GREEN ENERGY DEVELOPMENT AND COOPERATION AMONG EMERGING ECONOMIES - CHINA-BRAZIL COOPERATION AS AN EXAMPLE

新兴经济体绿色能源发展与合作

——以中国和巴西合作为例

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Contents

目录

Introduction

Emerging economies are increasingly committed to transforming their energy industries, as capital and operation costs fall and strategies for renewable energy deployment become more widespread.

To establish a green, low-carbon economy and energy system, peak carbon dioxide emissions and achieve carbon neutrality is a major strategic decision taken by the Chinese government. By 2060, China plans to fully establish a green, low-carbon and circular economy and a clean, low-carbon, safe and efficient energy system. In line with the UN Sustainable Development Goals (SDGs), Brazil aims to ensure universal access to affordable and reliable energy services, and at the same time increase the use of new sources of renewable energy and improve energy efficiency.

Both China and Brazil have a long history of multiple policies to promote green energy. International cooperation is an important and usual instrument for promoting energy transition and ensuring sustainable energy supply for the two countries.

China has also developed a complete industrial system of renewable energy technology during the past 10 years and renewable energy has become the principal source of the country's newly added installed generation capacity. Biomass is very relevant in the Brazilian energy mix. Biomass products represents 31% of the primary energy consumption in Brazil. Since 1975, when Proálcool was created, Brazilian public policies have stimulated the use of biofuels. The mandatory blending of biodiesel with fossil diesel (10%, with a forecast increase) and of ethanol with gasoline (27%) formed the basis for the great expansion of consumption and production of biofuels in Brazil.

China and Brazil have bright prospects for cooperation in the field of renewable energy. Brazil's rich resource endowment, necessity to expand installed capacity and power grid, and favorable market, legal, and policy conditions, aligned with China's financial might and technological capabilities, have created an ideal situation for the cooperation between the two countries. Hydropower, nuclear, biomass, solar and hydrogen might be the most promising categories. Through extensive cooperation based on respective comparative advantages, China and Brazil could further improve the power generation capacity of green energy and promote the optimization of energy mix in both countries. Leading-edge technologies, trade and investment related to raw materials and equipment could be the key points. Also, there are opportunities in improving land and sea logistics in order to promote trade and improve the availability of power equipment.

This report includes 5 chapters following this introduction. Chapter 1 introduces the background and definition of green energy, as well its goals and policies in both China and Brazil. Chapter 2 highlights the green energy development and achievement in both countries. Chapter 3 discusses the strengths and weakness of green energy development in respective sides. Chapter 4 discusses the potential areas of green energy cooperation between China and Brazil and Chapter 5 provides suggestions for further joint cooperation.

I. Overview of Green Energy Development and Cooperation among Emerging Economies

1.1 Overview of Green Energy

1.1.1 Background

Energy is a key factor for sustainable development in economic, social and environmental aspects. Growing population and higher income and consumption levels have elevated energy demand, placing increasing burdens on the environment, especially on the global climate (GIBSON, WILMAN, LAURANCE; 2017).

Fossil fuels (coal, petroleum and natural gas) are the dominant source of energy. They represent almost 85% of today's world primary energy demand (BP, 2021). Energy production accounts for 76% of global greenhouse gas emissions (WRI, 2022). In order to mitigate climate changes, a major shift in energy use is required, towards renewable and sustainable sources of energy (SEN, GANGULY; 2017). As of 2016, 176 countries have set targets to obtain certain proportions from so-called "green" energy sources (GIBSON, WILMAN, LAURANCE; 2017).

According to the Intergovernmental Panel on Climate Change (IPCC), in 2050, 80% of the electricity in the world should be generated from low carbon sources; in 2020, it is around 28% (added hydroelectric and renewable) (BP, 2021). To achieve the goals proposed at the 21st United Nations Climate Conference (COP21) including the maximum increase of 1.5°C in the average temperature of the planet, the business models and investments in energy and the necessary adaptations depending on the consequences of climate change, require a low carbon energy mix.

The rapid expansion of solar PV and wind over the past decade has resulted in global CO_2 emissions from electricity generation growing by only 9%, although electricity demand has experienced a 25% increase. Renewable energy technologies collectively met nearly 65% of the growth in electricity demand over the decade (IEA, 2021). The increase in the participation of these sources in the electrical dispatch causes the displacement of other plants, such as coal and natural gas.

Following the financial crisis of 2008, policies were first introduced to create "green" jobs as a means to reduce unemployment (Markandya et al., 2016). In 2009, the American Recovery and Reinvestment Act was passed and the stimulus package included a 'clean energy' or 'green' component of between US$ 67 and US$ 112 billion, which represented approximately 0.7% of GDP. Along with this stimulus package, President Obama announced clean energy goals for the US. One of these goals was to double the installed capacity of renewable energy generation by 2012 and create over 300,000 jobs. Another goal was to increase domestic manufacturing capacity for renewable energy and provide jobs in renewable energy supply chains. However, it was acknowledged that it will take considerable outreach to make the opportunity to work in a green job widely available. Then, the stimulus package included training programs as a pathway to renewable energy and other green jobs (MUNDACA, RICHTER; 2015).

The European Union has recently presented the Green Employment Initiative, a funding mechanism aimed to help Member States with employment opportunities and challenges in the transition to a greener economy. Besides that, the European Union has adopted the energy and climate framework for the year 2030 with the aim of reducing greenhouse gas emissions by 40%, a binding target to boost the share of renewables to at least 27% of energy consumption, and a 27% improvement in energy efficiency (MARKANDYA et al., 2016).

According to IEA (2021a), the emergence of a new energy economy requires appropriate government policies and technological innovation, and it has become a major new sector for investments and employment. In addition, IEA (2021a) stresses that international collaboration is needed for accelerating knowledge transfer and supporting rapid diffusion of new technologies.

In general terms, government support policies have been central in the global increase of renewable energy investments. Renewable energy support policies have continued to expand across all regions, and nearly all countries now have at least one renewable energy target. Besides that, the number of countries promoting renewables through direct policy support has tripled, from at least 48 in 2004 to at least 147 by 2017; more developing and emerging countries continue to adopt renewable energy targets and policies. Renewable energy targets, which serve as a principal way for public and private actors to demonstrate a commitment to the energy transition, range from official government announcements to codified plans with fully developed metrics and compliance measures. Besides that, targets also vary in focus, from a single technology or sector to economy-wide approaches (IRENA, REN 21, IEA; 2018).

