000), the Xinjiang Goldwind Science and Technology Company Ltd. (hereafter referred to Goldwind), the Xijiang Wind Energy Company, and the Xinjiang Wind Energy Research Institute jointly undertook a 'National Key Research Project for the R&D' project to develop local 600 kW wind turbines. It resulted in the production of the ten 600 kW wind turbines installed in the Xinjiang Dabancheng Wind Farm. These units were based on technological innovation and local intellectual property rights relating to the overall design, domestic electric control systems, generator, and gearbox design and have made notable contributions to the manufacturing of large wind turbine units in China.

- During the 10th FYP (2001–2005), two key projects were launched to develop large-scale wind turbines. The domestic industrial production of a 600 kW and a 750 kW wind turbine were undertaken by Goldwind with the support of the MoST. During the implementation of these programs, local manufacturing of 600 kW and 750 kW wind turbines reached mass production level. The national 863 program (described in paragraph 45 and 111) supported R&D activity undertaken by Goldwind, to manufacture key parts and components to develop megawatt wind turbines. By the end of the 2005, the program produced 1.2 MW turbines which were installed on the Xinjiang Dabancheng Wind Farm.

117. To bring equipment quality to international standards, China initiated several cooperation programs with wind standard institutions, namely the IEC. China was particularly active in the Technical Committee 88[61] (TC88) working group:

- It appointed 81 experts to participate in 27 out of 28 TC88 standards working groups.

- The China Standards Commission, established in 2002, adopted 24 IEC 16400 standards as national standards.

- IEC 16400 adopted at least one Chinese standard in November 2019 and published in May 2020.

118. To increase the number of wind power technology professionals, especially in R&D capacity, the government initiated basic curriculums in newly established technological institutes and training programs in existing ones with the assistance of more advanced countries:

61 In 1987, the IEC established a new technical committee (TC88) for the wind power industry, which is responsible for preparing and revising the unified standards for design requirements, engineering integrity, measurement techniques, and test procedures of wind turbines, namely the IEC 61400 series of standards.

- In 1997, the Institute of Measurement and Control of Rotating Machinery and Wind Energy Devices was jointly established by the Northwestern Polytechnical University and the Berlin Polytechnic University. By 2001, more than 150 undergraduates had participated in the module on wind power generation technology. However, since the wind industry was still nascent and there were few job opportunities, only 10 undergraduate students and one master's student chose wind power as their major and successfully graduated.

- In 2002, the Sino-German 'wind power talent training cooperation' project organized two rounds of training sessions in 2002 and 2005. Each round included a basic knowledge session and an advanced knowledge session. The basic knowledge sessions lasted three months and were completed at the Northwest Polytechnic University. They provided participants with basic wind power knowledge on topics like aerodynamic design, structural dynamics, fundamentals of power engineering, control systems, and grid connection constraints. The advanced sessions lasted four months and were conducted in Germany. They focused on the operation and maintenance of wind farms and the design technology of wind turbines. The advanced sessions were followed by trainee internships in German enterprises for six weeks. A total of 32 trainees participated in the two rounds. They constituted the initial core of Chinese wind industry leadership. They are still contributing to its development.

119. With the strong support of these policies, 11 wind turbine manufacturing enterprises have emerged in China and improved their competitiveness. In 2004, Goldwind-produced turbines reached 40 MW of installed capacity, making the company the third-largest wind turbine manufacturer in the Chinese market, trailing Spanish leader Gamesa (71 MW) and Danish NEG Micon (56 MW). This resulted in an increasing number of reliable parts manufacturers, including blades, gearbox, generator, tower, and electrical control. Manufacturing technology greatly improved as a result, leading to the development of 2 MW turbines and reduction of implementation costs to CNY 11,000 per kW (equivalent to US$1,358 per kW) installed by the end of 2005. Furthermore, the number of well-trained personnel increased significantly including policy makers, R&D professionals, and engineering and construction personnel. These achievements paved the way for the boom of wind power during the third stage.

## D. The Boom of the Wind Industry (2006–2017)

120. At the beginning of this stage, the wind power installed capacity began to grow steadily as cost declined owing to efforts deployed during the first two stages. R&D cooperation programs and the transfer of technology stemming from the 'Ride the Wind' program led to local manufacturing of 600 kW to 1.5 MW grid-compatible wind turbines. SOEs played an important role in the wind sector development; they developed most of wind power farms, contributed significantly to the scale-up of the market to bring the cost down, and extended their activities to manufacturing to become major players in the global wind industry. However, the quality of locally manufactured turbines varied, and they faced many technical hurdles and struggled to meet quality standards because there were numerous manufacturing companies at provincial and even county levels:

- A large number of Chinese manufacturers were unable to match the innovation and technological improvements of advanced countries, leading to a significant reliance on imports for key components (such as bearings) and control systems.

- The technical standards, product testing, and certification were not well established.

- Wind resources evaluation and wind farm micro-siting skills were insufficient to meet the fast-growing demand of wind farm development.

121. To address these issues, the government took a series of measures to (a) strengthen technological knowledge and build skills in wind resource assessment, (b) develop national quality standards along with testing and certification systems, and (c) increase R&D.

122. To meet the challenges encountered in the first two phases of the industry's growth, the government initiated several programs to develop domestic wind turbine manufacturing by (a) strengthening scientific knowledge at academic and fundamental research institutes, (b) promoting increased R&D and innovation in leading enterprises, (c) incentivizing domestic wind power manufacturing enterprises to improve their technical bases and promote creativity, (d) promoting the localization and development of large-scale wind power units, and (e) attracting a large number of technical talents and providing them with incentives to join the growing wind power industry.

123. Three major national scientific and technological programs illustrate the efforts deployed by the MoST to support the localization [62]of large-scale wind turbines:

- The 'National Basic Research Program of China (973 Program)' set up four projects to support the R&D and manufacturing of large wind turbines for seven years (2007–2014): basic research of large-scale wind turbine aerodynamics, basic research on large-scale off-grid wind power systems, basic research of large-scale wind power grid integration system, and key mechanical issues and design of large-scale wind turbines.

- The National High Technology Research and Development Program ('863' Program described in Chapter 2, paragraph 47) launched eight projects to support wind energy development and utilization from 2009 to 2014 and develop knowledge and R&D to further local manufacturing of state-of-the-art equipment.

- The National Science and Technology Infrastructure Program undertook six projects to support wind energy development and utilization from 2006 to 2012.

124. In addition, major in-house R&D and innovation efforts were deployed by the large SOEs and private enterprises and many, such as the Xinjiang Goldwind Science and Tech Company Ltd., Envision Energy Company Ltd., and Mingyang Smart Energy Group Ltd., achieved commendable results.

- Goldwind, which entered the wind power business as a developer, engaged in wind turbine manufacturing in 1977 by purchasing a license of a 600 kW fixed-pitch stall-controlled wind turbine and gradually managed to fully localize its production owing, in part, to the technological breakthroughs achieved by national programs. In November 2003, Goldwind signed a technology transfer contract for the joint design and development of a 1.2 MW direct drive permanent magnet unit with Vensys Energy Co. Ltd. in Germany. Later, the company deployed additional R&D efforts to develop 2 MW, 2.5 MW, and 3 MW high-power sets. By 2015, Goldwind had become the world's No. 1 supplier of wind turbines, with R&D centers in Beijing, Xinjiang, and Germany. In 2018, the largest offshore wind turbine made by Goldwind, with capacity of 6.7 MW, was installed in Xinghua Bay, Pingtan, Fujian Province. It again indicates that the wind enterprises are making great effort for innovation. Besides increasing the single wind turbine capacity, Goldwind is trying to make the wind farms and wind turbines much smarter and more friendly to the power grid, by integrating

62 Localization in this report means that wind turbines and their main components are produced in China.

the internet of things, digitalization, and artificial intelligence into the wind industry. Meanwhile, the revenue, safety, and reliability can also be improved.

- Envision Energy Co. Ltd. developed the concept of 'intelligent wind turbines' and focused on the development of onshore of low wind speed turbines. The concept of 'intelligent wind turbine' is based on using modern information technology to develop wind power turbines, by integrating sophisticated control systems, sensors, and cloud computing to reduce disturbances to the grid. The company developed an advanced, full-cycle smart wind farm management system which used more sensors and cloud computing to improve the performance of turbines in more developed markets.

- Mingyang Smart Energy Group Ltd. is another enterprise that experienced significant returns on R&D investments. It successively established the Danish R&D Center, the US North Carolina R&D Center, and the Shanghai Offshore Engineering R&D Center. During the third stage, it developed 1.5 to 6.5 MW series wind turbines suitable for various wind conditions, including typhoon and low-temperature resistant turbines, plateau and intertidal zone turbines, and low-wind-speed and offshore turbines. 125.
  During this stage, China initiated a long-lasting cooperation with international institutions to develop quality standards and a testing and certification system. It also created a number of national key laboratories and engineering research centers:

  - The NEA and MoST created a number of national key laboratories and engineering research centers:

    - The National Energy R&D (experimental) Center on Wind Power Blade was approved by the NEA in November 2011 and established by the Institute of Engineering Thermal physics of the Chinese Academy of Sciences.[63]

    - The National Offshore Wind Power Engineering Technology Research Center was approved by the MoST in 2009 and established by the China Shipbuilding Industry Company Limited (CSIC) Haizhuang Windpower Co. Ltd.

    - The National Key Laboratory of Wind Power Generation System was approved by the MoST in 2010 and established by the Zhejiang Windey Company Ltd.

    - The National Key Laboratory of Wind Power Equipment and Control was approved by the MoST in 2010 and established by the Guodian United Power Technology Company Ltd.

    - The National Wind Power Equipment Quality Supervision and Inspection Center was approved by the NEA in 2012 and established by the Hebei Electric Power Survey and Design Institute.

    - The National Center of Quality Supervision and Inspection for Wind Power Equipment (Gansu) was approved by the Certification and Accreditation Administration of the People's Republic of China (CNCA) in 2015 and established by the Gansu Special Equipment Inspection and Research Institute.

    - The National Center of Quality Supervision and Inspection for Wind Power Equipment (Jjiangsu) was approved by the CNCA in 2017 and established by the Jiangsu Yancheng Product Quality Supervision and Inspection Institute.

63 http://www.etp.ac.cn/jgsz/kybm/fd/

- In November 2010, the National Standards Committee approved the 'Rules and Procedures for Conformity Testing and Certification of Wind Turbine Generator Systems' (National Standard No. GB/Z 25458-2010). The wind turbine certification process comprised design, type, project, and parts certifications. This eventually allowed the Chinese certification system to become recognized internationally. Furthermore, Chinese certification organizations actively participated in international cooperation program and joined international institutions such as the IEC RE Program and gained recognition from other countries.

## E. Commercialization Development Stage (2018 to Present)

126. Even as China took the lead in the installed capacity of wind power, the industry still faced major hurdles as wind power struggled to compete with coal-fired power plants and overcome the challenges of the growing offshore market:

- The efficiency of wind turbine needed to be further improved.
- System controls and management systems needed to be improved to bring the disturbances to the grid to the acceptable level.
- Development and scale-up of offshore and deep sea wind farms.
- Accelerating of the integration of renewable energy and other energy.[64]

127. To overcome these problems, China embarked on the following initiatives:

- **Making wind turbines and wind farms more friendly to the power grid.** Grid disturbances were reduced by raising the power factor and using advanced fault management liability control systems.
- **Developing deep offshore wind power technology.** All the turbines ranging from 5 to 6.7 MW at the 80 MW Xinghua Bay offshore wind farm were jointly manufactured by seven SOEs and foreign private companies in 2018. The total capacity is 79.4 MW, 2 × 6.7 MW from Goldwind, 2 × 5 MW from CSIC Haizhuang Windpower Co. Ltd., 2 × 5 MW from Taiyuan Heavy Industry Co. Ltd., 2 × 5.5 MW from Mingyang Smart Energy Group Ltd., 1 × 5 MW from DEC Wind Power Co. Ltd., 2 × 6 MW from Shanghai Electric Group Co. Ltd. (Simons, a consortium), and 3 × 6 MW from GE. They successfully withstood the strong typhoon 'Maria', demonstrating the quality, suitability, and soundness of China's offshore wind power equipment.
- **Research and design on the high-capacity offshore wind turbines** applied in the deep sea and associated key components organized by the MoST started in 2019.
- **Developing larger-scale wind turbines.** Major wind turbine manufacturers such as Goldwind, Mingyang, and Envision are working on ultra large 8–12 MW offshore wind turbines.

64 Wind power and solar energy are intermittent/variable. RE development requires that grid operators are prepared to add measures that can instantly pick up the lost capacity of wind or solar capacity. These measures aim to better "integrate" intermittent/variable technologies in the system.

128. The positive outcome of these initiatives was demonstrated in 2018 by (a) the reduction of the cost of wind power to CNY 7,100 per kW (about US$1,059 per kW) and (b) the upcoming commercialization of the 6.7 MW wind turbine.

## F. Building the Implementation Capacity

129. In the first stage (up to 1994), China relied on other countries to develop wind farm pilot projects financed by government funds and grants from bilateral and/or multilateral institutions due to the lack of wind power expertise, talent, financial resources, and implementation capacity:

- China received international aid from Demark and Germany to deploy their wind turbines in some small wind farms constructed by local developers in several provinces, including Shandong and Xinjiang (see paragraph 100). Through these demonstration projects, China began to develop know-how and expertise in wind farm site selection, wind turbine installation, wind farm operation and maintenance, and so on.

- At the same time, the assistance programs of the World Bank, GEF, and UNDP helped China build capacity in assessment of wind resource and provided training to (potential) developers in implementation of small and pilot wind projects, mainly built by governments, such as the Government of Shandong Province and China's Ministry of Aviation.

130. During the second stage (1995–2005) of RE development, China issued a series of policies and regulations, which enabled the emergence of a national wind project developers industry. These included the wind power concession, Ride the Wind and Double Push Programs (see paragraph 57), the separation of the generation from grid (transmission and distribution) mandated the State Council Decree No. 5 in March 2002, and the favorable taxes and policies, which opened up a huge market for wind power development and allowed new entrants in the construction and exploitation of generation plants. These include some major fossil fuel and hydropower generation companies such as Huaray Group (hereafter Huaray) (100 MW), Guangdong Yudean Group (hereafter Yudean) (100 MW), Longyuan Electric Power Group Co. Ltd. (hereafter Longyuan) (350 MW), Beijing International Electricity (100 MW), China Huaneng Group Co. Ltd. (hereafter Huaneng) (200 MW), and China Huadian Group Co. Ltd. (hereafter Huadian) (200 MW). The wind generation projects benefitted greatly from their expertise in construction, management, and operation and maintenance, but their wind portfolio remained modest compared to their momentous other generation assets.

131. During this stage, China began borrowing from the World Bank and other financiers to build larger wind farms, which with the continued assistance of CRESP and WED (see paragraph 70) introduced Chinese wind project developers to international best practices in preparing, building, and operating large wind arms.