However, the overall benefits of renewable energy technologies are often not well understood, leading to such technologies often being assessed as less cost-effective than traditional technologies. For renewable energy technologies to be assessed comprehensively, all their benefits must be considered. For example, many renewable energy technologies can provide, with short lead times, small incremental capacity additions to existing energy systems and it is important to consider that such power generation units usually provide more flexibility in incremental supply than large devices like nuclear power stations (DINCER, ROSEN; 2005).

In general, despite the significant increase in renewable energy deployment over the past decade, propelled by the numerous drivers and players advancing renewables and efficiency and the steady increase in support policies and targets, renewables are still far from being fully integrated into the larger energy system (IRENA, REN 21, IEA; 2018).

Emerging economies are increasingly committed to transforming their energy industries, as capital and operation costs fall and strategies for renewable energy deployment become more widespread. China, for example, since 2009 has become the largest developer of renewable power and heat (IRENA, REN 21, IEA; 2018).

UNCTAD (2017) emphasizes the important role that renewable energy can play in emerging economies. More specifically, considering commodity-dependent countries, it states that sustainable management of the commodity sector can foster economic growth while promoting employment, fiscal revenues and infrastructure development. Some of the goals associated with such agenda are: (i) to provide food and energy security; (ii) to increase resource efficiency and the use of renewable energy; (iii) to promote industrial diversification and adding value to commodities, and to support domestic technology development, research and innovation. In order to achieve these goals, cooperation and collaboration among governments, as well as private sector and civil society will be of crucial importance.

1.1.2 Definition

The energy sector is the source of approximately three-quarters of the current greenhouse gas emissions today and holds the key to averting the worst effects of climate change, perhaps the greatest challenge humankind has faced (IEA, 2021a).

Zarnikau (2003) defines green energy as the electricity generated by renewable energy sources, and including technologies such as photovoltaic solar panels, biomass projects, geothermal projects and wind farms. Besides that, the usage of green energy sources for electricity generation involves zero greenhouse gas emission, thereby offering a lasting solution to climate change. Chernysheva (2019) understands that green energy includes any sector that promotes the reduction of CO_2 emissions. According to that definition, green energy includes solar, wind, hydro energy as the dominant sectors, as well as geothermal and tidal energy production, and the construction of infrastructure for these industries.

Mohanty (2012) distinguishes three generations of green energy technologies. The first generation technologies include, for example, hydropower, geothermal and biomass combustion. Second-generation technologies are e.g. solar heating and cooling, solar photovoltaic, and wind power; third-generation technologies are biomass gasification, bio-refinery, geothermal and ocean/marine energy - tidal, waves, ocean thermal differences.

According to Omer (2008), sustainability has been defined as the extent to which progress and development should meet the needs of the present without compromising the ability of the future generations to meet their own needs. However, since all energy resources lead to some environmental impact, increased efficiency can somewhat alleviate the concerns regarding environmental emissions and their negative impacts. Efficiency increases when less resource is used and less pollution is generated for the same services or products levels (DINCER, ROSEN; 2005).

For IEA (2021a), renewable energy technologies are key to reducing emissions from electricity supply, at a global level. Hydropower has been a leading low-emission source for many decades, but it is mainly the expansion of wind and solar that triples renewables generation by 2030 and increases it more than eight times by 2050 in the net zero emission scenario. Besides that, renewables play an important role in reducing emissions in buildings, industry and transport, and can also be used either indirectly, via the consumption of electricity or district heating that was produced by renewables, or directly, mainly to produce heat. In transport, renewables play an important indirect role in reducing emissions by generating the electricity to power electric vehicles. They also contribute to direct emissions reductions through the use of liquid biofuels and biomethane.

According to IRENA, REN 21, IEA (2018), biofuels are primarily used in road transport, but can also be used for rail, shipping and aviation. Using low-level blends with conventional energy infrastructure and vehicle fleets, biofuels can power the existing transport system. High-level blends often require adjustments in engines and fuel distribution infrastructure.

1.1.3 Literature Review

Sen and Ganguly (2017) consider that energy quality is an important factor for the development process. To achieve sustainable development, continuous flow of clean and secure energy is required which has lower environmental impacts. In the same perspective, Midilly, Dincer and Ay (2006) suggest that sustainable development requires a supply of energy resources that is sustainably available at reasonable cost and causes zero or minimal negative societal impacts.

For Dincer and Rosen (2005), green energy resources and technologies are a key component of sustainable development for three main reasons. First, because it generally causes less environmental impact than other energy sources, and the variety of green energy resources provides a flexible array of options for their use. The second point is that it cannot be depleted. If used carefully in appropriate applications, green energy resources can provide a reliable and sustainable supply of energy almost indefinitely. The third reason is that it favors system decentralization and local solutions that are somewhat independent of the national network, thus enhancing the flexibility of the system and providing economic benefits to small isolated populations. In addition, the smaller scale of the equipment often reduces the time required from initial design to operation, providing greater adaptability in responding to unpredictable growth and changes in energy demand.

As per socioeconomic development, Sen and Ganguly (2017) emphasize that per capita income is positively correlated with per capita energy use and so is Human Development Index. Economic growth is the most important factor behind increasing energy demand and consumption in the last decades. As the economy grows, the demand for more sophisticated and flexible energy increases. Hence, economic growth has been associated with a shift from burning conventional fuels to modern energy sources. This need has hugely been felt in the developing countries, and the reliable energy is one of the requisites for human development; it can contribute to income generation, increasing health and education quality, as well as decreasing poverty levels. In addition, as these technologies are decentralized, they can play an important role in rural development and the generation of new employment opportunities is one of the most positive long-term effects in developing and developed countries.

Dincer and Rosen (2005) suggest that renewable energy technologies can provide cost-effective and environmentally beneficial alternatives to conventional energy systems. Among other benefits that make energy conversion systems based on renewable energy attractive, supply cost becomes less susceptible to fossil fuel price fluctuations. Thus, cost estimates can be made reliably for renewable energy systems and they can help reduce the depletion of the world's non-renewable energy resources; implementation is relatively straightforward; they normally do not cause excessive environmental degradation and so can help resolve major environmental problems - widespread use of renewable energy systems would certainly reduce pollution levels; they are often advantageous in developing countries. In fact, the market demand for renewable energy technologies in developing nations will likely grow as they seek a better standard of living (DINCER, ROSEN; 2005).

IEA (2021a) stresses the role of governments in the definition and implementation of appropriate policies to encourage the use of renewable energies. In addition, public financial institutions – such as international development banks – may play a crucial role in financing investment, particularly in emerging economies.