132. During the third stage (2006–2017), the government set ambitious targets for the development of renewable energy and mandated a percentage of non-hydropower renewable energy in the generation mix of all power generation companies. The 2007 Medium and Long-term Development Plan of Renewable Energy[65] mandated that (a) the proportion of non-hydropower RE generation in the total power generation consumed in the areas covered by the major power grids should be more than 1 percent in 2010 and 3 percent in 2020 and (b) the share of non-hydropower RE generation in the total generation of companies

65 https://baike.baidu.com/item/%E5%8F%AF%E5%86%8D%E7%94%9F%E8%83%BD%E6%BA%90%E4%B8%AD%E9%95%BF%E6%9C%9F%E5%8http://www.china.org.cn/e-news/news070904-11.htm

fully owning more than 5 GW of generation assets should exceed 3 percent in 2010 and 8 percent in 2020. In 2016, the government issued the Guidance on the Establishment of Institution of Renewable Energy Exploitation[66] that mandated that non-hydropower RE generation should amount to 9 percent of the total generation of all power generation companies in 2020.

133. These two regulations, combined with a generous FiT and other tax and financial benefits (see paragraph 63), which ensured that wind power investments were profitable, attracted power enterprises and developers and some non-power enterprises, with high capacity in project preparation, construction, management, and operation and maintenance, to decisively enter the wind power development market.

134. The majority of these wind power developers are SOEs (CHN Energy, Huaneng, Datang, SPIC, Huadian, CGN, China Resources Power, and CTG; see Table 6.1), which accounted for 68.1 percent of the installed capacity by 2017. Provincial and lower administrative levels such as the Jingneng Group[67] (1,996.75 MW), Hebei Construction Investment (3,600 MW), Luneng Group[68](800 MW), and Shenzhen Energy[69] (615.4 MW) benefited from the decentralization of project approval to lower administrative levels and accounted for 3.3 percent of the total installed wind capacity in 2017. Finally, several private companies such as Beijing Tianrun New Energy Investment Co. Ltd. (Tianrun), China wind power (later renamed Concord New Energy), Beijing Jieyuan New Energy Investment Co. Ltd. (hereafter Jieyuan), and Jingtai New Energy (Shanghai) Co. Ltd. (hereafter Jingtai) successfully entered the market and accounted for about 4.2 percent of the wind installed capacity by 2017.[70]

135. The predominance of SOEs in large wind bases development is mainly due to (a) the high financial and technical risks related to the development of large wind projects that required access to local financing, strong implementation, and management capacity of large and complex projects; (b) access to training and capacity building from bilateral and multilateral programs; and (c) the obligation for generation capacity to develop a minimum RE capacity.

136. Several foreign enterprises participated in bidding of the wind concession program and other projects in the initial stage of wind power development. In the first round of the concession program, Navara, a company from Spain, and Inverness, a company from Germany, participated in the bidding, but their bidding price was too high and they failed to secure concessions. As a consequence, foreign enterprises did not participate in the next rounds of the wind concession program alone. Some of them tried to enter the market through association with Chinese companies. For example, in August 2007, AES of the United States established a joint venture with Guohua Energy Investment Company, one of China's leading RE producers, to develop wind power projects in China. In January 2008, BP cooperated with Goldwind to develop wind farms in China. However, with the advent of the financial crisis in 2008, foreign enterprises began to withdraw from China's wind power market as financial outweighed the benefits of investing in China's wind power market.

137. Some Chinese private enterprises have participated in the development of wind power projects in China. Huarui participated in the first round of concession bidding (2003) and won the bid of Jiangsu Rudong 100 MW wind power project. Xiongya (virgin) Co. Ltd. associated with Longyuan Power Group Co. Ltd. and the consortium won the bid for the Bayin 200 MW wind farm in Inner Mongolia. In 2007, the Hong Kong Construction Engineering Co. Ltd. and China Energy Conservation Investment Corporation won the

66 http://zfxxgk.nea.gov.cn/auto87/201603/t20160303_2205.htm
67 https://news.bjx.com.cn/html/20180213/880850.shtml
68 http://www.luneng.com/business/index8.html
69 http://xinpi.cs.com.cn/new/file/bulletin/2020/11/18/1208756966.PDF
http://pdf.dfcfw.com/pdf/H2_AN201804121122321885_1.pdf
70 Available statistics are incomplete. There are still some enterprises, including state-owned enterprises and private enterprises, whose wind power scale is relatively small.

bid for Gansu Yumen Changma 200 MW wind farm. In 2009, after the issuance of the FiT policy, which guaranteed higher returns on wind power investments, several Chinese private companies, such as Tianrun, Jieyuan, Jingtai, and Concord New Energy began to invest in wind farms. But their participation remained marginal because of their limited financing capacity because of the stringent rules for developers without substantial collaterals to secure debt from government-owned commercial banks.

138. Table 6.1 lists some key wind project developers, which played an important role in the Chinese wind project industry.

**Table 6.1: Cumulative Installed Capacity of China's Wind Power Developers (MW)**

| Name | SOE/Private | By 2005 | By 2017 | By 2019 |
|---|---|---|---|---|
| Huaray Power[70] | Private | 100 | n.a. | n.a. |
| Guangdong Yudean[71] | Local government | 100 | 526 | 505 |
| Longyuan[72] | SOE | 350 | 18,395 | 20,032 |
| Beijing International Electricity[73] | local government | 100 | n.a. | n.a. |
| Huadian | SOE | 200 | 13,020 | 14,630 |
| Huaneng | SOE | 200 | 19,030 | 22,620 |
| CHN Energy[74] | SOE | n.a. | 37,680 | 41,820 |
| Datang | SOE | 0 | 16,890 | 19,530 |
| SPIC[75] | SOE | n.a. | 13,680 | 18,450 |
| CGN[76] | SOE | n.a. | 11,790 | 14,750 |
| China Resources Power[77] | SOE | n.a. | 6,680 | 11,190 |
| Tianrun[78] | Domestic private enterprise | n.a. | 5,550 | 7,020 |
| Power China[79] | SOE | n.a. | 5,250 | 6,690 |
| CTG | SOE | n.a. | 4,230 | 5,710 |
| Concord New Energy | Domestic private enterprise | n.a. | 2,490 | 3,113 |
| Jieyuan | Domestic private enterprise | n.a. | 780 | 1,300 |
| Jingtai | Joint venture by China and foreign companies | n.a. | n.a. | 1,650 |

Source: Company annual reports; data provided by the China Renewable Energy Engineering Institute and the internet.

71 No information can be searched after 2006.
72 Guangdong Yudean altered the name to Guangdong Energy Group in 2019.
73 In 2002, Longyuan became the part of the China Guodian.
74 No more data updated after 2006.
75 China Guodian and China Shenhua merged into CHE Energy in 2017.
76 State Power Investment Coporation Limited (SPIC) was founded in 2015.
77 In 2007, China General Nuclear Power Corporation (CGN) officially operated wind power business.
78 China Resources Power bought the first wind power project in 2005.
79 Tianrun was founded in 2007.
80 Power China was founded in 2009.

139. During the fourth stage (2018 to present), the large companies continued to grow and adapt to the slower growth of the Chinese wind power market by

- Encouraging the development of distributed onshore wind power and building capacity in implementation and management of offshore wind power projects and
- Competing in the international wind power market.

140. By the end of 2019, the top 10 wind power developers' total installed capacity increased to about 162 GW, accounting for about 69 percent of the total installed capacity: (a) eight SOEs—CHN Energy (41,820 MW, of which 2,039 MW of offshore), Huaneng (22,620 MW, of which 915 MW of offshore), Datang (19,530 MW, of which 302 MW of offshore), SPIC (18,450 MW, of which 802 MW of offshore), CGN (14,750 MW, of which 247 MW of offshore), Huadian (14,630 MW, no disclosure of data on offshore), China Recourses Power (11,190 MW, its first offshore wind project of 400 MW ratified in 2019), and CTG (5,710 MW, of which 928 MW of offshore)—and (b) two privately owned—Tianrun (7,020 MW, no disclosure of data on offshore) and Power China (6,690 MW, no disclosure of data on offshore). The remaining installed capacity, about 31 percent, was developed by smaller companies owned by lower administrative levels such as Jingneng Group, Hebei Construction Investment Company, Luneng Group, and Shenzhen Energy.

## G. Lessons Learned

141. Localizing wind turbine manufacturing requires a steady market, estimated by some international companies at 400 MW per year.

142. Building a local competitive manufacturing industry requires (a) a large and sustained market capacity that is only possible in large and resource rich countries because smaller countries, with sizable resources, need to look beyond their borders and cooperate with neighboring countries to create regional and sustainable markets and (b) medium- and long-term planning, cooperation with more advanced countries to build an integrated chain including testing and learning about available state-of-the-art equipment, developing a strong knowledge and R&D base, gradually developing a manufacturing industry, and cooperating with advanced country and recognized institutions to develop capacity in standards and certification.

143. Although China has a large capacity to produce wind turbines, several manufacturers still need to make breakthroughs in manufacturing of core components, including high-quality blades, bearings, gearboxes, and control systems. These are essential to high efficiency and safety of wind turbines and play a key role in the development of a wind power industry. These manufacturers need to continue developing R&D in this area.

144. Regarding the wind farm project industry, China's experience indicates that policy and regulatory measures and price and tax incentives are necessary to create a vibrant RE market and attract developers and investors and sustain RE development. However, they may not be sufficient to meet government ambitious targets and time frame. In addition to building the regulatory framework and generating price incentives, mandating minimum RE shares in total electricity generated by large power generation companies has been critical for China to promote a project developers' industry with growing skills in project planning, management, construction, and operation and maintenance of progressively larger and more complex projects.

# Chapter 7. Solar PV Industry

**Key Messages**

The development of China's PV industry has taken a different path from wind power. It was driven by entrepreneurs who invested in China to take advantage of overseas capital, highly skilled technical personnel and lower domestic labor costs to compete in growing overseas markets from the outset. It started relatively late but caught up quickly, covering the entire PV supply chain and transformed the RE market during the last 15 years. China was propelled in less than two decades to a dominant position in the global market as about 70 percent of the modules used worldwide since 2015 were manufactured in China. In 2019, 6 of the top 10 polysilicon producers in the world and 15 of the top 20 modules manufacturers in the world were Chinese companies. Technological advancements and economies of scale contributed to significant price reduction and during 2006–2019, the cost of solar PV modules decreased by 96 percent and the cost of balance of system (BOS) decreased by 93 percent in China.

This dramatic development was achieved in four stages, which do not exactly mirror the stages of RE development in China because the PV industry relied heavily on exports, which never dropped below 40 percent of the total module production and reached 60 percent in 2019.

During the first stage (before 2000), China's PV module manufacturing capacity was clearly lagging the industry leaders, BOS products were inefficient, manufacturers were overly reliant on imported materials, and the market was too small to support commercial development and technological progress.

During the second stage (2001–2010), Chinese entrepreneurs invested in PV industry taking advantage of overseas technology, human resources, capital, market, and low cost labor forces, especially after the country joined the WTO in 2001. They took advantage of the general policy of 'invite investment from overseas' to benefit from preferential conditions, such as tax deduction, access to land, and financing provided by advanced provinces to first movers to establish manufacturing PV capabilities in their territories. The highly skilled executives of these private companies brought their technical capacity, professional networks, and capital and advanced management skills to China. They hired international experts to improve design and production processes, sought grants and loans from international financial institutions to improve their products, and secured certification for their products from recognized universities and certification laboratories.

To meet their vast financing needs, all emerging Chinese PV companies relied on foreign capital taking advantage of the PV utilization boom in developed countries and increased interest of investors in Asian markets. China's solar cell production capacity exploded from 300 MW in 2005 to 30 GW in 2010. In China, they were sought after by local governments and offered financial and land use concessions to invest in their administrative areas.

During the third stage (2011–2017), the industry entered a period of massive expansion. To encourage the PV utilization in the domestic market, the Chinese government adopted policy measures such as feed-in tariff and relied on 'traditional' Chinese industry support methods—large-scale demonstration and pilot projects, such as the 'Golden Sun' program and the PV poverty alleviation program. Based on the experience gained during the development of the wind industry, the government intervened forcefully, issuing a series of specifications and standards to protect consumers against low-quality products.

More than 40 Chinese standards were adopted from the IEC, Semiconductor Equipment and Materials International (SEMI), and other international standard institutions, and Chinese experts led the development of several standards published by the IEC.

During the fourth stage (2017–), the PV industry entered into a new era. The emergence of new technologies has led to a new round of cost declines, and the increased efficiency brought on by the application of intelligent control systems has promoted the rapid development of distributed PV in China.

Very high growth is usually disruptive and requires constant oversight. The ‘PV rush’ in China was no exception and the domestic market, shocked by delayed or no payment of subsidies, spiraled down and investments were cut by about 17 percent in 2018. Chinese companies refocused on overseas markets, delocalizing manufacturing closer to target markets, developing technology advances to achieve higher photoelectric conversion efficiency, and developing standards for recycling and reuse of decommissioned modules.

Regarding the project industry, in the first stage, the Chinese government initiated several projects supported by grants provided by bilateral and multilateral institutions to develop electricity access in the poor northwestern provinces and build the capacity of PV developers in project planning and preparation, PV station construction, operation, and maintenance, introducing them to international best practices.

During the second stage, the financing provided to developers and the policies mandating a minimum share of RE at the generation level opened up a huge market for solar PV power development and allowed new entrants in the construction and exploitation of generation plants, including some major fossil fuel and hydropower generation companies.

With continuing decreasing PV cost, the government tested and adopted a gigawatt-level utility-scale PV concession program, which contributed to the surge of PV during the late years of the third stage of RE development, especially 2018 and 2019.

For utility-scale solar PV projects, the market was dominated by SOEs, local government-owned enterprises, and large private enterprises.

For distributed solar PV, which accounted for 66 GW, about 31 percent of the total installed capacity, the market is dominated by medium and small private enterprises and RE service companies. The corresponding Chinese association counts more than 5,000 members.

The lessons learned from the development the PV industry in China are as follows:

First, China has adopted law ruling, planning guidance, financial support and other measures in recent years to vigorously promote the rapid and large-scale development of renewable energy and make a prominent contribution to the global energy transition. In particular, the rapid technology development of PV has resulted in significant cost reduction, which greatly increased the cost effectiveness of the investment, and therefore made PV competitive to the traditional energy. It made it a reality for renewable energy to become the main stream energy source in the global energy market.

Second, China has used development target as measures at different stages for the development of renewable energy. China has continuously adjusted its policies to adapt to the changed situation to address issues and create a healthy development environment of the industry. For example, in response to the down turn of global PV market, challenges in export market, and unbalanced supply chain of the industry, the Government issued "Several Opinions on Promoting the Healthy Development of the PV industry" in a timely manner in 2013 (Guo Fa [2013] 24 No). In order to reduce the grid connection price of PV, NEA has adopted the unified bidding policy and measures at national level since 2019, which significantly contributed to the quick cost decline of the PV and bring it to the path to grid parity and now sector is at the gate of non-subsidy development era.

Third, the opening of China's PV market to various market players, SOEs, private enterprises, Chinese companies, and foreign companies can all participate in all parts of the supply chain. For example, the upstream manufacturing industry is dominated by private enterprises, the downstream power station investment, and utility scale projects are dominated by SOEs and large private enterprises, and distributed PV projects are mainly constructed by small and medium private enterprises. Various market players have played their respective advantages and jointly promoted China's PV to become bigger and stronger.

145. The development of China’s PV industry has taken a different path from wind power. It was driven by private entrepreneurs who targeted the overseas market from the outset. Expansion of overseas PV markets provided strong incentives for the development of PV manufacturing industry and focus on high-quality products and cost reduction. The development of the PV industry started relatively late but caught up quickly and transformed the RE market during the last 15 years:

- In the first stage (before 2000), China’s PV module manufacturing capacity was limited, and the BOS manufacturing was rudimentary. Private manufacturers relied overly on imported materials and China’s PV market was too small to support commercial development and technological progress.

- At the second stage (2001 to 2010), with the introduction of more capital and advanced technology from overseas, China’s PV industry gradually grew into an important supplier in the world market. However, raw materials such as polysilicon wafers/ingots were still imported.

- During the third stage (2011 to 2017), the growth of the domestic market boosted the industry and led to the establishment of private companies and joint ventures in the entire manufacturing supply chain. The increased number of market players, technological progress, and economies of scale led to vibrant competition that increased quality and significant cost reduction. Government agencies struggled to keep up with the market and timely regulation of the industry and gradually developed standard and certification capabilities.

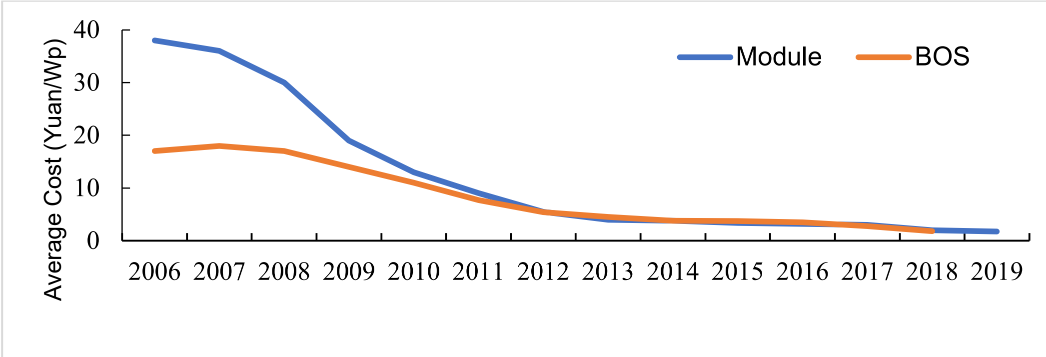
- At the fourth stage (2018 to present), the emergence of new technologies, such as PERC technology and Diamond Wire Sawing technology, is leading to a new round of cost declines, and the increased efficiency brought on by the application of intelligent control systems is promoting the rapid development of distributed PV in China.

## A. Achievements of the Solar PV Industry

146. During the 2000s, China's PV industry was driven by exports as PV use began to develop at a large scale in developing countries. This early development was accompanied by fast quality improvement and efficiency and a dramatic decrease in prices. Concerned government agencies quickly embraced the opportunity and played an important role in stimulating the domestic market by developing policies, providing incentives, and developing standards and certification capabilities. The boom that ensued was beyond all expectations and propelled China's PV industry to a global leadership position with the following characteristics:

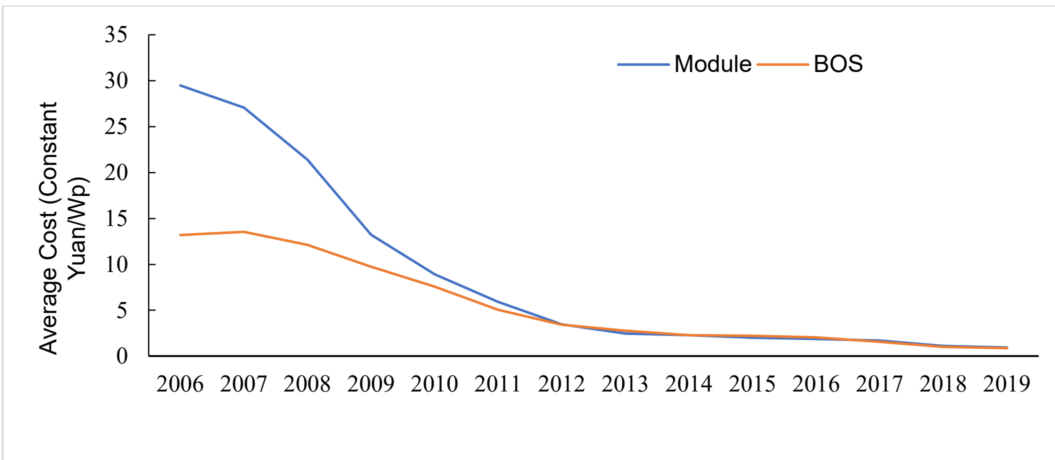
- **Quasi total coverage of the solar supply chain.** According to the China Photovoltaic Industry Association (CPIA), in 2019, 6 of the top 10 polysilicon producers in the world and 15 of the top 20 modules manufacturers in the world are Chinese companies. During 2006–2019, technological advancements and increasing economies of scale reduced the price of solar PV modules in China by 96 percent and the price of BOS by 93 percent (see Figure 7.1).

**Figure 7.1: (a) Average Solar PV Module and BOS Costs (Current Yuan) in China**




Source: Study team.[81]

**Figure 7.1: (b) Average Solar PV Module and BOS Costs in China (Constant Yuan 1995)**

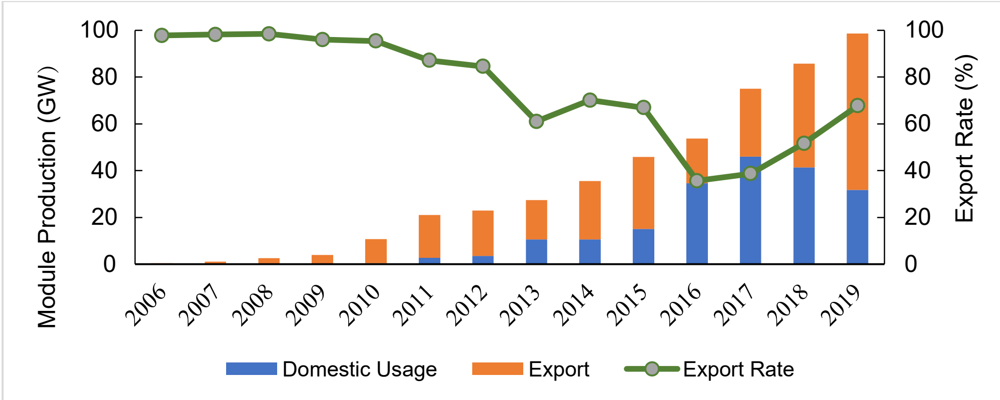



Source: Study team.[82]

- **Dominant position in the global PV market.** Overseas markets have played a significant role in the development of China's solar PV industry. China's PV module export rate has never dropped below 40 percent of the total production and reached over 60 percent in 2019 (see Figure 7.2). About 70 percent of the modules used worldwide since 2015 were manufactured in China (see Figure 7.3).

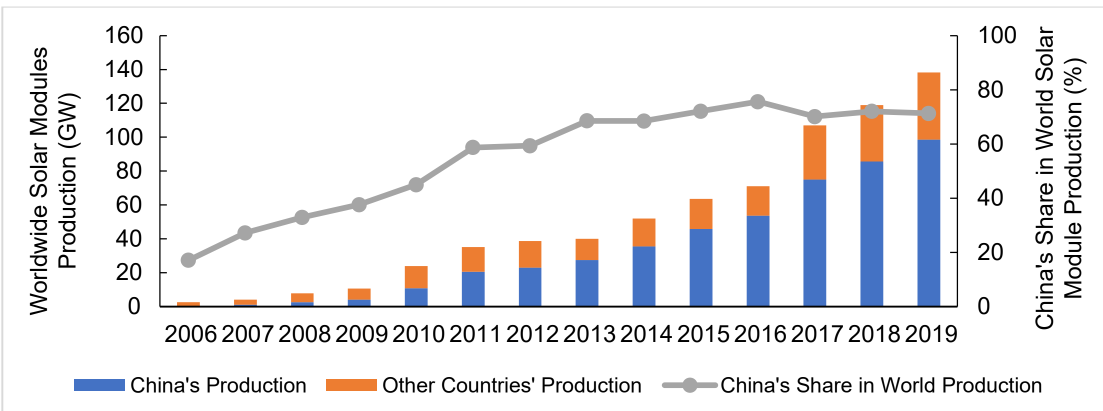
81 Based on the CPIA database.
82 Based on the CPIA database.

**Figure 7.2: China Solar PV Module Production and Export Rate**




Source: Study team.[83]

**Figure 7.3: Worldwide Solar Modules Production Situation**

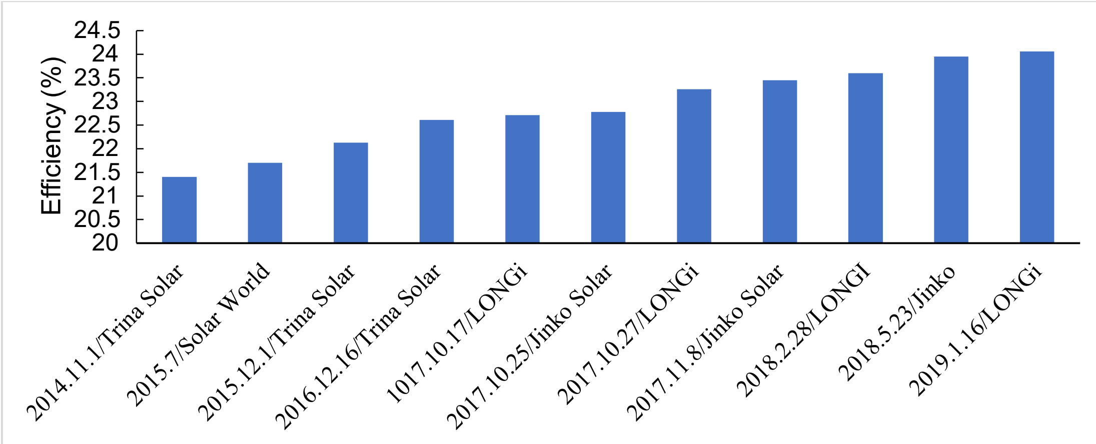



Source Study team.[84]

- **World leader in technological progress.** Despite fierce competition at home and abroad, aggressive private sector companies achieved impressive results. China's solar cell conversion efficiency increased from 15 percent in 2005 to 24 percent in 2019. Since 2014, Chinese companies have broken the world conversion efficiency record for Passivated Emitter and Rear Cell (PERC) 10 times (see Figure 7.2). Specific technical paths for improving conversion efficiency reported by different companies vary. For example, Jinko used Topcon technology to improve the PERC efficiency while LONGi used double screen printing. From silicon wafer to cell to module, different technical paths show the diversity of China's solar PV research and this diversity from different companies leads China's solar PV technological progress.

83 Based on the CPIA database and General Administration of Customs export data.
84 Based on CPIA data.

**Figure 7.4: PREC Conversion Efficiency World Records in Recent Years**




Source: Study team.[85]

## B. The Infancy (before 2000)

147. By the end of 2000, China's solar PV development was modest, technological capacity was limited, and manufacturing processes were quite backward. Given the high price of PV modules, RE development focused mainly on hydro- and wind power and use of PV modules was limited to small applications, such as signal stations for communication, negative pole protection of petroleum pipeline, and weather forecast stations. Several issues limited the development of solar PV in China during this stage:

- **Limited market.** The size of domestic market is too small to support commercial and technological development. The overseas market is relatively large, but China's PV products were not competitive on the international market because of high price and low quality.

- **Lack of advanced domestic manufacturing.** Although China imported 4.5 MW PV cell production lines from European, Canadian, and US companies in the 1980s and 1990s, the crude production processes and unskilled labor led to low production rate and poor product quality. The average annual production was only about 2 MW and some products lasted from three to five years.

- **Lack of systematic R&D framework.** China started the solar PV R&D in the 1960s. However, due to the lack of systematic training for researchers and lack of research fund, China's PV R&D was far behind the global level and only achieved few results.

- **Lack of investment.** The Chinese government did not consider PV development as a priority at this stage of RE development. Therefore, SOEs were not interested in entering the PV industry, private companies did not have access to financing from state-owned banks like the large wind SOEs, and domestic venture capital showed little interest in the PV industry.

- **Lack of vertical integration of the supply chain.** Local manufacturers relied on imports of not only core materials requiring high competency to produce such silicon ingots and silicon wafer but also basic materials such as silver paste and tempered glass. There was no specialized domestic

85 Based on Chinese Renewable Energy Society Photovoltaic Professional Committee data and company's reports.

manufacturer for the BOS. Few research institutions produced small quantities of PV systems but struggled to overcome low product performance and reliability and high price.

148. During this stage, China's PV module manufacturing capacity is still lagging the industry leaders, BOS products are inefficient, manufacturers are overly reliant on imported materials, and the market is too small to support commercial development and technological progress.

## C. The Rise of Private Sector (2001 to 2010)

149. Contrary to the wind industry, solar PV developed from the bottom owing to overseas Chinese entrepreneurs, who were educated abroad and worked for foreign research institutions or solar PV companies. They came back to take advantage of China's opening and integration in the globalized economy, especially after the country joined the WTO in 2001. They had the knowledge, entrepreneurship, and belief in the potential of PV market to jump-start the industry and play a significant role in its emergence and vibrancy. Under the general policy of 'invite investment from overseas', some provincial and municipal governments also gave preferential conditions, such as tax deduction, access to land, and financing, to support these overseas Chinese entrepreneurs in establishing manufacturing companies as first movers.

150. The market limitation was addressed by improving quality and reliability to enter growing foreign markets and the emerging government interest in the technology through the development of domestic demonstration programs:

- Following the signing of the Kyoto Protocol, developed countries began to formulate longer-term RE strategies and commit to ambitious targets, resulting in surging global demand for RE, most notably in the European PV market.

- In the early 2000s, China launched a series of programs to provide electricity access to poor remote areas and nomadic populations, mainly in the northwest region of the country. These programs created the initial domestic demand for PV. These programs contributed to the emergence of the domestic market for solar PV, demand remained modest, and more than 98 percent of modules were exported to overseas markets before 2009.

- In 2009, to reduce its excessive reliance and dependence on fossil fuels and in response to the overseas market shrinkage caused by the economic crisis, China launched the 'Golden Sun' program (see Chapter 4 for details), which supported the installation of a total of 500 MW PV projects before 2011. Although the module export rate dropped by only 3 percent, the 'Golden Sun' program laid the base for future policies to promote the large-scale development of domestic photovoltaics.

151. The lack of technological knowledge was mitigated by the return to China of Chinese expatriates to take advantage of growing business opportunities and set up private enterprises and joint ventures for early entry in a promising market. According to some experts, in 2011, more than 60 percent of board members of the three largest PV manufacturers had gained experience abroad.[86] These highly skilled executives brought their technical capacity, professional networks, and capital and advanced management skills to China:

86 de la Tour, A., M Glachant, and Y. Ménière. 2011. "Innovation and International Technology Transfer: The Case of the Chinese Photovoltaic Industry." *Energy Policy 39* (2).

- In 2001, Suntech is founded in Wuxi to invest in China's first commercial solar cell production line based on technology and experience acquired in Australia. The 10 MW annual production capacity of the factory was four times higher than China's annual production at the time.

- These private companies hired international experts to improve design and production processes and to train engineers and skilled labor to operate the lines of production and ensure quality control. Virtual PV production line software, developed by foreign universities for college courses, was also introduced to China's PV companies to help their engineers understand the complex PV cell production process.