1.2 Goals

1.2.1 China

To establish a green, low-carbon economy and energy system, peak carbon dioxide emissions and achieve carbon neutrality is a major strategic decision taken by the Chinese government. According to China's *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy*[①] its main objectives are as follows:

By 2025, China will implement a framework for a green, low-carbon and circular economy that improves energy efficiency of key industries. Energy consumption per unit of GDP will be lowered by 13.5% from the 2020 level; carbon dioxide (CO_2) emissions per unit of GDP will be lowered by 18% from the 2020 level; the share of non-fossil energy consumption will reach around 20%.

By 2030, CO_2 emissions per unit of GDP will drop by more than 65% compared with the 2005 level; the share of non-fossil energy consumption will have reached around 25%, with the total installed capacity of wind power and solar power reaching over 1,200 gigawatts.

By 2060, China plans to fully establish a green, low-carbon and circular economy and a clean, low-carbon, safe and efficient energy system. Energy efficiency will be at the international advanced level, and the share of non-fossil energy consumption will be over 80%. China will be carbon neutral, and it will have achieved fruitful results in ecological civilization and reached a new level of harmony between humanity and nature.

1.2.2 Brazil

Electricity generation in Brazil is mainly based on hydro power, that represents 60% of Brazilian generating capacity (ANEEL, 2022). In the last decade (2012-2021), hydropower accounted for 64% total electricity generated in the country (EPE, 2022). Large Brazilian hydroelectric plants have reservoirs that can accumulate 213 TWh on total (ONS, 2022), which is equivalent to 43% of electricity consumption in 2021 (EPE, 2022).

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① The National Development and Reform Commission (NDRC): https://en.ndrc.gov.cn/policies/202110/t20211024_1300725.html.

The popular use of biofuels in Brazil is evident in its light vehicle fleet: flexible fuel vehicles that can use ethanol or gasoline in any proportion constitute around 95% of the sales new car and represent 72% of the light vehicle fleet in 2016. As a result, 24 million vehicles can use pure (unblended) ethanol (IRENA, REN 21, IEA; 2018).

As mentioned before, most of the energy generated in Brazil come from renewable sources, particularly due to the importance of hydroelectric plants. However, Losekann and Hallack (2018) stress that the expansion of hydroelectric generation faces growing costs and restrictions. Therefore, Brazil must invest in new sources of renewable energy in order to fulfill its energy needs without the need to expand fossil-based energy generation.

The diffusion of wind and solar energy in Brazil initiated latter than advanced economies. However, wind and solar generating capacity have strongly expanded in the last decade. Wind power capacity increased from 1.9 GW in 2012 to 20.7 GW in 2021. Solar generating capacity was almost zero in 2012 (7 MW) and reached 13.7 GW in 2021.

Regarding wind energy, industrial policy requiring local content to access funding attracts several suppliers to Brazil. The presence of these new manufacturers increases competition in the wind generation sector, which reduces the investment per MW of installed wind generation and decreases the cost of the produced energy. In 2013, 12 manufacturers were producing wind turbines in Brazil for Europeans, Americans, Argentinians, and Brazilians. Brazil is self-sufficient regarding wind turbines and the equipment used on wind farms. The consolidation of renewable energy, particularly in relation to wind energy, is crucial for the continuity of long-term financing. This financing supports the energy sector and the industrial sector, including capital goods industry, which supports a potentially promising technology (DA SILVA et al., 2013).

In line with the UN Sustainable Development Goals (SDGs), Brazil aims to ensure universal access to affordable and reliable energy services, and at the same time increase the use of new sources of renewable energy and improve energy efficiency. In order to attain such goals, international cooperation is needed, particularly to facilitate access to clean energy research and technology, and for the expansion of investments in energy infrastructure.

Miranda et al. (2021) consider that Green Technology has become an alternative strategy for Brazil's sustainable and economic development. In general, Miranda et al. (2021) describes that most studies in Brazil focus on Green Technology practices over products/processes/raw material. These practices try to reverse some scenarios by improving sustainable processes. In addition, the adoption of these practices allows results aimed at the use of alternative sources of water and energy, as well as the possibility of correlating environmental legislation, industrial improvements linked to innovation and improving the environmental performance of organizations, and also the use of less productive processes, impacting environmentally, socially, and economically.

1.3 Policies

1.3.1 China

1.3.1.1 Relevant Laws and Regulations

The existing general laws and regulations on energy in China mainly include: *the Production Safety Law (2002)* , *the Law on Environmental Impact Assessment (2003)* , *the Law on the Safety of Special Equipment (2014)* , *the Renewable Energy Law (2006)* , *the Mineral Resources Law (1986), the Environmental Protection Law (2015), the Electric Power Law (1996), the Coal Industry Law (1996)*, and *the Energy Conservation Law (2008)* ① .

China will remove the contents in existing laws and regulations that are incompatible with the task of green energy and strengthen integration and coordination between laws and regulations. In addition to conducting research on formulating a specific law on carbon neutrality, China is expediting the revision of the *Energy Conservation Law,* the *Electric Power Law,* the *Coal Industry Law,* the *Renewable Energy* Law, the *Law on Promoting* the *Circular Economy*, and other laws to make relevant laws and regulations more targeted and effective.

China will improve standard and measurement systems for green energy. China will also accelerate the upgrading of energy conservation standards and promptly revise a number of mandatory national standards for energy consumption caps, compulsory national standards for the energy efficiency of equipment and products, and project construction standards. It will speed up to improve carbon emissions verification, accounting and reporting standards for regions, industries, businesses, and products and establish a unified, well-regulated carbon accounting system. China will take an active part in formulating relevant international standards and ensuring domestic standards are consistent with international ones.

1.3.1.2 Fiscal Policies

China will promote the development of green and low-carbon financial products and services in an orderly manner. It will develop monetary policy tools to support carbon emission reduction. The green credit initiative should be included in a macro-prudential evaluation framework, and guidance will be given to banks and other financial institutions on providing long-term, low-cost capital to green and low-carbon projects. China will encourage development and policy-backed financial institutions to provide continued long-term funding support for the goals of peak carbon dioxide emission and carbon neutrality through market-oriented and law-based means. China will support qualified enterprises in going public and refinancing for the purpose of developing and running green and low-carbon projects, and will increase green bonds. It will also carry out exploratory work on establishing a national fund for low-carbon transformation. Non-governmental capital will be encouraged to set up green and low-carbon industrial investment funds. China will establish and improve a sound system of standards for green finance.

① National Energy Administration: http://www.nea.gov.cn/nyflfg/index.htm.

According to *The Opinions on Improving the Institutional Mechanisms and Policy Measures for the Green and Low-Carbon Transformation of Energy* ① jointly issued by the National Development and Reform Commission and the National Energy Administration in January 2022, China will improve the diversified investment and financing mechanisms that support the green and low-carbon transformation of energy. China will further increase investment and financing support for clean and low-carbon energy projects and energy supply security projects. The National Green Development Fund and the existing low-carbon transformation related funds should take the development and utilization of clean and low-carbon energy, the construction of new power systems, and the green and low-carbon transformation of fossil energy enterprises as key support areas. China will promote market-oriented investment and financing of clean and low-carbon energy-related infrastructure projects, and study the inclusion of clean and low-carbon energy projects in the pilot scope of Real Estate Investment Trusts (REITs) in the infrastructure sector. The central financial funds are further inclined to rural energy construction, using existing financial channels to support the construction of rural energy supply infrastructure.

1.3.1.3 Tax Incentives

The State Taxation Administration issued *the Guidelines for Preferential Tax Policies to Support Green Development* in May 2022 ② . In order to help the comprehensive green transformation of economic and social development and implement the sustainable development strategy, the state has implemented 56 preferential tax policies to support green development in 4 aspects: supporting environmental protection, promoting energy conservation and environmental protection, encouraging the comprehensive utilization of resources, and promoting the development of low-carbon industries. The preferential tax incentives includes: 50% of the value-added tax paid for wind power projects is eligible for immediate refund after payment; the urban land use tax will be partially exempted for hydropower and nuclear power stations.

1.3.1.4 Subsidy Policies

The renewable electricity price subsidy fund is a government fund established in accordance with the requirements of the *Renewable Energy Law*, by raising funds in the form of collecting funds from the electricity price, in order to support power grid enterprises to acquire renewable energy generation such as photovoltaic, wind power and biomass. Renewable energy power generation projects that enjoy subsidy for renewable electricity prices must comply with national planning and be included in national scale management, comply with electricity price policies, and generate electricity into the grid as required. At present, the technology level of China's wind power, photovoltaic power generation and other renewable energy power generation continues to improve, the cost continues to decline, as the basis for competition with traditional energy, and gradually become an important force in the transformation of China's energy mix . In the medium and long term, subsidies show a trend of gradual decline. Among others, the wind power and photovoltaic power generation industries

① http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/47673/48000/xgzc48006/Document/1721203/1721203.htm.

② The State Taxation Administration: http://www.chinatax.gov.cn/chinatax/n810341/n810825/c101434/c5175740/content.html.

have carried out pilot projects with no subsidy parity grid in 2019, and the subsidies of other renewable energy power generation industries have also been gradually reduced in an orderly manner. According to documents issued by the Ministry of Finance and other three departments, starting from 2020, new offshore wind power and solar thermal projects will no longer be included in the scope of central financial subsidies. Starting from 2021, for newly registered centralized photovoltaic power stations, industrial and commercial distributed photovoltaic projects and newly approved onshore wind power projects, the central government will no longer provide subsidies.

1.3.1.5 Technology Policies

China will formulate an action plan to ensure science and technology to better support the endeavor to peak carbon dioxide emissions, carbon neutrality and action plans as well as to develop a technological roadmap to carbon neutrality. China will continue with the open competition mechanism to select the best candidates to lead research on low-carbon, zero-carbon and carbon-negative technologies and on new materials, technologies, and equipment for energy storage. China needs to strengthen research on basic theories and methods concerning the cause and impact of climate change, as well as on carbon sinks in ecosystems. China must work toward breakthroughs in cutting-edge low-carbon technologies such as high-efficiency solar batteries, hydrogen production from renewable energy sources, controlled nuclear fusion, and zero-carbon industrial process re-engineering. China needs to develop key national laboratories, national technological innovation centers, and major scientific and technological innovation platforms for the research and development of energy-saving, carbon-reducing, and new-energy technologies and products. China needs to develop a talent pool for the task of peaking carbon dioxide emissions and carbon neutrality, and to encourage universities and colleges to establish disciplines and majors relevant to peak carbon dioxide emissions and carbon neutrality.

China needs to develop smart grid technologies that can support the smooth, large-scale integration of wind and solar power into the grid. China must strengthen research and industrial application of advanced energy storage technologies such as electrochemistry and compressed air energy storage. China also needs to advance the research and large-scale application of key technologies for hydrogen production, storage, and application. China will promote energy-conserving and low-carbon technologies such as the energy cascade utilization in industrial parks. The research and application of aerogel and other new materials will be strengthened. China will advance research, demonstration and industrial application of technologies of carbon capture, utilization and storage on a large scale. Steps should be taken to establish sound systems for the assessment and trading of green and low-carbon technologies as well as service platforms for scientific and technological innovation.

According to *The Opinions on Improving the Institutional Mechanisms and Policy Measures for The Green and Low-Carbon Transformation of Energy* [①], a major scientific

① http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/47673/48000/xgzc48006/Document/1721203/1721203.htm.

and technological collaborative innovation system for clean and low-carbon energy is established. It will give full play to the role of national laboratories in the field of energy, form a market-driven energy technology innovation system led by national strategic scientific and technological forces, and deepen integration of production, education and research, as well as accelerate breakthroughs in a number of key technologies for clean and low-carbon energy. It will support leading enterprises in the industry to jointly build a national R&D and innovation platform in the field of energy by joining forces with colleges and universities, scientific research institutes, and upstream and downstream enterprises in the industry and will promote the sharing and optimal allocation of resources of various scientific and technological forces. It will carry out joint research on key technologies such as basic components, basic software, basic materials, and basic processes in the energy field; and will implement collaborative innovation research on major energy science and technology. It will strengthen the research and development of safety technologies related to new energy storage, and will improve technical standards and specifications for equipment and facilities, planning and layout, design and construction, and safe operation.

1.3.1.6 Talents and Policies

According to *the Renewable Energy Development Plan during the 14th Five-Year Plan period* [①] jointly issued by the National Development and Reform Commission, the National Energy Administration and other seven central government departments in June 2022, China will improve the talent evaluation and incentive mechanism, and will create a group of internationally competitive scientific and technological talents and innovation teams. China will increase the training and introduction of high-level talents; encourage all kinds of colleges and universities to open renewable energy professional disciplines, and to cooperate with enterprises in talent training; improve the mechanism for introducing high-end talents in the field of renewable energy.

1.3.2 Brazil

Brazil has a long history of policies to promote green energy sources to electricity generation and for transportation. Initially, the objective was energy security, given the limited reserves of fossil energy.