- These companies also sought support from the world's most advanced research institutions to improve PV efficiency. For example, in 2002 and 2003, Suntech was the first among the prominent PV companies to request REDP grants to undertake cost-shared activities to improve its products first and then secure their certification by a renowned US university. In 2009, it followed up with the Pluto cell project[87] with a US$50 million loan from IFC, which was implemented with the University of New South Wales.

152. To meet their vast financing needs, all emerging Chinese PV companies relied on foreign capital taking advantage of the PV utilization boom in developed countries and increased interest of investors in Asian markets:

- Between 2006 and 2008, 9 of the top 10 Chinese solar cell companies were listed on the US stock market and favored by investors. According to Martin Green, from 2005 to 2010, the top 10 China solar cell manufacturers raised US$7 billion through stocks and convertible bonds on US stock markets, with employee stocks and options totaling US$10 billion. [88] The behemoth investment from international investors promoted the development of China's PV manufacturing industry. China's solar cell production capacity exploded from 300 MW in 2005 to 30 GW in 2010.

- After 2007, local governments began to attract local investment from PV companies through tax and land use concessions, bringing local economic growth and employment opportunities, and reducing the initial investment costs of PV manufacturing.

153. With the cell and module production capacity growth, the demand of material grew dramatically. The demand for polysilicon grew faster than the production capacity and the price increased from around US$20 per kg in 2004 to US$500 per kg in 2008.[89] The soaring raw material prices stem mainly from efforts deployed by polysilicon producers using their market power to limit production. This drove Chinese companies to vertically integrate their supply chains to reduce reliance on imports, better control their production costs, and maximize their profits. They explored domestic manufacturing processes in trial production. Some Chinese companies involved in the entire PV supply chain shared their technologies and manufacturing processes with other companies at no cost to increase competition and reduce their input costs and ultimately the cost of production of PV cells. It also enhanced the overall competitiveness of China's photovoltaics. As an example, after domestic manufacturers developed mature polysilicon manufacturing capabilities in 2009, China's polysilicon import rate fell to 49 percent (see Figure 7.3).

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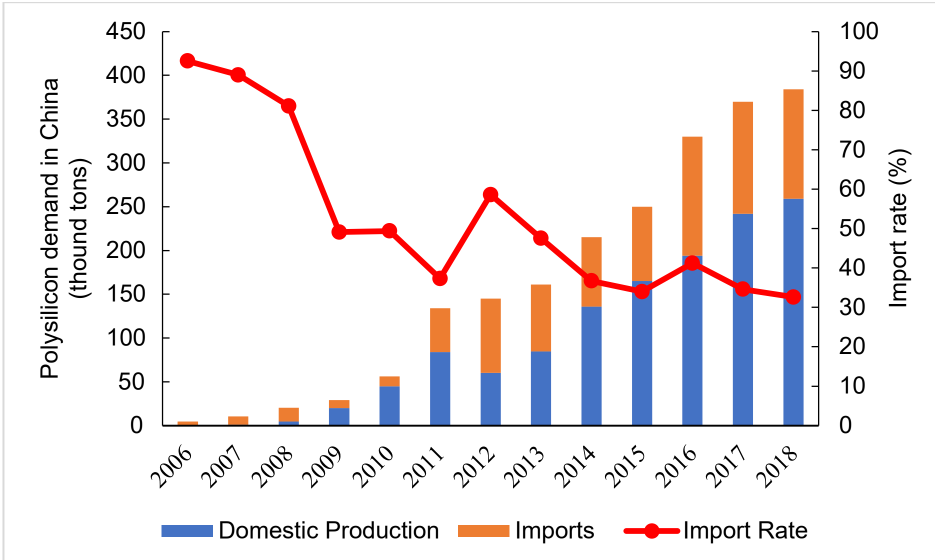
87 In 2009, Suntech Power Holdings Co. Ltd. has signed a US$50 million convertible loan agreement with the International Finance Corporation (IFC), a member of the World Bank Group, to support Suntech's transition to its Pluto technology and debt refinancing requirements. The convertible loan has a fixed rate coupon of 5.0 percent per year, which is payable on June 15 and December 15 each year.

88 Martin Green, China's Photovoltaic Development History.

89 Source: Sandor, Debra. 2018. *System Dynamics of Polysilicon for Solar Photovoltaics: A Framework for Investigating the Energy Security of Renewable Energy Supply Chains.* Figure 1.

**Figure 7.5: Polysilicon Demand and Import Rate in China**




Source: CPIA.

154. In 2008, China's PV exports tapered as the economic crisis engulfed the world. Thankfully, the increased deterioration of the local environment, the dramatic cost reduction of PV systems, and the policy support from the central government contributed to spur larger-scale PV utilization and drive the growth of China's PV industry in the next stage.

## D. Massive Expansion (2011–2017)

155. After 10 years of progress, China's leading manufacturing technology and capabilities were widely recognized. With the recovery of the international PV market, China's solar PV module exports increased by 2.5 times in 2010 compared to 2009. The popularity of Chinese products in foreign markets and fast decreasing prices brought the potential of PV to the attention of the Chinese government. PV is more flexible than wind power and can be distributed to produce electricity at the consumer level and empower consumers. If paired with storage, PV can contribute to mitigate pollution, address climate change, and shorten the transition toward a greener and sustainable power sector. To materialize these potentials, the central government began to promote the application of photovoltaics in China. However, some problems emerged lately and needed to be addressed to sustain the development of the industry:

- The domestic market was too small to support large development. Although the cost of PV modules dropped more than 70 percent in the 2000s, the PV power generation cost was still higher than thermal power.
- Although China's PV export products maintained high quality due to compliance with international standards, the lack of domestic production processes and product standards led to 'bad money drives out good'.[90]
- The pace of technological progress and cost decline slowed.

90 'Bad money drives out good' is a Chinese proverb of Gresham's Law, which means in the market without standard, the product of low quality would take more market share with a lower price, and the product of high quality would lose the opportunity of further development.

156. To encourage the PV utilization in the domestic market, the Chinese government adopted policy measures such as feed-in tariff and carried forward the 'traditional' Chinese industry support methods—large-scale demonstration and pilot projects, such as the 'Golden Sun' program for utility-scale projects and the PV poverty alleviation program.

157. It should be noted that, while the government deployed efforts to promote the domestic PV utilization, companies actively explored emerging overseas market opportunities. Although the exports to Europe and the United States fell steeply, they were compensated by exports to huge emerging markets such as Brazil, Mexico, and India, which increased demand from new overseas markets.

158. The high domestic demand led to commercialization of lower-quality systems by some companies taking advantage of lack of domestic standards and certification. The government stepped in to better regulate the domestic market.

- In 2013, MoIIT issued the 'Specifications for the Photovoltaic Manufacturing Industry'. This policy set minimal annual production capacity requirements for factories, unit water and power consumption limits, and quality standards for intermediate and end products. This policy also required that modules should be covered by 10-year warranties and their service life should be no less than 25 years. This policy is revised annually or biannually to ensure that standards and certification requirements are up-to-date and enforced.

- China actively formulated its own PV standards system and contributed to the improvements in the international standard system: (a) MoIIT published the 'Standardization Technology System of Photovoltaic Industry' in 2017 to impose quality standards to all segments of the PV industry; (b) by the end of 2018, China developed 194 national and industry standards (currently) for the PV industry, of which more than 40 are adopted from the IEC, SEMI, and other international standards; and (c) the development of five standards published by the IEC TC82 was led by Chinese experts, and three ongoing TC82 standards working groups were led by China.[91]

159. To promote technology progress and cost reduction, the government institutions developed many cooperation programs to build R&D capacity and promote innovation (see Chapter 2, paragraph 45). Chinese companies also deployed efforts to maintain their leading position in international markets:

- SOE developers established PV power plant experiment bases to test different modules, BOSs, layouts, and energy storage solutions and improve solar efficiency in practice. Testing scope was also extended to environmental technologies. The impact of PV power stations on the local environment was observed in many instances in China with positive effects on grassland restoration and evaporation capacity. One PV test station in Qinghai also announced positive impacts on local temperature, wind speed, air humidity, and soil organic matter by years of monitoring. However, the latter conclusions require further studies and research.

- Manufacturers acquired advanced technology through self-development or mergers and acquisitions. By 2013, Hanergy acquired five foreign companies, which enabled it to acquire the copper indium gallium selenide (CIGS) film cell technology from the United States, and it would eventually lead the world in conversion efficiency. Certain solar PV companies established their own research institutes. These institutes recruited domestic chemical, semiconductor, electronics, and other industrial engineers to tackle the production process. The cooperation between these institutes further boosted research progress.

91 China Electronics Standardization Institute.

## E. Back to the Fundamentals (2018 to Present)

160. Very high growth is usually disruptive and requires constant oversight. The ‘PV rush’ in China was no exception and the domestic market, shocked by delayed or no payment of subsidies, spiraled down and investments were cut by about 17 percent in 2018 and Chinese companies refocused on oversea markets.

161. At the same time, the first batch of PV power plants are ready for decommissioning and the government and industry are yet to develop policies and requirements to remove the panels, properly dispose of or recycle the components to safeguard the environment, and restore the land.

162. Companies and associations are taking steps to further the development of China’s solar PV industry in a sustainable and environment-friendly manner based on market fundamentals:

- **Expand overseas markets through localizing production closer to promising markets.** To increase their competitivity, Chinese companies are delocalizing manufacturing closer to target markets. As an example, LONGi has already installed 1 GW manufacturing facility in India and a 2.3 GW manufacturing capacity of monocrystalline silicon wafer, solar cells, and modules in Malaysia. Jinko has deployed six production bases and 15 branches worldwide.

- **Seek new technology routes.** The new technology route is key to achieving higher photoelectric conversion efficiency. Advanced technologies such as PERC and black silicon have been developed recently and have increased cell conversion efficiency to a new level, from 20 percent to more than 24 percent. Meanwhile, the heterojunction technology (HJT) already become the new research hotspot for higher efficiency.

- **Carry out module recycling technology research and standard formulation.** The CPIA established the standard working group on module recycling and reuse in November 2018 to benchmark relevant international standards and formulate a domestic standard system.

## F. Building a Solar PV Implementation Capacity

163. Before 2000, solar PV development was marginal and supported by international partners such as Germany, United Nations Educational, Scientific, and Cultural Organization (UNESCO), and other international parties through their aid programs. During that period, China seized the opportunity to launch programs to increase access to electricity in remote areas of the country such as Gansu, Qinghai, Xinjiang, and Xizang. As a result, several small solar companies were entrusted to implement the proposed small solar PV projects. These companies were mostly owned by the provincial level government and private integrator companies focusing on electricity access.

164. During 2001–2010, the Chinese government initiated several projects supported by grants provided by bilateral and multilateral institutions. These projects were developed to further electricity access in the poor northwestern provinces and build the capacity of PV developers in project planning and preparation, PV station construction, operation, and maintenance. They provided subsidies to reduce the cost of the systems and introduced international best practices to the emerging Chinese PV developers.

- During 2002–2007, the Government of the Netherland provided a US$15 million grant to complement the Xinjiang government's US$10 million to implement the Xinjiang Silk Road Brightness Program, which led to the implementation of 78,000 solar home systems.

- The REDP (see paragraph 54), a GEF/World Bank project, provided a US$25 million grant to deploy solar home systems in Northwest China. But more importantly, it included a significant technical assistance program that supported the small and some large companies participating in the project and built their capacity in developing sound and profitable projects. By the closing of the project in 2008, 625,000 systems, with a total capacity of 12 MW, had been installed. The number of companies participating in the project, as vendors and developers, grew from 8 at the beginning to 28 at closing. Some of these companies became key players in the Chinese PV market.

165. In addition, China has also formulated a series of policies, including the Renewable Energy Law, preferential tax policies, the mandatory share of renewable energy in total energy consumption, and the separation of the generation from grid (transmission and distribution) mandated by the State Council Decree No. 5 in March 2002. In particular, the 2007 Medium and Long-term Development Plan of Renewable Energy[92] mandated that (a) the proportion of non-hydropower RE generation in the total power generation consumed in the areas covered by the major power grids should be more than 1 percent in 2010 and 3 percent in 2020 and (b) the share of non-hydropower RE generation in the total generation of companies fully owning more than 5 GW of generation assets should exceed 3 percent in 2010 and 8 percent in 2020.[93] All these opened up a huge market for solar PV power development and allowed new entrants in the construction and exploitation of generation plants, including some major fossil fuel and hydropower generation companies such as SPIC, Datang, Huadian, China Energy Conservation and Environmental Protection Group (hereafter CECEP), CGN, CHE, Chint Group Co. Ltd. (hereafter CHNT), and Co. Ltd. (hereafter TBEA). The solar power generation projects benefitted greatly from their expertise in construction, management, and operation and maintenance but their solar PV portfolio accounted for a large part of their considerable generation assets.

166. During 2011–2017, as solar PV cost began to significantly decrease, the government set ambitious targets for the development of PV and mandated a percentage of non-hydropower renewable energy in the generation mix of all power generation companies. In 2016, the government issued the Guidance on the Establishment of Institution of Renewable Energy Exploitation[94] that mandated that non-hydropower RE generation should amount to 9 percent of the total generation of all power generation companies in 2020.

167. The regulation, combined with a generous FiT and other tax and financial benefits (see paragraph 64), which ensured that solar PV project investments were profitable, attracted power enterprises and developers and some non-power enterprises. with high capacity in projects preparation, construction, management, and operation and maintenance to decisively enter the solar PV project development market.

168. With continuing decreasing PV cost, the government tested and adopted a gigawatt-level PV demonstration program, which contributed to the surge of PV during the third stage of RE development, especially 2018 and 2019, and state-owned energy enterprises entered the market forcefully and quickly secured a leading position in the utility scale solar PV segment.

92 http://www.china.org.cn/e-news/news070904-11.htm
93 http://www.china.org.cn/e-news/news070904-11.htm
94 http://zfxxgk.nea.gov.cn/auto87/201603/t20160303_2205.htm

169. By 2019, there were thousands of solar PV project developers in China with greatly diversified ownership, SOEs and private enterprises, large and small.

170. For utility-scale solar PV projects, the market was dominated by SOEs, local government-owned enterprises, and large private enterprises (see Table 7.1):

- SOEs with large installed capacity such as SPIC (19,290 MW), CECEP (3,830 MW) CHE (1,340 MW), Huaneng (4,000 MW), Datang (1,462.7 MW), Huadian (3,199.4 MW), CGN (874.3 MW), CTG (4,400 MW), and SINOMACH (1,500 MW) accounted for 18 percent of the total installed capacity in 2019.

- Provincial and lower administrative level companies such as the Beijing Energy Group (2,071 MW), Beijing Enterprises Group (2,256 MW), Jinneng Holding Power Group (795 MW), and Shenzhen Energy (1,062 MW) accounted for 3 percent of the total installed capacity in 2019.

- Large private companies such as GCL, Jinko, Xinyisolar, CHNT, Sungrow Power, AKCOME, Trina solar, Rise Energy, Kongsun, and TBEA accounted for about 9 percent of the total installed capacity in 2019. All of them, except Kongsun and TBEA, are also module or solar cell manufactures,

- Developers with diversified ownerships accounted for 39 percent of the total installed capacity. An important number of small projects developed amounted to 79 GW. However, information about these project developers is not available because of their large number. They are consolidated at the county or provincial level in the statistical system. There are too many of them and the market of each company is limited.

    171. For distributed solar PV, which accounted for 66 GW, about 31 percent of the total installed capacity, the market is dominated by small private enterprises

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171. For distributed solar PV, which accounted for 66 GW, about 31 percent of the total installed capacity, the market is dominated by small private enterprises. These companies built recognized capacity in implementing decentralized projects and contributed significantly to achieving China's EE targets. For example, Beijing Yuanshen Energy Saving Technology Ltd. (Yuanshen) is one of three ESCOs funded by the World Bank/GEF China Energy Efficiency Promotion Project. Yuanshen gained rich experience from the implementation of the project. Its strong project implementation capacity was recognized by the Beijing municipal government and the World Bank and it was selected as an implementation agency to implement a 100 MW distributed solar PV investment project in Beijing from 2013 to 2019 in education, industry, commercial, agriculture, and infrastructure sectors. The installed capacity of the project accounted for 20 percent of the total installed capacity of distributed solar PV in Beijing as of 2019. The China Association of Energy Management Companies (EMCA) has more than 5,000 members, many of whom are doing business in distributed solar PV development.

172. Table 7.1 lists some key solar PV project developers which played an important role in the Chinese solar PV power project industry.

**Table 7.1: Cumulative Installed Capacity of China's Solar Power Developers (MW)**

| Name | SOE/Private | 2013 | 2018 | 2019 |
|---|---|---|---|---|
| SPIC | SOE | 2,226 | 16,457 | 19,290 |
| CECEP | SOE | 1,265 | 3,137.3 | 3,830 |
| Huadian | SOE | 780 | 2,949.3 | 3,199.4 |
| CHE | SOE | 881 | 1,220 | 1,340 |
| CTG | SOE | 418 | 3,630 | 4,400 |
| Huaneng | SOE | 380 | 3,180 | 4,000 |
| SINOMACH | SOE | n.a. | 1,400 | 1,500 |
| Datang | SOE | 474 | 1,111.6 | 1,462.7 |
| CGN | SOE | 467 | 403.8 | 874.3 |
| Beijing Energy[94] | Local government | n.a. | n.a. | 2,071 |
| Beijing Enterprises Group | Local government | n.a. | n.a. | 2,256 |
| Shenzhen Energy[95] | Local government | n.a. | n.a. | 1,062 |
| Jinneng holding power group | Local government | n.a. | n.a. | 795 |
| GCL[2] | Domestic private enterprise | n.a. | 7,309 | 6,719 |
| Jinko | Domestic private enterprise | 213 | 3,000 | 2,950[96] |
| Xinyisolar[3] | Domestic private enterprise | n.a. | 2,500 | 2,630 |
| CHNT | Domestic private enterprise | 570 | 1,635 | 3,500 |
| Sungrow Power | Domestic private enterprise | n.a. | 1,800 | 2,000 |
| AKCOME | Domestic private enterprise | n.a. | 1,040 | 700 |
| Trina solar | Domestic private enterprise | n.a. | 1,000 | 1,100 |
| Rise Energy | Domestic private enterprise | n.a. | 1,780 | 1,947 |
| Kongsun | Domestic private enterprise | n.a. | 1,789 | 1,629 |
| LONGi | Domestic private enterprise | n.a. | 540 | 1,470 |
| TBEA | Domestic private enterprise | n.a. | n.a. | 1,300 |

Source: Company annual reports, data provided by the China Renewable Energy Engineering Institute and the internet.

## G. Lessons Learned

173. **Establishment of an enabling business environment is the key to reverse the 'brain drain' and attract investors and talents.** It took China time to loosen the command and control on the economy and gradually establish a friendly business environment that appealed to Chinese expatriate entrepreneurs and attracted them back with their technical capacity, professional networks, capital, and advanced management skills. They were key to starting the PV industry and maintaining its growth through technical innovations that improved the quality and efficiency of outputs and decreasing costs. However, to avoid disruption, governments need to avoid abrupt changes in policy and regulations and interference in management of these companies. At least, one successful company stopped manufacturing modules in China rather than accepting government interference that might disrupt its development strategy.

95 https://www.sohu.com/a/386461675_749304
96 https://oss.sec.com.cn/202004301627372808.pdf
97 GCL sold some projects in 2018, and therefore the number in 2018 is higher than that in 2019. Similarly for Jinko, AKCOME, Kongsun.

174. **Standard system is the safeguard of product quality.** During the 2000s, China's PV products were mainly exported to overseas markets and the quality of these products was widely recognized because they were certified to meet international standards. However, PV product quality problems frequently occurred in the domestic market before the development of a comprehensive standard system in the late 2010s.

175. **Strict oversight must be in place during the deployment of heavily subsidized programs.** The 'Golden Sun' program was hastily deployed to extend the domestic PV market in China. The project's quality supervision and project acceptance were entrusted to a private company. However, this company colluded with project developers to defraud state financial subsidies by issuing false audit reports and illegally profited CNY 25.78 million[98] from the scheme.

176. The Chinese experience indicates that to develop a strong 'project industry' to meet the rapid development of PV, it is required to (a) rely on and support SMEs by introducing policies such as 'policy opinions on encouraging and promoting the development of small and medium-sized enterprises' (2009) and 'policies on supporting the technological innovation' (2013) and (b) attract well-established state-owned energy enterprises to implement gigawatt utility-scale projects to strengthen the implementation capacity in the sector.

98 Source: National Audit Office

# Chapter 8. Hydropower

**Key Messages**

After 70 years of development, China became a world leader in hydropower development. By the end of 2019, China had built more than 22,000 hydropower stations (over 500 kW). The total installed capacity had reached 350 GW and the power generation 1,300 TWh, which accounted for 65 percent of total RE power generation and 18 percent of the total power generation.

Currently, China's hydropower equipment manufacturing capability is widely recognized. China mastered the manufacturing of the 700 MW single turbine during the development of the Three Gorges Project (1994–2010) and the 1 GW single turbine in the under-construction Baihetan Hydropower Station (2013–2022). By the end of 2019, Chinese enterprises had participated in 406 international hydropower projects, amounting to 127 GW of installed capacity, and China has established cooperative relations in this areas with more than 80 countries.

China's hydropower development was and is still driven by the government through mammoth SOEs that were awarded the development of river basins plans in consecutive FYPs. It went through three distinctive periods:

(a) The first covers the development before the open-door policy (1949–1977) and focused mainly on small hydropower to meet the needs of a dominantly rural population. During the 1950s and 1960s, with the assistance of the Soviet Union, China began to develop relatively larger projects, increase quality and size of turbines, and develop national institutes. The progress made during this period was disrupted by the Cultural Revolution.

(b) The second period covers more than two decades (1978–2000) and is characterized by the opening of China to the world and the development of large hydropower projects with international financing. The advent of the open-door policy provided cooperation opportunities to learn from advanced countries and build state-of-the-art projects. The buildup of the industry focused on the following:

- Revising the hydropower development plan for the market to reach a critical mass conducive to the development of domestic manufacturing. By the end of the 1980s, the average annual production of hydraulic turbines had increased to 2 GW and China had the ability to design and produce 300–320 MW hydraulic turbines.
- Launching the 'Twelve Hydropower Bases' program in October 1989, which included a comprehensive resource assessment and preparatory work for the development of 12 of the major rivers in the country. This led to the installation of about 210 GW, generating about 994 TWh per year.
- Commercializing and corporatizing the hydropower engineering bureaus into enterprises, following the issuance of the first Company Law in 1994. This facilitated access to equity and debt financing and attracted and motivated skilled workers by offering higher salaries than those of civil servants.

- Mastering technologies through international cooperation by building upon the success of the Lubuge Hydropower Station (see Chapter 2, Box 2.1). China began allowing the import of advanced equipment for large-scale projects. Many of the winning international bidders subcontracted manufacturing of some parts to Chinese companies to reduce cost. Subcontractors were introduced to international advanced manufacturing standards and quality assurance protocols.

- Accumulating knowledge about pumped storage through demonstration projects to increase the flexibility of the systems to meet peak loads, enabling to accommodate more variable renewable energy with the surge of wind generation capacity.

(c) The third period covers the last two decades (2001–2021). During this period, the government took several initiatives to enable Chinese hydropower manufacturers and developers to compete in the thriving global market, including

- Organizing technical meetings and conferences,

- Participating in the formulation of international standards, and

- Carrying out hydropower resource assessments and development plans for other countries within regional and international associations.

During this period, China's hydropower manufacturing capacity continued to progress including building the capability to manufacture 1 GW hydraulic turbines and 350–400 MW pumped storage units fit for the development of 500-meter-level-head stations.

However, as experienced earlier in developed countries, China’s domestic hydropower manufacturing industry quickly faced underutilized capacity issues. In 2018, its manufacturing capacity was over 30 GW, but its production was limited to 7.6 GW as domestic and international demand significantly decreased.

While it can be argued that China’s experience in developing a world-class large turbine and large hydropower plant industries can only be replicated in other large developing countries, the following lessons are still worth considering in smaller countries:

- Creating a framework for the environmentally sustainable development of hydropower and building strong teams to integrate knowledge transfer related to manufacturing of advanced equipment can lead to accelerated industry growth.

- Assessment of resources, inventory of potential sites, and sound development planning are essential for sound hydropower development. They allow ranking of potential sites and channeling limited financial resources toward high-return investments with limited environmental and social impacts. This increases the confidence of investors in securing adequate returns and allays worries about financial and environmental and social risks.

Environmental protection can bring additional benefits to hydropower development. While slightly increasing investment costs, safeguarding the biodiversity around the reservoir and avoiding the blockage or delay of upstream fish migration routes can contribute to developing tourism and fishery activities to benefit the local population.

177. After 70 years of development, China became a world leader in hydropower development with strong engineering and manufacturing capabilities. Since 1950s', China promoted the hydropower development through the establishment of specific purposed funds. Since the reform and opening up, through the power system reform, a market based project development model, with more diversified stakeholder and financing sources, has been gradually established. It went through three distinctive stages:

- The first stage covers from 1949 to 1977. Before the open door policy, China's hydropower industry was developed mainly to meet the needs of a dominantly rural population and suffered from rudimentary technology and equipment.

- The second stage covers the two decades following the open door policy from 1978 to 2000. In the first half of the 1980s, China developed Yunnan Lubuge project with World Bank financing, which adopted international competitive bidding for the first time in China. The project triggered the so called "Lubuge wave". As a result, many other hydropower projects, such as Guangxu, Yantan, Manwan, Geheyan, and Shuikou were developed following the Lubuge model. Adopting the new systems and operating mechanisms, people noticed that contract management improved, quality was enhanced, and cost went down. Hydropower development embarked then on a fast track journey. The development of various type of hydropower project also promoted the development of dam construction and equipment manufacturing technology.

- The third stage, covering from 2001 to present, is highlighted by the construction and operation of the Three Gorges Project. China has by now entered the stage of innovation independence and global recognition of its place as a first-class hydropower country. During this period, in addition to advancing the technology of equipment and civil engineering, China has paid more and more attention to environment and social protection, aiming at coordinated economic and social development. In the last ten years, China has vigorously promoted the ecological environment protection and the clean-up and reform of small hydropower in the Yangtze River Basin, and is currently further promoting the construction of pumped storage power stations to accommodate the high penetration of variable renewable energy such as wind and PV. This would lead to a synchronized development of various type of generation sources, including thermal, hydro, nuclear, wind, and PV.

## A. The Achievement of the Hydropower Industry

178. By the end of 2019, China had built more than 22,000 hydropower stations (over 500 kW). The total installed hydropower capacity was 356GW, and the power generation was 1153.4TWh, accounting for 58.3% of the total renewable energy power generation and 16.1% of the total energy power generation. The annual added capacity grew to as high as 30 GW in 2013, accounting for 27 percent of the total added capacity, then dropped to 3.8 GW in 2019 due to various factors such as more remote geographic locations and less favorable resources conditions. In addition, the requirements for resettlement and ecological environmental protection have been continuously enhanced, which resulted in an increase of the investment cost and risks. Hydraulic turbine manufacturing capacity grew from 0.5 MW in 1950s to 1 GW in 2018.

- **China acquired world-class dam engineering and technology ability.** By the end of 2019, China had developed 23 dams with a height of more than 200 meters, out of which 10 dams with a height of more than 250 meters . Those dams include the world's highest Arch Dam (Jinping, 305 m), the Earth-Rock Dam (Shuibuya, 233 m)and the world's second highest RCC Gravity dam

(Huangdeng,203m). It has also made remarkable achievements in underground engineering, flood discharge, slope treatment, and earthquake prevention and resistance.

- **China achieved remarkable progress in hydropower equipment manufacturing.** It mastered the manufacturing of the 700 MW single turbine during the development of the Three Gorges Project (1994 to 2010), the 800 MW single turbine during the development of the Xiangjiaba Hydropower Station (2008 to 2015), and the 1 GW single turbine in the under-construction Baihetan Hydropower Station (2013 to 2022). Currently, China's hydropower equipment manufacturing capability is widely recognized.

- **China's pumped storage power station technology developed rapidly.** Based on the advanced technical capacity of conventional hydropower and strong international support in the 1990s, pumped storage caught up with most advanced countries in a short time.

- **China's hydropower became internationally competitive.** By the end of 2019, Chinese enterprises had participated in 406 international hydropower cooperation projects, amounting to 127 GW of installed capacity. More than 80 countries have established long-term cooperative relations with China in hydropower planning, construction, and investment.

## B. The Reconstruction (1949–1977)

179. The early years of the new China were plagued by electricity shortages because its main hydropower stations were destroyed by the successive wars the country endured. By 1949, China had only 21 dams higher than 30 m, the total hydropower installed capacity was 540 MW, and the size of the largest turbine was 750 kW.[99] The Electric Power Conference held in 1950 acknowledged that hydropower development started late, at a small scale, and suffered from low technical level and rudimentary equipment. At the time, the country was an autarky facing an international economic blockade and had no manufacturing capability to develop its hydropower resources.

180. To develop domestic hydropower construction capabilities, China deployed the following efforts:

- During the 1950s, China established several hydropower project design institutes, engineering bureaus, and scientific research institutes.

- From 1950 to 1956, China conducted a general assessment of water resources and planned the hydropower development of major rivers. These plans guided the orderly development of large hydropower in China. Most of the famous hydropower projects, such as Three Gorges, were preliminarily planned at this stage.

- From 1950 to 1953, China repaired and reconstructed existing hydropower stations to mitigate power shortages and provide on-the-job training for hydropower construction teams.

- Beginning in 1957, China began the development of new hydropower stations featuring domestic design, equipment, and construction.

99 Yuanfang, Huang. 2014. "Who Is the First Designer of Hydraulic Turbine in China." Energy News. http://www.cnenergynews.cn/lslm/ztbd/201412/t20141230_2325.html.

181. To develop its large hydropower station during the early years of this stage, China imported the major equipment mainly from the Soviet Union. The imports were paired with cooperative efforts to develop China’s hydropower design, construction, and manufacturing capabilities:

- Several public companies at different administrative levels were established to manufacture small turbines (from 0.5 to 5 MW) that in most cases did not meet international standards but met the requirements of rural electrification efforts.

- During the 1950s, the Soviet Union provided hydraulic design drawings along with the equipment to develop the hydropower project. At the same time, the Soviet Union supported China’s efforts to master the design, equipment manufacturing, installation, and operation of modern hydropower power plants. This resulted in the domestic manufacturing of larger-size turbines installed in the Xin'anjiang (662.5 MW) and Yunfeng (400 MW) hydropower stations in the early 1960s.