In this sense, the Proálcool Program was instituted in the 1970s to deal with the effects of the oil crisis, reducing imports of petroleum products. In 1975, Proálcool Program promoted the use ethanol in light vehicles. More recently, policies to encourage biofuels were resumed with environmental motivation. In 2004, Brazil has adopted a new framework of regulations and legislation to support biofuels. Nowadays, the biofuel mandate requires standard gasoline to contain 27% of ethanol and standard diesel to contain 10% biodiesel by 2019. Taxes on biofuels are lower than on fossil fuels. Brazil is the second largest ethanol producer in the world, producing approximately 30 billion liters per year.

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① http://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202206/t20220601_1326719.html.

Beginning in 2018, the country has established the RenovaBio Program, that sets national emission-reduction targets for the national fuel supply. Fuel distributors can meet these targets by increasing sales of all biofuels (ethanol, biodiesel, and biomethane), which is expected to lead to a significant increase in their production and use. Complementary laws on ecological zoning, industrial activities, forest preservation and agricultural practices facilitate the enforcement of sustainability.

The policy of diffusion of renewable sources for the generation of electric energy had the Proinfa (Program of Incentive to Alternative Sources of Electric Energy) as a starting point in 2002. The program was based on commitments to purchase solar, wind and bioelectricity at prices incentives (feed in rates). Subsequently, the auction system came into effect to promote renewable sources.

For distributed generation, the net metering system is the mechanism used to stimulate the diffusion of solar panels in households and businesses. The net metering program was instituted in 2012 and the diffusion boom took place in 2016, with the drop in panel prices.

In 2022, the incentive regime for distributed generation was revised and, progressively, subsidies will be eliminated.

The Brazilian nuclear energy program was boosted during the military governments in Brazil, when the two nuclear power plants were built in Angra dos Reis, Rio de Janeiro. More recently, expansion planning once again contemplated the completion of the third plant in Angra and the construction of new plants in other locations.

1.3.2.1 Green Energy - related Laws

Currently, the most relevant set of laws to encourage renewable sources are the mandates for the addition of biofuels, the RenovaBio program, the distributed generation framework, auctions in the regulated electricity market aimed at renewables, and the discounts for renewable generation in distribution and transmission tariffs.

The mandate for adding ethanol to gasoline is governed by Law No.1 9,478 of 1997. According to the law, the government must define the percentage of ethanol between 18% and 27.5% of gasoline. Currently, the mixture is 27%. Recently, Decree 10,940 of 2022 established that the National Energy Policy Council (CNPE) is responsible for defining the mixing potential.

The National Program for the Production and Use of Biodiesel (PNPB) was created in 2004 and established a schedule for progressive blending of biodiesel in mineral diesel, starting with 2%. Law 3,263 of 2016 established an increase of 1% each year until reaching 10% in 2018 and gave power to the CNPE to define new increases up to the target of 15%. The CNPE implemented a new schedule of increases of 1% per year until reaching 15% in 2023. However, with the increase in diesel prices, resolution 16 of the CNPE of 2021 determined the reduction of the percentage from 13% to 10% and postponed the schedule of new elevations. The Law No. 13.576 of 2017 established RenovaBio, which is a government policy that seeks to promote the use of biofuels through the sale of carbon credits to fossil fuel distributors.

Regarding solar power, Law 14,300 of 2022 reviewed the ANEEL Resolution 482 of 2012, that introduced the net metering scheme in Brazil. The new law reduces progressively the amount of consumption that can be compensated by new distributed generation. It stimulated a rush to install PV panels before the change in the rule of compensation.

Law No. 14,182 of 2021 implemented auctions for the regulated market, aimed at the demand of electricity distributors. The law includes specific auctions for renewable sources, which was very relevant for the dissemination of wind and solar energy.

Law No. 9,648 of 1998 established 50% discounts on transmission and distribution tariffs for small hydroelectric power plants. Laws No. 10,438 of 2002 and No. 10,762 of 2003 extended the discount to wind, biomass and solar sources.

Law No. 14,120 of 21 established that discounts on the distribution and transmission tariff for new renewable projects will only be granted for another three years, when new renewable projects will have the same treatment as conventional sources. It should be noted that the discounts remain for the entire useful life of renewable generators that come into operation before that date. The Brazilian Congress proposed an extension of two years for the discounts to the new projects.

1.4 International Cooperation

1.4.1 China

China will uphold the UN-centered international system, comply with the objectives and principles laid out in the *UN Framework Convention on Climate Change* (UNFCCC) and its *Paris Agreement*, and strive to deliver the *2030 Agenda for Sustainable Development*. China intends to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. This major strategic decision is made based on its sense of responsibility to build a community with a shared future for mankind and its need to secure sustainable development. Moreover, China has decided to accept the *Kigali Amendment to the Montreal Protocol* and to tighten regulations over non-carbon dioxide emissions.

China will strengthen partnerships and cooperation with international community and will make common progress toward global carbon neutrality[①]. China has made marked progress in building a green Belt and Road Initiative (BRI), and it will make consistent efforts to tap its potential to promote low-carbon transition worldwide. In recent years, the country's investment in renewable energy projects in countries and regions involved in the BRI has kept growing. China has proactively helped developing countries and regions promote the application of green energy technologies. One example is the Karot Hydropower Project, a priority project within the China-Pakistan Economic Corridor, with a total investment of $1.74

① Remarks by Xi Jinping, President of China at the Leaders Summit on Climate, 22 April 2021. http://language.chinadaily.com.cn/a/202104/23/WS6082197fa31024ad0bab9c28.html billion. The hydropower project has been put into commercial operation by the end of 2021, and provided Pakistan with about 3.2 TWh of clean electricity each year, servicing 5 million people, and reduce carbon dioxide emissions by 3.5 million tons per year. Facilitated by a BRI environmental big data platform and a BRI environmental technology transfer center, China has promoted sharing of green development information and the application of green technologies among BRI countries.

China will accelerate a green transformation in BRI investment and cooperation practices, and will support the development and the use of clean energy in participant countries. According to *The Opinions on Improving the Institutional Mechanisms and Policy Measures for the Green and Low-Carbon Transformation of Energy* ①, China will encourage innovation in financial products and services, and support the development and utilization of clean and low-carbon energy under the framework of BRI. China will promote practical cooperation on green energy and explore the establishment of a collaborative development and cooperation mechanism between upstream and downstream enterprises in the clean and low-carbon energy industry chain. China will guide enterprises to make outbound investment in clean and low-carbon energy, and will pay attention to resource conservation, environmental protection and production safety in related projects. China will also promote the construction of best practice projects for energy cooperation. China will build a closer partnership for green development, and will make green development a defining feature in the joint pursuit of the BRI.

China will actively promote cooperation on green development in global energy governance. The Belt and Road Energy Partnership (BREP) was created in 2019 to promote policy cooperation and build technology exchange platforms in the energy field among members. Relying on the platform of China-League of Arab States, China-African Union, China-ASEAN, China-Central and Eastern Europe, APEC Sustainable Energy Center (APSEC), China will continue to support the cooperative training of technical personnel related to clean and low-carbon energy and carry out capacity building, policies, standards and personnel exchanges. China will improve cooperation with international organizations such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), and will actively participate in green and low-carbon energy transition cooperation under multilateral frameworks such as the United Nations, the G20, APEC, BRICS and The Shanghai Cooperation Organization (SCO).

1.4.2 Brazil

International cooperation is an important and usual instrument for promoting energy transition and ensuring sustainable energy supply. Cooperation can take place through universal institutions (such as the United Nations), blocks of countries (such as the G20, Mercosur, BRICS) or bilaterally.

① http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/47673/48000/xgzc48006/Document/1721203/1721203.htm.

International cooperation in the energy area has intensified in Brazil in recent years. On the Concordia Platform at Itamaraty, 608 international acts with the participation of Brazil that include energy issues were registered in the last 30 years ①. Of these, 120 acts involve renewable energy ②.

Santos and Silva (2018) point out that in the 1990s, Brazilian international energy cooperation was characterized by the approximation with South American countries, especially Argentina and Bolivia, due to the binational electricity interconnection and gas pipeline projects. The acts in the nuclear area also stood out in the period.

In the 2000s, international partnerships diversified and renewable sources began to motivate partnerships. A greater number of countries started to cooperate with Brazil in the energy area, with the participation of African and Asian countries, as well as Europe and the Americas. The prospect of international success of biofuels boosted Brazilian international initiatives.

The last decade remains characterized by partnerships in renewable sources. BRICS countries gain greater relevance in Brazilian international agreements. Among the most recent initiatives, the biofuture platform and the *Memorandum of Understanding on Bioenergy* signed with India in 2020 stand out.

The platform is an initiative led by Brazil and includes 20 countries. The platform was created in 2016, and aims to promote the bioeconomy, especially biofuels. In addition to governments, international institutions in the energy sector collaborate with the platform, such as the International Energy Agency International Renewable Energy Agency (IRENA) and the Global Bioenergy Partnership (GBEP).

The cooperation between Brazil and India aims to strengthen sustainable mobility, with an emphasis on biofuels and vehicles with flexfuel technology. India intends to reach the addition of 10% ethanol to gasoline by the end of 2022 and 20% in 2025. Among the nine key areas of cooperation established between Brazil and India are topics such as the development of second-generation ethanol ③, sustainable fuels from aviation and policies and incentives for biogas and biomethane.

① Number of international acts that resulted from the search engine for the keyword "Energy" in the period 01/01/1990 to 07/01/2022. International acts include treaties, agreements, memoranda of understanding, agreements, joint declarations, communiqués, programs, memoranda of understanding or deals.
② Número de atos internacionais que resultaram do mecanismo de busca para as palavras chaves Solar, Eólica, Etanol e Biodiesel no período 01/01/1990 a 01/07/2022.
③ Second-generation ethanol allows the energy use of biomass waste that is discarded from the first-generation ethanol production process, increasing its productivity and CO_2 sequestration.

II. Green Energy Development in China and Brazil

2.1 Green Energy Development in China

During the past decades, China's green energy has achieved leapfrog development, and the installed capacity has exceeded 1 Terawatt, accounting for more than 40% of the country's total installed power generation capacity. Among them, the installed capacity of hydropower, wind power, photovoltaic power generation and biomass power generation ranked first in the world for 17 consecutive years, 12 years, 7 years and 4 years respectively, and the international competitive advantages of photovoltaic, wind power and other industrial chains are prominent. China has also developed a complete industrial system of renewable energy technology during the past 10 years and renewable energy has become the principal source of the country's newly added installed generation capacity. In the first five months of 2022, China's newly-added installed capacity of renewable energy generation rose to 43.49 GW, 82.1% of the country's newly added power generation installed capacity. China's installed capacity of wind, solar, biomass and hydropower generation continued to rank first globally.

2.1.1 Speed-up Development of Hydropower

Since the construction of the first hydropower station in 1904, China's hydropower has strongly grown, and its installed capacity and annual power generation have ranked first in the world for many years.

China has clearly defined the goal of carbon neutrality at peak carbon and issued a series of important policy measures to reduce pollution and reduce CO_2 emissions, providing major development opportunities for the higher quality development of clean energy, including the hydropower industry. In order to accelerate the construction of a new power system with new energy as the main body, the construction and development of pumped storage power stations, an unconventional hydropower station with powerful peak regulation and frequency regulation functions, will also usher in a new round of development opportunities.

2.1.1.1 Distribution of hydropower resources

The hydropower resources are concentrated in the southwest of China, with Tibet, Sichuan and Yunnan province hosting over two-thirds of the total hydroelectric resources. From the perspective of regional proportion, in 2020, hydropower generation in the southwest accounted for 58.51%, central China accounted for 18.5%, and that of northwest accounted for 10.9%. southern China, eastern China, northeast China and northern China accounted for a relatively small proportion of hydropower generation, 5.9%, 4.2%, 1.1% and 0.9% respectively.
2.1.1.2 Hydropower generation

According to *China Statistic Yearbook 2021*, China's hydropower industry has grown steadily from 1,130.3 TWh in 2015 to 1,304.4 TWh in 2019, showing an increase of 15.40% in five years.

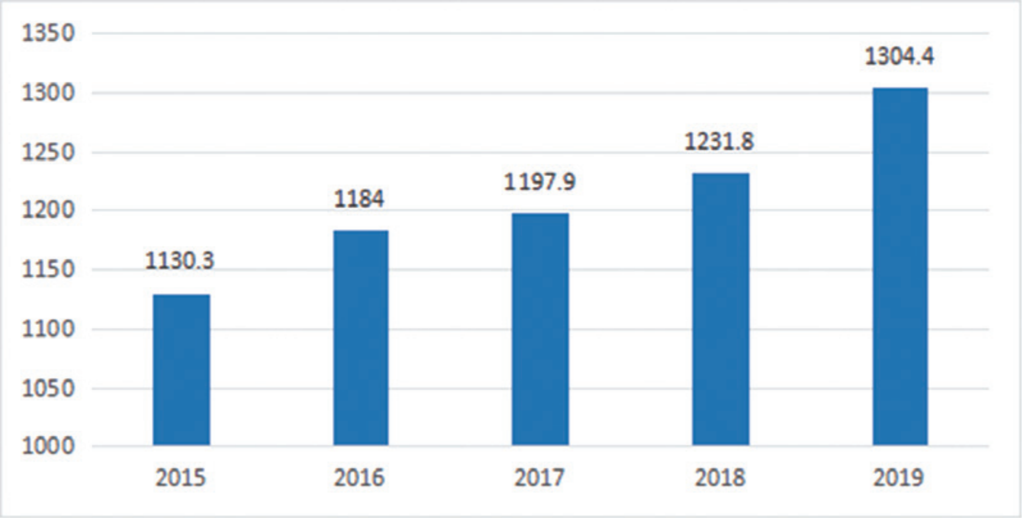

Figure 2.1 Hydropower generation (2015-2019) (TWh）

Source: China Statistic Yearbook 2021.