- By the 1970s, China had mastered the manufacturing of 100 MW turbines and managed to meet the needs of larger projects initiated during the decade. However, some of these turbines had quality problems during operation, and some could not meet the rated capacity.

182. During the 1950s and 1960s, China gradually mastered hydropower know-how to develop at a larger scale: (a) domestic manufacturers improved the quality and increased the size of turbines; (b) institutes and utilities improved their design and planning activities; and (c) construction companies acquired skills to manage large projects and got acquainted with industry standards. However, the cessation of the Soviet Union’s support and the Cultural Revolution disrupted the progress achieved and hydropower development regressed during 1970s. Design and research institutions were abolished, leading to the development of projects at low administrative levels without adequate hydrologic surveys and ill-managed construction sites. This chaotic management model resulted in extensive delays and cost overruns that drastically reduced the economic and financial benefits of the projects.

## C. Learning and Catching Up with Hydropower Leaders (1978–2000)

183. At the start of this stage, China’s hydropower installed capacity was 18 GW and the number of dams over 30 m had increased to 3,600, but the hydropower industry was still reeling under the disruption experienced during the Cultural Revolution and constrained by inadequate planning, subpar technologies, and low equipment quality. The reforms of the early 1980s opened cooperation opportunities to learn from advanced countries as they had already developed their own domestic resources by that time. China took advantage of these opportunities to elevate its hydropower development back on a solid and scientific base through the following:

- **Rebuilding hydropower R&D system.** Beginning in 1978, China began reestablishing hydropower research and design institutions to enforce government regulations, carry out proper evaluation of hydrologic resources, and supervise construction. These efforts were especially focused on rebuilding hydropower R&D institutions to improve domestic hydropower design and equipment manufacturing.

- **Extending the market to reach a critical mass conducive to the development of domestic manufacturing.** The national hydropower development plan was revised in 1980 to put China’s hydropower industry on the development fast track. The small hydropower market expanded owing to pilot and demonstration programs intended to increase electricity access in rural areas.

In the 1980s, the average annual production of hydraulic turbines was nearly 2 GW. This increased market size encouraged domestic manufacturers to produce new, higher-quality products to meet developers' needs. By the end of the 1980s, China had the ability to design and produce 300–320 MW hydraulic turbines, 6-meter-diameter runners, and other advanced manufacturing processes.[100]

- **Making an ambitious planning for hydropower development.** In October 1989, the planning of 'Twelve hydropower bases' was carried out under the leadership of the former Ministry of Electric Power. Comprehensive resource assessment and development planning were undertaken for a series of large-scale hydropower bases in the upper reaches of the Yellow River, Nanpanjiang River, Hongshui River, Jinsha River, Yabijiang River, Dadu River, Wujiang River, upper reaches of the Yangtze River (including Qingjiang River), middle reaches of the Lancang River, Western Hunan and Fujian, Zhejiang, Jiangxi, Northeast China, and north main stream of the middle reaches of the Yellow River. Currently, the total installed capacity of these 12 hydropower bases is about 210 GW and their annual power generation is about 994 TWh.

- **Promoting a modern enterprise system.** Following the issuance of the first Company Law in 1994, hydropower engineering bureaus were transformed into engineering companies, and project owners were allowed to establish development companies. The new system entrusted the private sector with the development of projects according to industry standards and enabled standardized operation of hydropower projects in accordance with company requirements and government regulations. This improved the overall quality of projects, facilitated access to equity and debt financing, and attracted and motivated skilled workers with sector salaries that were higher than those of civil servants.

- **Mastering technologies through international cooperation.** Building upon the success of the Lubuge Hydropower Station (see Chapter 2, Box 2.1), China began allowing the import of advanced equipment for large-scale projects. Chinese teams gained essential experience and expertise in design and construction management. More importantly, taking advantage of China's heavy industry strength and low cost, many of the winning bidders subcontracted manufacturing of some parts to Chinese companies to reduce cost. Subcontractors were introduced to international advanced manufacturing standards and quality assurance protocols. Subcontractors were introduced to advanced international manufacturing standards and quality assurance protocols. The knowledge accumulated through these experiences helped China develop domestic design and manufacturing capacity in line with international hydropower equipment standards.

**Box 8.1: 700 MW Hydraulic Turbines Manufacturing Progress through the Three Georges Project**

The construction of the Three Georges Project was divided in two stages with the installation of 26 x700MW turbines on the left and right banks. In 1996, the China Three Gorges Corporation, called for bids for 14 turbines on the left bank. A total of 22 manufacturers from nine countries offered bids. Two consortiums won the bids for the provision of eight and six turbines, respectively.

To reduce the cost of manufacturing and fulfill bidding requirements, Chinese manufacturers were involved in the manufacturing of the first 14 turbines, which were predominately manufactured by international companies with a local content of less than 20 percent. In about seven years, Chinese companies' contribution had jumped to about 70 percent in the manufacturing of the two last units.

100 Xilin, Sha. 1991. "China's Hydropower quipment Development Achievement and Outlook." Hydropower 10: 57–60.

In 2003, when the China Yangtze Power company called for the second international bids for 12 turbines to be installed on of the right bank of the power station, Chinese manufacturers were awarded contracts to supply 8 units and a French manufacturer was awarded a contract to supply 4 units. When all the 12 turbines were put into operation in 2008, performance of the turbines made in China reached the same level as abroad.

The experience gained during the joint manufacturing of the first 14 units allowed Chinese companies to get acquainted with advanced industry standards, integrate modern machinery and other heavy equipment, and import advanced control software to upgrade their manufacturing plants to industry specifications. Moreover, Chinese manufacturers developed the competencies to independently design and manufacture extra-large turbines. It took less than 10 years for Chinese teams to make up for a 30-year technological lag as noted by Li Jugen in "China Hydropower Development and Equipment Technology Innovation." (see Hydropower Automation and Dam Monitoring, 2011, Vol. 35 (No. 3) page 1–4).

- **Accumulating knowledge about pumped storage through demonstration projects.** During the late 1980s and 1990s, China's power sector development was mainly based on coal-fired power plants, most lacking the flexibility to follow load fluctuations. The government allowed public power companies to undertake more than 10 pumped storage projects to improve and optimize the operation of provincial power systems. By the end of the 1990s, the total installed capacity of pumped storage power station reached 5,600 MW. Several of these projects were built with imported equipment and introduced Chinese utilities to anti-seepage measures during the construction of the reservoirs. Utilities and subcontractors also gained knowledge of advanced engineering, construction and operation of pumped storage, and the installation of pumped storage power stations.

## D. Access to Leadership Status (2001 to Present)

184. At the beginning of this stage, abundant domestic opportunities were generated by the power sector reform. The separation of generation and transmission and distribution introduced competition on both the generation side and the distribution side. The reform opened the power generation market to non-utility power generation companies. This generated a great investment opportunities to domestic hydropower development companies. However, the following issues restricted the further development of China's hydropower industry:

- **The lack of acknowledgement from the global market.** While Chinese manufacturers had overcome the major technical and managerial issues, their lack of familiarity with the process and requirements of the global market restricted their competitiveness and hindered their ability to export. Hydropower unit manufacturers realized that optimal use of their vast production capacity would require entering the highly competitive international markets.

- **Irrational planning.** Because of delays, the government's river basin development plan did not played its due guiding role. In addition, local governments did not properly follow the standards applicable to hydropower projects construction and operation, which caused serious negative impacts on environments. (See Box 8.2).

**Box 8.2: Case Study of Disorderly development of Small Hydropower Plants Upstream the Ledong River**

During 2003–2007, 10 small hydropower plants were built upstream of the 29-km-long Ledong River in Jiangxi following a poorly prepared river basin development plan. The ecological flow was not secured as required by the standards and downstream water flow was interrupted.

The roots causes of this mismanagement were the lagging planning of river basins and the poor management by local governments. The plan for the Zhangjiang River basin, which the Ledong River belongs to, was formulated in 1985 and had not been updated. In 2010, Jiangxi Province launched the revision of the Zhangjiang River Basin Planning but had not yet completed it at the end of 2018. The lagging planning paired with the approval of a single power plant based on maximum economic benefit led to the disorderly and chaotic development of small hydropower plants.

185. The government then undertook several initiatives to allow Chinese hydropower manufacturers and developers to compete in the thriving global market by

- **Participating in the formulation of international standards.** In 2002, China held the IEC/TC4 (hydraulic turbine committee) plenary meeting in Beijing to announce China's intention to embrace international hydropower standards and participate in their formulation. By the end of 2015, China's experts had participated in 10 IEC/TC4 working groups and led 1 working group to share Chinese standard-setting hydropower experience; and

- **Carrying out hydropower resource assessments and development plans for other countries.** Within the Association of Southeast Asian Nations (ASEAN) and other international organizations framework, China began exporting accumulated know-how by carrying out a series of preliminary hydropower development work plans for Myanmar, Pakistan, and other countries. China advocated and promoted coordinated regional development and comprehensive planning for transboundary rivers. These activities provided opportunities for Chinese hydropower companies to develop international project management and equipment export experience.

186. To increase environmental awareness and integrate stricter environmental assessment and mitigation measures during the preparation and implementation of hydropower projects, the government promoted the following initiatives:

- Since the early 2000s, several vegetation restoration and soil and water conservation studies were initiated and taken into account in the subsequent construction of large-scale hydropower stations.

- The China Institute of Water Resources and Hydropower Research (CIWRHR) began technical research on impacts of dam construction on fish migration in 2011. The first dam, taking into account fish migration requirements to protect 16 kinds of rare species, was built in 2014 and fish migration has been considered in subsequent dam projects.

- The 13th hydropower development FYP (2016–2020) strictly limited the further development of medium and small hydropower stations to retain the necessary habitats of the river basin and ensure the ecological health of the river basin.

- In 2018, the Ministry of Water Resources, NDRC, the Ministry of Ecology and Environment, and NEA jointly deployed the clean-up and rectification of the Yangtze River Economic Belt. The clean-up and rectification of 25,000 power stations was completed. The ecological flow of all power stations was restored, the development intensity was greatly reduced the integrity of the natural ecosystem was better taken into account, and river connectivity and water resources conditions were improved.

187. At the same time, building upon the momentum of the last development stage, China's hydropower manufacturing technology continued to progress and improve. Two of the largest Chinese companies built the capability to manufacture 1 GW hydraulic turbines. Manufacturing has also been mastered for other equipment such as 350 to 400 MW pumped storage units fit for the development of 500-meter-level-head stations. China's dam engineering and technology performance, acquired during the construction of more than 100,000 dams, has also gained wide recognition.

188. However, as experienced earlier in developed countries, China's domestic hydropower industry quickly faced issues stemming from unutilized capacity. In 2018, its manufacturing capacity was over 30 GW, but its production was limited to 7.6 GW as domestic and international demand significantly decreased.[101] The planned development rate of major rivers in China exceeded 80 percent and the development of small hydropower had slowed to a near standstill. The development of the global hydropower market also tapered.

## E. Lessons Learned

189. While it can be argued that China's experience in developing a world-class large turbine and large hydropower plant industries cannot be replicated in smaller developing countries, it can be relevant to large middle-income countries such as Brazil, India, and Indonesia. Lessons learned during the last 30 years regarding the development of domestic hydropower resources are worth considering in the latter countries and regional markets with large untapped potential:

- **Developing noncore technology and promoting subcontracting in the early stages of industry development can increase domestic or regional experience and create opportunities to make up for technological lag in a short time.** Creating a framework for the environmentally sustainable development of hydropower and building strong teams to integrate knowledge transfer related to manufacturing of advanced equipment can lead to accelerated industry growth. China not only managed to fill the technological gap in a relatively short time but also laid the foundation for further innovation and technological development.

- **Environmental and biodiversity protection can bring additional benefits to hydropower development.** Although environment and biodiversity protection measures can slightly increase investment costs, they greatly increase the ecological benefits of hydropower stations. For example, safeguarding the biodiversity around the reservoir and avoiding the blockage or delay of upstream fish migration routes can contribute to developing tourism and fishery activities to benefit the local population as experienced in many Chinese hydropower projects.

- **Assessment of resources, inventory of potential sites, and sound development planning are essential for sound hydropower development.** They allow ranking of potential sites and channeling limited financial resources toward high-return investments with limited environmental and social

101 Source: China Society for Hydropower and China Electricity Council

impacts. The latter is important for attracting government as well as private investments as they significantly increase the confidence of investors in securing adequate returns and allay worries about financial and environmental and social risks relating to the development of hydropower projects.

# Chapter 9. The Biomass Energy Industry

**Key Messages**

China's biomass energy industry started in the 1950s. After 70 years, it has become a global leader covering biomass and MSW incineration for power generation, biogas, bioethanol, and biodiesel.

- The total installed capacity of biomass power grew from about 2 GW in 2005 to about 22.5 GW in 2019, amounting to about 17 percent of the global installed capacity.
- Biogas production amounted in 2018 to about 19 billion m$^3$, also domestically produced.
- Ethanol consumption amounted to about 3.4 million tons, 2.8 million tons produced in China and 600,000 tons imported.
- Biodiesel production amounted in 2018 to about 680,000 tons, of which 320,000 tons was exported. China ranked 10th in biodiesel production in the world.

Production however remains limited in relative terms compared to fossil fuels alternatives that biomass is supposed to displace. It accounted for 6 percent of total power generation, 3.7 percent in total gas production, and 1.4 percent in total automotive fuels.

The industry developed over three periods, progressively building a complete vertical industrial chain from R&D to equipment manufacturing and project implementation.

The first period (up to 1994) was dedicated to developing biogas equipment, with mixed success, to meet energy demand in rural areas. Pilot demonstrations of biogas digesters in China experienced setbacks at every step due to the lack of a qualified workforce and management skills to meet the extensive needs of the household biogas programs launched by the government during this period. To address the biogas industry shortcomings and promote MSW incineration, the government launched several large and medium biogas projects:

- **Biogas.** In 1964, it undertook a first 2,000 m$^3$ industrial biogas project in Nanyang, Henan Province, to produce biogas from residues and wastewater in the distilleries, followed by increasingly larger projects, up to 12,000 m$^3$ in 1980, with the installation of a 30,000 m$^3$ storage tank to increase the reliability of supply. The experience was replicated in many provinces. In 1988, the China Biogas Association was established to help integrate new key anaerobic digestion progress achieved abroad and rebuild the population's trust in biogas.
- **MSW power.** In 1982, China launched its first MSW project in Sichuan Province to process 30 tons of waste per day. A few years later, it imported a waste incineration equipment with a capacity of 150 tons per day that was installed in Shenzhen in 1988. The experience accumulated during the implementation of this project laid the foundation for developing a local R&D capability in China.

By the end of this stage, China's R&D was still weak and the industry was suffering from the lack of a skilled equipment manufacturing, engineering, and construction workforce.

The second stage, the experimental and demonstration stage (1995–2005), focused mainly on R&D, to reinforce and widen the industrial biomass energy knowledge base and attract high-caliber technical and management talents:

- **Biogas.** The government relied on international cooperation, in particular with UNDP/GEF support, and imported state-of-the art equipment from advanced countries, in particular from Germany. During this period, China began to address digesters quality issues. It adopted four standards relating to household biogas projects, including biogas pipeline, biogas tank, acceptance checklist of biogas digesters, and operating instructions.
- **Bioethanol.** In 2000, China launched its first project using grains as raw material to produce bioethanol. From June 2002 to June 2003, ethanol gasoline was piloted in three cities in Henan Province and two cities in Heilongjiang Province. In February 2004, the scope of the pilot was expanded to 27 cities and cities in nine provinces.
- **Biomass power.** In 2004, the first three biomass power generation projects, around 25 MW each, were launched in three different provinces, one using imported equipment and two domestic equipment. The government also initiated international cooperation programs with more advanced countries and multilateral institutions to increase the number and improve the skills of technology professionals, the Chinese government/World Bank/GEF CRESP I being one of these (see paragraph 54).
- **MSW incineration power.** This still remained at the demonstration stage during this period, with two notable projects, one with a daily treatment capacity of 160 tons commissioned in 2001 in Wenzhou Dongzhuang, using a domestic equipment, and one larger with a daily treatment capacity of 3 × 365 tons per day, the first large-scale incineration power plant project in China, commissioned in September 2002 in in the Pudong New Area (Shanghai Municipality).
- **Biodiesel.** In 2001, Hainan Zhenghe bioenergy Co. Ltd. established the first biodiesel experimental plant in Handan, Hebei Province, using recovered waste oil from kitchens as raw materials. In 2004, the MoST launched the 'Biofuel Oil Technology Development' project and the NDRC launched the 'key technologies for saving and replacing oil' project, including 'biodiesel production and process control at industrial scale', aiming to overcome the main barriers for biodiesel production.

In the third stage (2006 to present), China experienced an unprecedented boom in local biomass industries; this phase was characterized by the development and enforcement standards of a series modern industry standards. Still, China continues to face many technical hurdles and is struggling to meet the growing demand of biomass energy.

To meet the challenges encountered in the first two phases of the industry's growth, the government undertook several demonstration programs:

- **Biogas.** In 2008, the MoST launched the ‘Research on high-efficiency and large-scale biogas engineering’ project to promote anaerobic digestion technology, engineering equipment, and biogas slurry treatment technology. The government also supported joint ventures between Chinese and foreign companies to develop demonstration projects and engaged in several cooperation programs with more advanced countries such as Sweden and Germany. The objective was to enable a more market-oriented business environment, with an increasing industrial standards basis, but still supported with subsidies. This also included a series of demonstration projects on key technologies. By 2019, more than 95 standards had been formulated.

- **Biomass power.** On July 28, 2009, the Shandong Biomass Direct Fired Power Engineering Technology Center was established to eventually become the R&D reference base to the Chinese biomass power sector. During the 12th and 13th FYPs, the MoST launched numerous projects to “test and demonstrate advanced biomass power generation technology.” On January 19, 2018, the NEA announced the implementation of biomass cogeneration in 100 towns, whose main purpose is to promote clean heating. By 2019, three straw power generation standards were developed.

- **MSW incineration power.** In 2006 and 2008, Zhejiang and Tsinghua University developed three different types of circulating fluidized bed (CFB) incinerators. These incinerators have been installed in more than 60 MSW incineration power projects. Chinese companies also purchased licenses from more advanced countries, in particular Japan and Germany. These license acquisitions enabled substantial improvement of waste combustion and promoted biomass power generation technology in China. By 2019, eight industry standards were formulated for waste incineration power generation.

- **Bioethanol.** During this phase, R&D focused on non-grain ethanol. In 2006, the first domestic bioethanol factory was commissioned, with an annual output of 200,000 tons. In February 2009, Sinopec Group, COFCO Group, and Danish Novozyme signed a cooperation agreement to jointly develop crop waste-based second generation of bioethanol using corn straw. In May 2008, the first industrial trial production line of domestic cellulose ethanol was constructed by the Henan Tianguan Group. On July 23, 2010, the NEA approved the establishment of the National Energy Research and Development (Experiment) Center, established by COFCO and dedicated to the development of non-grain ethanol, particularly from cellulose. During the 14th FYP (2016–2020), the MoST launched the ‘solid waste recycling’ project dedicated to R&D of cellulose to ethanol. By 2019, 20 ethanol standards were formulated.

- **Biodiesel.** During the 12th FYP, the MoST supported demonstration projects to develop manufacturing of key equipment and the cultivation of new energy algae. The MoST followed up during the 13th FYP with similar projects to support ‘Clean Production and Efficient Separation of Biomass Liquid Fuels’. In 2018, 2019, and 2020, the MoST launched the ‘Solid Waste Recycling’ project dedicated to R&D of ‘straw to gasoline’ and ‘straw to diesel’ transformations. By 2019, more than 15 standards for biodiesel were developed but none are yet approved nationally.

Through the abovementioned measures, China built a strong knowledge base in diverse biomass technologies and an important industrial base to deploy biomass at a larger scale.

- The efficiency of biomass power and MSW generation continues to improve, from 24.5 percent in 2005 to 33 percent in 2018, but still lower than Danish 42 percent.

- Biogas production technology also greatly improved but still trailed behind most advanced countries in terms of size.

- Bioethanol technology greatly progressed regarding both first generation, using corn as the raw material, and the 1.5 generation bioethanol technology, using cassava as the raw material. However, China still did not catch up with advanced countries regarding the second generation of bioethanol technology, using crop straw as raw material, still remaining at the demonstration phase.

- Biodiesel technology caught up with advanced nations. Chinese market players developed patents with independent intellectual property rights, which make them more competitive globally. In 2018, 1 million tons of biodiesel was produced, roughly 17 percent of 1.8 billion gallons (about 5.8 million tons) produced by the United States.

The lessons learned include, but are not limited to, the following: (a) supporting technology R&D and standard setting is an important factor for biomass development as early Chinese projects suffered from their absence; (b) biomass raw materials, including a variety of organic wastes, vary extensively from country to country and the development of biomass needs to be adapted to local conditions; (c) the government-driven approach that led to a recognized success in the deployment of wind power was not appropriate for deployment of biomass power technologies—national agencies set up ambitious targets and high feed-in tariffs as for other priority RE sources, but biomass was the only technology that did not achieve the objectives set by the government; (d) explicit support for non-power utilization of biomass energy should not be neglected in RE laws and regulations; and (e) adequate and reliable supply chain is a prerequisite to successful deployment of all biomass technologies. Deployment of projects and/or programs, especially those based on agricultural and forest residues, requires clear long-term legal arrangement between communities and concerned government agencies to develop reliable fuel supply chains.

190. The development of China's biomass energy industry started in the 1950s. After 70 years of development, it has become a global leader covering biomass and MSW incineration power, biogas, bioethanol, and biodiesel. It has developed a complete vertical industrial chain from R&D to equipment manufacturing and project implementation. The biomass energy industry growth has experienced three stages of growth. The first stage (up to 1994) was dedicated to developing biogas equipment, with mixed success, to meet energy demand in rural areas. The second stage, known as the experimental and demonstration stage or diversification (1995–2005), focused mainly on R&D and improving the quality of the budding industry's product quality, namely biogas, bioethanol, biomass, and MSW power. In the third stage (2006 to present), China experienced an unprecedented boom in local biomass industries as technology improved, and standards were implemented to modernize the industry and contribute to furthering the rapid growth of biomass technologies to catch up with most advanced countries.

## A. The Achievements of the Biomass Energy Industry

191. Following the issuance of the Renewable Energy Law in 2005, China made significant progress in developing biomass energy. The total installed capacity of biomass power grew from about 2 GW in 2005 to about 22.5 GW in 2019, amounting to about 17 percent of the global installed capacity. It included about 12 GW of MSW power, about 9.7 GW straw-fired power, and 0.8 GW biogas power. Power generation grew

from 5.2 TWh to 111 TWh. Furthermore, by 2018, the consumption of (a) biomass briquette amounted to about 15 million tons, all domestically produced; (b) biogas amounted to about 19 billion $m^3$, also domestically produced; (c) ethanol amounted to about 3.4 million tons, with 2.8 million tons produced in China and 600,000 tons imported from abroad; and (d) biodiesel amounted to about 680,000 tons domestically produced with 320,000 tons of excess production exported. China ranked 10th in production in the world. Despite these achievements, modern biomass accounted for a small share of China's 2018 energy matrix: 1.6 percent of total power generation, 3.7 percent in total gas production, and 1.4 percent in total automotive fuels.

192. China's biomass energy industry made significant progress in the following:

- **Increasing the number of biomass energy enterprises:** The number of biomass energy enterprises grew from 60 in 2005 to more than 600 in 2018, covering the entire industry supply chain including R&D, manufacture, and project construction and maintenance.

- **Improving the knowledge and technological base of the industry.** China has achieved great progress in biogas engineering, straw-based direct combustion power generation, waste incineration power generation, and biodiesel production. The number of patents grew from 1,388 in 2006 to 49,401 in 2018.

193. These achievements are the result of a gradual and pragmatic approach characterized by extensive testing and knowledge transfer from developed countries during the early stages, and localization and quality improvement through increased R&D, and establishment of standards and certification processes in later stages.

## B. The Early Years (up to 1994)

194. At this stage, the global biomass energy industry developed rapidly. Germany was leading the pack in biogas production, Denmark excelled in biomass power generation and biomass heating, Japan was proficient in MSW power generation, and Brazil and the United States both boasted strong bioethanol industries. China's biomass energy, meanwhile, was mainly limited to the development and utilization of biogas for rural areas and lagged behind the aforementioned countries in other areas of bioenergy, biomass technology, R&D capacity, the availability of a skilled workforce, and experience with developing and operating large-scale projects.

195. Rural household biogas construction had undergone a particularly tortuous development path since the 1950s. Pilot demonstrations of biogas digesters experienced setbacks at every step due to the lack of a qualified workforce and management core to meet the extensive needs of the household biogas programs launched by the government during this period. Based on government requirements, local communities and even individual families installed rudimentary and hastily designed biogas digesters with the support of a few technicians. Less than satisfactory results led to distrust of the technology by the rural population.

196. To address these problems, the government undertook the following measures to promote the development and improve the quality of the local biomass energy industry:

**Biogas**

- Large and medium biogas projects were revived in 1964 by undertaking a 2,000 $m^3$ industrial biogas project in Nanyang, Henan Province, to produce biogas from residues and wastewater in the distilleries.

- In 1980, two more 5,000 $m^3$ biogas projects were commissioned and their capacity was later increased to 12,000 $m^3$. A 30,000 $m^3$ storage tank was installed to increase the reliability of supply. During the 1980s, many alcohol-, sugar-, and food-processing factories and animal husbandry farms across the country emulated this experience and built large and medium biogas digesters during the 1980s.

- In 1988, the China Biogas Association was established to unify more than 1,700 biogas technologists to carry out collaborative research on biogas digesters, carry out large-scale technological research, and integrate new key anaerobic digestion progress achieved abroad to rebuild the population's trust in biogas and initiate a period of sustained development.

**MSW Incineration Power**

- In 1982, China launched its first MSW project, the Lingyun waste incineration power project, in Leshan City, Sichuan Province. The project, commissioned in February 1982, processed 30 tons of waste per day, far behind the average capacity of Japanese MSW projects, which amounted to about 150 tons per day in 1980.[102]

- In 1988, the Shenzhen Qingshuihe waste incineration power project in Guangdong Province was commissioned. The project purchased two sets of waste incineration equipment with a capacity of 150 tons per day manufactured by Mitsubishi Heavy Industry of Japan. The project was the key scientific and technological research undertaken during the 8th FYP (1991–1995). Based on the experience gained during the implementation of this project, China began to do research and study MSW incineration equipment, laying the foundation for developing a local R&D capability in China.

197. By the end of this stage, China has implemented several large-scale biogas projects and MSW incineration power generation projects, which laid the foundation for the development of the ensuing stages. Main achievements include the following:

- Biogas. The country accumulated significant experience in construction and operation of large-scale projects, especially large-scale biogas anaerobic digesters.

- MSW power. Construction and operation experience about MSW incineration power projects was accumulated; particularly the research and study on the MSW incineration boilers were made, benefitting the localization of the boilers.

## C. The Diversification Stage (1995–2005)

198. While China gained some experience during the first stage, by the mid-1990s its biomass energy industry was still lagging far behind the leading countries like Denmark, Germany, Japan, Brazil, Sweden, the

102 https://www.sohu.com/a/286460971_120047582

Netherland, and the United States. It lacked the technical knowledge, industrial infrastructure, and human resources to build a competitive industry mostly due to the following:

- Weak R&D and lack of a skilled equipment manufacturing, engineering, and construction workforce.
- The absence of quality standards and certification systems leading to spotty quality of equipment, engineering, and products.
- Most of the bioenergy projects that have been built in China were developed with rudimentary technology, low-efficiency equipment, and unskilled workers. This led to low return on investments and high operational cost, which limited biomass development in a sustainable way.
- The bad, sometimes dismal, financial situations of the biomass energy enterprises, largely established at low administrative levels, did not allow them access equity or debt financing to introduce more advanced foreign technologies and upgrade the quality of their products.

199. To address these issues, the government took measures and launched many programs to improve R&D, reinforce and widen the industrial biomass energy base, and attract high-caliber technical and management talents:

**Biogas**

- In 1999, the Hangzhou Dengta Pig Farm Biogas Project (Zhejiang Province), a UNDP/GEF demonstration project, was commissioned. It adopted Up-flow Anaerobic Sludge Bed (UASB) with anaerobic fermentation at normal temperature and produced on average 8,500 $m^3$ per day of biogas. The chemical oxygen demand (COD) concentration reached 10,000 mg per liter and the overall removal efficiency of COD reached about 85 percent, matching efficiencies reached in more developed countries. It was the first biogas project that adopted the LIPP[103] anaerobic digester from Germany.
- In 2001, the Shunyi pig farm biogas project (Beijing Municipality) was built with the support of UNDP/GEF to test large-scale biogas projects.
- In 2003, the Qingdao alcohol waste liquid biogas project (Shandong Province) was developed to introduce and test advanced technologies in China.
- During this period, China began to address digesters quality issues. It adopted four standards relating to household biogas projects, including biogas pipeline, biogas tank, acceptance checklist of biogas digesters, and operating instructions.

**Bioethanol**

- In 2000, China launched its first project using grains as raw material to produce bioethanol to study and explore the production of bioethanol from corn, wheat, and other aged grains.

103 Lipper technology is the world's advanced technology to build steel plate can, invented by Xavaf Lipp of Germany. LIPP tank has the advantages of fast construction progress, a short construction period, and convenient construction. Compared to concrete tanks, it is more suitable for the construction of large anaerobic digesters.

- In April 2001, testing of the use of ethanol gasoline was approved by the government and several companies were established for the production of ethanol: the Jilin BioEthanol Company Ltd. to produce 300,000 tons, the Henan Tianguan Bioethanol Company Ltd. to produce 300,000 tons, the Anhui Fengyuan Biochemical Company Ltd. to produce 320,000 tons, and the Heilong Jianghuarun Alcohol Company Ltd. to produce 100,000 tons. The Henan Tianguan Group mainly used wheat as raw material and the other three companies used corn. The total production capacity of the ethanol pilot projects was 1.02 million tons, which roughly amounted to one-fourth of the US ethanol production in 2000.

- From June 2002 to June 2003, ethanol gasoline was piloted in three cities in Henan Province and two cities in Heilongjiang Province. In February 2004, the scope of the pilot was expanded to 27 cities and cities in nine provinces.