In the past decade, China's installed wind power capacity has increased from 232.98 Gigawatts in 2011 to 370.28 Gigawatts in 2020, an showing increase of 58.93% in ten years.

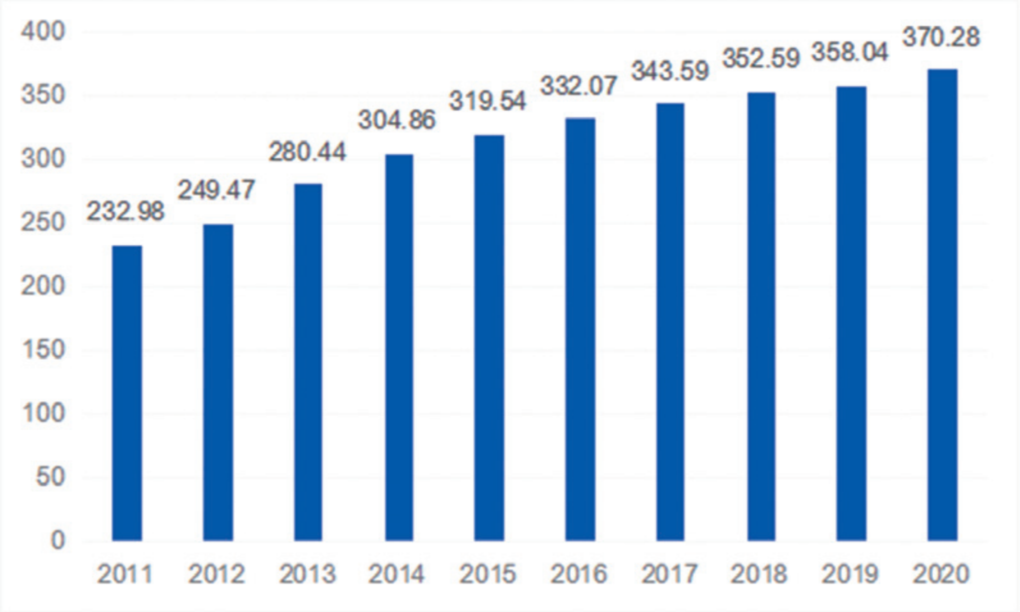

Figure 2.2 Installed capacity of hydropower generation (2011-2020) (GW)

Source: China Statistic Yearbook 2021 and China Electricity Council.

China is ramping up pumped-storage hydroelectricity (PSH) capacity in an effort to boost new energy development and ensure stable operations of the grid. The total installed capacity of PSH in China increased 15.6 percent year-on-year to 36.39 million kW by the end of 2021.

The government has also released supportive policies for the development of PSH. In 2014, the National Development and Reform Commission and the National Energy Administration successively issued the *Opinions on Issues Related to Promoting the Healthy and Orderly Development of Pumped Storage Power Stations and the Notice on Issues Related to Improving the Price Formation Mechanism of Pumped Storage Power Stations*, which promoted the healthy development of pumped storage power stations and formed a new round of hydropower construction climax. In April 2021, the National Development and Reform Commission and the National Energy Administration came up with a series of suggestions to improve the PSH price mechanism. In September 2022, a mid to long-term development plan (2021-2035) for PSH was released by the National Energy Administration, which included promoting small and medium-sized projects and strengthening technology innovation. According to the plan, China aims to have its installed capacity of PSH in operation surpass 62 GW by 2025 and 120 GW by 2030.

2.1.1.3 Leading enterprises and major projects

China Yangtze Power Co. (CYPC) is mainly engaged in hydropower generation, power distribution business, intelligent integrated energy, and investment and financing businesses. The company has expanded its business to several countries, including China, Portugal, Peru, Brazil, and Pakistan. CYPC is the largest listed electric power company in China and the largest listed hydropower company in the world. CYPC has a total installed capacity of 45,595 MW, including 45,495 MW of domestic installed capacity, accounting for 12.3% of China's total hydropower installed capacity. It generates 262.88 TWh of electricity in 2021. CYPC currently owns four giant hydropower stations, namely the Three Gorges, Gezhouba, Xiluodu and Xiangjiaba, and is entrusted with the management of two hydropower stations, Wudongde and Baihetan.

SDIC Power Holdings CO., LTD. is a leading power generation company in China. SDIC Power operates a diversified portfolio of projects across hydropower, wind power and solar power. Among all power generation companies currently listed in China, the Company is the third largest hydropower company in terms of consolidated hydro installed capacity. Hydropower projects are mainly distributed in Sichuan, Gansu, Yunnan, Xinjiang and other provinces and regions. Yalong River Hydropower, which holds 52% of the shares, is the only hydropower development entity in the Yalong River Basin and ranks third among the 13 major hydropower bases in China. The river basin has 14.7 Gigawatts of installed capacity and 4.5 Gigawatts under construction at the end of 2019.

The Three Gorges Hydropower Station is located at Sandouping in Yichang City, Hubei province, in the middle section of the Xiling Gorge of the Yangtze River. It is the largest hydropower station in the world, with major functions including flood control, power generation, shipping and water resource utilization. The total installed capacity of the station is 22,500 MW, including 32 units with a single capacity of 700 MW and another two units with a single capacity of 50 MW. As of December 31, 2021, the cumulative power generation capacity of the Three Gorges Hydropower Station reached 1,502.8 TWh.

Baihetan Hydropower Station is located within the borders of Ningnan County of Sichuan province and Qiaojia County of Yunnan Province on the lower reaches of the Jinsha River. The Station focuses on power generation, and also plays a role of flood control. It also helps to block sands, and improve navigation conditions in the reservoir area and downstream river sections. The underground powerhouses on the left and right banks of the power station are each installed with eight sets of 1,000 MW hydro-turbine generators, with a total installed capacity of 16,000 MW. The construction of Baihetan Hydropower Station began in 2011, and the first batch of generating units started to generate electricity in July 2021. After being fully completed, it will be the second largest hydropower station in the world after the Three Gorges Hydropower Station.