**Biomass Power**

- In 2004, the first three biomass power generation projects were launched: the 25 MW biomass power generation project in Shan county (Shandong Province), the 25 MW straw power generation project in Rudong (Jiangsu Province), and the 24 MW straw power generation project in Jinzhou (Hebei Province). The Shandong Shan County project was the first to burn straw for power generation in China, using equipment imported from Denmark. The boiler high pressure and temperature parameters were 9.2 million Pa (MPa) and 540°C, respectively. The other two projects used domestic equipment with middle pressure and temperature parameters of 3.82 MPa and 450°C.

- To increase the number of technology professionals, especially in R&D, the government initiated international cooperation programs with more advanced countries and multilateral institutions. The Chinese government/World Bank/GEF CRESP I (see paragraph 54) played an essential role in the rapid growth and quality improvement of the biomass manufacturing industry. The 25 MW Rudong biomass-fired power plant, supported by CRESP I, faced difficulties due to higher-than-expected moisture content in the fuel. The issue was successfully addressed with the assistance of international experts, supported by GEF. High moisture in straw was common in China and the solution befitted the biomass power industry and was disseminated widely.

**MSW Incineration Power**

- In 2001, the Wenzhou Dongzhuang waste incineration power plant Phase I was commissioned, with a daily treatment capacity of 160 tons. It was the first in China to adopt domestic equipment in line with modern international practices at the time.

- The Yuqiao waste incineration power plant in the Pudong New Area (Shanghai Municipality) was commissioned in September 2002, with a daily treatment capacity of 3 × 365 tons per day. It was the first large-scale incineration power plant project in China. It was partially financed by a French Export Credit and key equipment was from the French company Alstom to handle 1,000 tons of daily waste.

**Biodiesel**

- In 2001, Hainan Zhenghe bioenergy Co. Ltd. established the first biodiesel experimental plant in Handan, Hebei Province, using recovered waste and wild oil[104] as raw materials, marking the birth of China's biodiesel industry.

- In 2004, the MoST launched the 'Biofuel Oil Technology Development' project aiming to overcome the main barriers for biodiesel production.

- In 2004, the NDRC launched the 'key technologies for saving and replacing oil' project, including 'biodiesel production and process control at industrial scale'.

## D. The Catch-Up Stage (2006 to Present)

200. During the first stage (up to 1994) and the second stage (1995–2005), China achieved significant progress in developing biomass energy, which benefited local manufacturing of biomass boilers, grate boilers, biogas digesters, and so on. However, China was still facing many technical hurdles and struggled to meet growing demand of biomass energy:

- The Chinese manufacturing industry was unable to match the innovation and technological improvements of advanced countries, leading to low economic and financial returns from the biomass energy.

- The technical standards and product testing and certification were not well established.

- The technologies to exploit biomass resources were insufficiently mastered to meet the diversified energy demand such as biogas for cooking, bioethanol and biodiesel for transportation, and biomass for clean heating.

- Biomass resources evaluation and distribution were insufficient to meet the demand of biomass energy development, which was already growing fast despite the many technical hurdles mentioned above.

201. To meet the challenges encountered in the first two phases of the industry's growth, the government undertook several demonstration programs. Four major national scientific and technological programs illustrate the efforts deployed by the MoST to support biomass energy development:

**Biogas**

- In 2008, the MoST organized many institutions to carry out the project of 'Research on high-efficiency and large-scale biogas engineering' and comprehensively researched the anaerobic digestion technology, engineering equipment, and biogas slurry treatment technology, with a total investment of CNY 180 million (about US$25.7 million), which played a positive role in promoting biogas technological and engineering progress.

- On June 9, 2009, Heilongjiang Longneng Gas Investment Co. Ltd. and Bioprocess Control Sweden AB signed a comprehensive cooperation agreement on biomass energy technology. Both sides will

104 Waste oil mainly refers to the oil recovered from kitchen waste. Wild oil mainly refers to the oil recovered from wild oil crops, such as Pistacia, jatropha, and castor.

jointly develop new technologies and processes in the design of large and medium biogas projects, complete equipment, and engineering services.

- In January 2009, the German Agency for International Cooperation (*Deutsche Gesellschaft für Internationale Zusammenarbeit*, GIZ) and the Foreign Economic Cooperation Center of the MoA started the implementation of a 'Biomass Energy Optimization Project' to improve biomass technical standards, optimize the performance of large and medium biogas projects, and incentivize government agencies and individuals to invest in biogas industry. The project benefitted China by improving design and construction of large-scale biogas project to launch larger-scale the biogas projects.

- In December 2010, Niras Company of Denmark and Qingdao Tianren Environmental Engineering Company successfully established a biogas project in Anyang City (Henan Province) and will produce vehicle gas. The Danish government's business partner support program (the B2B project), managed by the Danish Embassy in China, provided financial and technical support for the establishment of the biogas project.

- During the 12th FYP (2011–2015), the MoST supported biogas through the following initiatives: (a) demonstration of key technologies and clean biomass fuels, (b) high-efficiency bio refining and comprehensive utilization of agricultural residue, (c) research on and demonstration of key technologies of waste resource utilization in modern livestock and poultry farms, and (d) technology and demonstration of dry anaerobic digestion of MSW and utilization of biogas in North China.

- During the 13th FYP (2016–2020), the MoST followed up with a project to support the R&D and manufacturing of key equipment: Efficient Production and High Value Utilization of Biogas.

- In 2018, 2019, and 2020, the MoST launched a the 'solid waste recycling' project, which played a key role in the R&D of biogas production from livestock farm waste.

- On August 28, 2018, the NEA issued the 'notice on submitting the industrialized demonstration of upgraded biogas projects'.[105] The purpose of the notice was to (a) improve key biomass technologies to support industrial capacity, (b) explore the establishment of business models to increase the market orientation of biomass development, (c) improve industry standards and industrial system, (d) build a number of commercial projects to promote ecological and recycling business activities, and (e) establish policy support and management system and improve the subsidy policy.

- By 2019, more than 60 national standards hade been formulated for biogas and about 35 industrial standards have been formulated.

**Biomass Power**

- On July 28, 2009, the Shandong Biomass Direct Fired Power Engineering Technology Center was established. This was the first of its kind in China. It was entrusted to carry out research and use the research results in developing biomass power projects. It aspires to become the base of resource evaluation, project design, R&D, and a consultation institute to support Chinese biomass power sector.

105 The content of methane in the biogas is normally 50–60 percent. The methane content can be raised to over 90 percent when upgraded by separation technology. And therefore it is called upgraded biogas if the methane content is over 90 percent.

- During the 12th FYP (2011–2015), the MoST supported a project, 'test and demonstration of advanced biomass power generation technology' to increase biomass power R&D capacity and develop manufacturing of key equipment.

- During the 13th FYP (2016–2020), the MoST followed up with a project to support the R&D and manufacturing of key equipment: Advanced Combustion of Biomass Briquettes and Combined Heating Power Generation.

- On January 19, 2018, the NEA announced the implementation of biomass cogeneration in 100 towns. The main purpose of the program is to promote clean heating at the county level and build a distributed clean heating production and consumption system. The main technology requirements are as follows: (a) design power generation based on heat demand, (b) establish distributed clean heating systems and adequate customer service, (c) meet the national and local pollutant emission standards and other requirements, and (d) use twin biomass heating boilers and heat storage devices to further improve the heating capacity and expand the heating area.

- By 2019, three straw power generation standards were developed (one national standard and two industrial Standards).

**MSW Incineration Power**

- In 2006 and 2008, Zhejiang University's Institute of Thermo physics, Chinese Academy of Sciences, and Tsinghua University developed three different types of CFB incinerators. These incinerators were designed in parallel with China's MSW technical requirements and have been installed in more than 60 MSW incineration power projects.

- During the 11 FYP (2006–2010), Chongqing Sanfeng Environmental Protection Industry Company acquired the license of the Martin grate boiler to solve combustion of problematic low-grade waste from Martin GmbH of Germany. Hangzhou New Century Environmental Protection Energy Engineering Co. Ltd. and Weiming Environmental Protection Energy Company of Wenzhou (Zhejiang Province) purchased Martin grate boilers from Mitsubishi Heavy Industry Company of Japan. Everbright Environmental Protection Co. Ltd. and Shenzhen Energy Source Environmental Protection Co. Ltd. purchased SEGHERS grate boilers from Keppel Company of Singapore. All these improved waste combustion and promoted biomass power generation technology in China.

- During the 12th FYP (2011–2015), the MoST supported a project 'Demonstration of Key Technologies and Clean Biomass Fuel' to increase domestic R&D capacity and develop manufacturing of key equipment.

- In 2016 and 2016, three Chinese candidates joined a postgraduate biomass training organized by the Sino Dutch cooperation program.

- By 2019, eight industry standards were formulated for waste incineration power generation.

**Bio Ethanol**

- In August 2006, China Oil and Foodstuffs Corporation (COFCO) issued the '2007–2011 Biochemical Energy Strategic Plan', which aimed to build bioethanol factories using cassava, sweet potato, and corn as raw materials. In October 2006, COFCO invested in the first domestic bioethanol factory with an annual output of 200,000 tons. It used cassava as raw material and realized the first breakthrough of non-grain bioethanol.

- In February 2009, Sinopec Group, COFCO Group, and Danish Novozyme signed a cooperation agreement to jointly develop crop waste-based production of bioethanol, aiming to develop a large-scale commercial production based on the second generation of bioethanol using corn straw. The cooperation related to the entire production and supply chain of bioethanol.

- In May 2008, the first industrial trial production line of domestic cellulose ethanol was constructed by the Henan Tianguan Group.

- On July 23, 2010, the NEA approved the establishment of the National Energy Research and Development (Experiment) Center, established by COFCO. The R&D center is dedicated to the development of biomass energy and will focus on the development of non-grain ethanol, particularly ethanol made of cellulose.

- During the 12th FYP (2011–2015), the MoST supported projects to further domestic R&D capacity and develop manufacturing of key equipment, including (a) demonstration of key technologies and clean biomass fuel, (b) efficient technology to utilize cellulosic biomass, and (c) breeding and large-scale utilization of new energy plants.

- During the 13th FYP (2016–2020), the MoST followed up with a project to support the R&D and manufacturing of key equipment: Clean Production and Efficient Separation of Biomass Liquid Fuel.

- In 2018, 2019 and 2020, the MoST launched the ‘solid waste recycling’ project dedicated to R&D of cellulose to ethanol.

- By 2019, 20 ethanol standards were formulated.

**Bio Diesel**

- During the 12th FYP (2011–2015), the MoST supported projects to increase domestic R&D capacity and develop manufacturing of key equipment. These include (a) demonstration of key technologies and clean biomass fuels and (b) cultivation of new energy algae.

- During the 13th FYP (2016–2020), the MoST followed up with a project to support the R&D and manufacturing of key equipment: Clean Production and Efficient Separation of Biomass Liquid Fuel.

- In 2018, 2019 and 2020, the MoST launched the ‘Solid Waste Recycling’ project dedicated to R&D of ‘straw to gasoline’ and ‘straw to diesel’ transformations.

- By 2019, more than 15 standards for biodiesel were developed but none approved nationally.

- Through the above measures, China’s biomass energy built a strong knowledge base in diverse biomass technologies and an important industrial base to bring biomass to a larger development scale.

- The efficiency of biomass power and MSW generation continues to improve. The parameters of boilers and steam turbines have continuously progressed. Boiler temperature and pressure characteristics increased to reach 540°C and over 14 MPa. The power generation efficiency improved from 24.5 percent in 2005 to 33 percent in 2018, still lower than Danish 42 percent.

- Biogas production technology also greatly improved. Design, construction, and operation of large and medium biogas projects were mastered. The maximum volume of single anaerobic digester reached 12,000 $m^3$ per day, and the COD concentration of feed material reached 50,000 mg per liter. The maximum biogas gas production reached 100,000 $m^3$ per day. Use of raw materials was diversified, and the mixed fermentation technology of animal manure and straw has been demonstrated. The largest project in Hebei Province can produce 100,000 $m^3$ biogas per day, roughly 41 percent of the Güstrow biogas project (producing 240,000 $m^3$ biogas per day) in Germany.

- Bioethanol technology greatly progressed. The first generation of bioethanol technology, using corn as the raw material, and the 1.5 generation bioethanol technology, using cassava as the raw material, were competitive globally, but the second generation of bioethanol technology, using crop straw as raw material, is still in the demonstration phase. China still did not catch up with advanced countries. For example, (a) in Denmark, Novozymes has developed the enzyme successfully and Inbicon A/S has built a large-scale cellulose ethanol project, producing 1.4 million gallons of ethanol per year, and (b) in the United States, Range Fuels Company built a commercial cellulose bioethanol in Georgia in 2008 and DuPont commissioned a 30 million gallon (about 114 liters) cellulosic ethanol refinery in Nevada, Iowa, on October 30, 2015.

- Biodiesel technology caught up with advanced nations. In terms of biodiesel production, market players developed patents with independent intellectual property rights, which make them more competitive globally. In 2018, 1 million tons of biodiesel was produced, roughly 17 percent of 1.8 billion gallons (about 5.8 million tons) produced by the United States.

## E. Lessons Learned

202. **Supporting technology R&D and standard setting is an important factor for biomass development.** Since 2000, China has invested a lot on R&D of biomass energy development and utilization, especially in biomass power generation, thus overcoming the technical problems faced by the industry in early projects and laying the foundation for large-scale deployment.

203. **The development of biomass needs to be adapted to local conditions.** Biomass raw materials, including a variety of organic wastes, vary extensively from country to country and can be used to produce heat, gas, and electricity. Therefore, biomass development plans need to be adapted to the country resources and energy needs. As China’s experience indicate, it is adapted to meeting rural areas’ modern energy needs to avoid deforestation and acute indoor pollution. It also contributes to develop the local economy, which is also one of the reasons for the rapid development of biomass in China.

204. **Adequate and reliable supply chain is a prerequisite to successful deployment of all biomass technologies.** Biomass energy development strongly depends on raw material collection and storage to ensure timely supply of generation facilities. Inadequate fuel supply chains and disputes about long-term pricing affected the development of many power projects in China. The country embarking on large-scale deployment of biomass should develop detailed statistical databases on the quality and distribution of raw materials to meet the needed accuracy required for the development of successful projects and attract investors, especially in the riskier segment of small RE projects. Fuel supply chains are specific to each segment of the biomass industry. Deployment of projects and/or programs, especially those

based on agricultural and forest residues, is decentralized and requires involvement of agriculture and forest management departments and a clear long-term legal arrangement between communities and concerned government agencies to develop reliable fuel supply chains.

205. **The government-driven approach that led to a recognized success in the deployment of wind power was not appropriate for deployment of biomass power technologies.** National agencies rightly developed and recommended standards for biomass energy to guide the development of the different segments of the biomass industry. However, it proved difficult to apply national standards because the characteristics of the resources and the diversity of products are determined by regional and sometimes even local specific characteristics. These agencies set up ambitious targets and high feed-in tariffs as for other priority renewable energy sources, but biomass was the only technology that did not achieve the objectives set by the government. Countries engaged in biomass development could learn from these deficiencies and rely, as much as possible, on market-based initiatives, involving all local concerned parties and developing long-term legal arrangements as enabling preconditions before undertaking large deployment of biomass energy.

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