The Gezhouba Hydropower Station is located at the end of the Three Gorges section of the Yangtze River in Yichang City. It is the first large-scale hydropower project constructed on the main stream of the Yangtze River, with a comprehensive function of power generation and waterway improvement. It has 22 units with a total capacity of 2,735 MW. Its first unit was put into operation on July 30, 1981, and the project was fully completed in 1988. As of December 31, 2021, the cumulative electricity output reached 605.4 TWh.

Xiluodu Hydropower Station is located at the Jinsha River Gorge, where Leibo County of Sichuan Province and Yongshan County of Yunnan Province are bordering. The electricity it generates is mainly supplied to east and south China. A total of 18 hydroelectric generating units with a single-unit capacity of 770 MW are installed in the power station. The total installed capacity of the power station is 13,860 MW, and the highest dam is 285.5 meters. It is the world's first high-arch mega hydropower station with double-digit gigawatt capacities, which won the FIDIC Project Awards in 2016. The Station was officially put into operation at the end of 2005, and the first units began to operate in July 2013. All of its 18 units were put into operation at the end of June 2014. As of December 2021, the cumulative electricity output reached 475.4 TWh.

Xiangjiaba Hydropower Station is located at the outlet of Jinsha River Gorge, at the junction of Yibin City in Sichuan province and Shuifu City in Yunnan province. The Station was designed primarily for electricity generation, and has integrated functions including flood control, shipping, irrigation, and sand control. It is equipped with eight hydropower generating units with a single capacity of 800 MW and the world's largest vertical ship-lift with a lifting height of 114.2 meters. Its construction officially commenced in November 2006, and the first unit was put into operation in November 2012. All of its units began to generate electricity in July 2014. On May 26, 2018, the ship-lift was opened to traffic on a trial base. By the end of 2021, the cumulative electricity output of the power station topped 260 TWh.

Wudongde Hydropower Station is located at the border river section between Yunnan province and Sichuan province. It is mainly for power generation, and has integrated benefits including flood control, shipping improvement and facilitating local economic and social development. The Station has a total installed capacity of 10,200 MW, with six 850 MW hydroelectric generating units installed in each of the left and right bank underground workshops. The construction of project started in 2011 and all units went into operation in June 2021.

The Changlongshan pumped storage power station, the largest pumped storage hydropower facility in East China in terms of installed capacity, achieved maximum operational capacity in June 2022. The station, which is equipped with six pumped storage power units with a total installed capacity of 2.1 million kilowatts, can generate nearly 2.5 billion kilowatt hours (kWh) of electricity each year. On a full charge, the station can generate more than 6 million kWh of electricity, equivalent to the normal daily consumption of nearly one million households. It is also expected to reduce emission of carbon dioxide by about 420,000 metric tons and sulfur dioxide by 2,800 tons, annually after all units are put into operation.

2.1.2 Coordinated Development of Wind Power

2.1.2.1 Distribution of wind power resources

China's wind energy resources are mainly distributed in three major regions: the northern region (Inner Mongolia, northeast China, and northwest China); the eastern and south-eastern coasts and offshore islands bordering the sea; Hunan Hengshan, Hubei Jiugongshan, Anhui Huangshan, Yunnan Taihuashan and northern Qinghai-Tibet Plateau and other inland areas are rich in wind energy resources.

According to the 14th Five-Year Plan for Renewable Energy Development, China will advance the construction of offshore wind power bases in an orderly manner, focusing on the construction of five major offshore wind power bases in the Shandong Peninsula, the Yangtze River Delta, southern Fujian, eastern Guangdong and the Beibu Gulf.

2.1.2.2 Wind power generation

According to China Statistic Yearbook 2021, in recent years, China's wind power industry has grown rapidly, from 185.8 TWh in 2015 to 406 TWh in 2019, with an increase of 118.51% in five years.

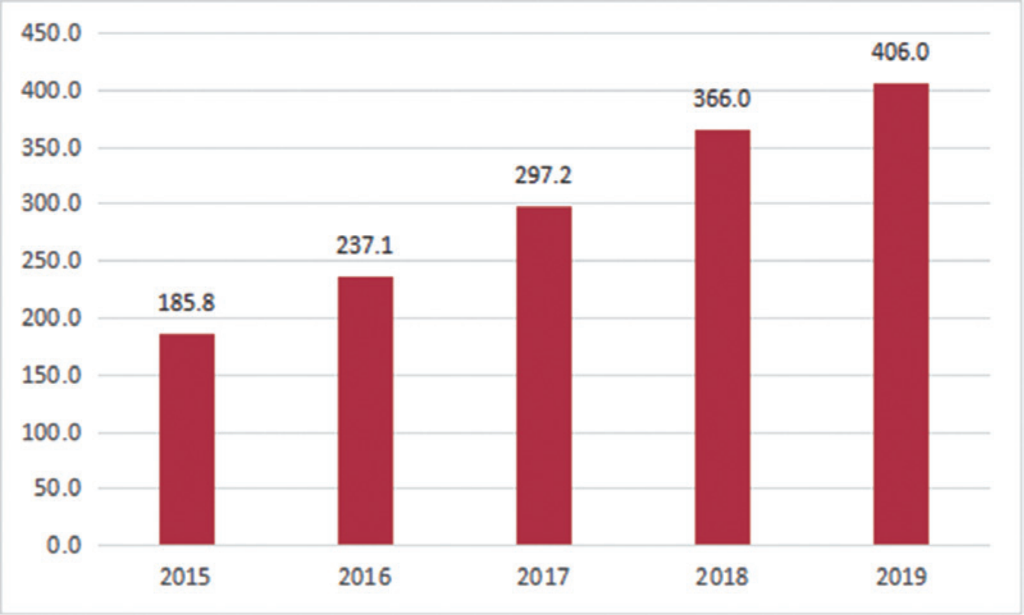

Figure 2.3 Wind power generation (2015-2019) (TWh)

Source: China Statistic Yearbook 2021.

Over the past decade, China's installed wind power capacity has shown an upward trend. From 46.23 Gigawatts in 2011 to 281.65 Gigawatts in 2020, an increase of more than 5 times in 5 years. Data from the National Energy Administration showes China's installed capacity of grid-connected wind power has reached 300.15 Gigawatts in 2021, doubled that of 2016, and it has topped globally for 12 consecutive years. With its contribution to the country's power supply continuously increasing, wind power currently accounts for 13 percent of the country's total power installation. Generating capacity of wind power accounts for 7.5 percent of total power consumption. The two figures increase 0.3 percentage and 1.3 percentage points, respectively, compared to 2020.

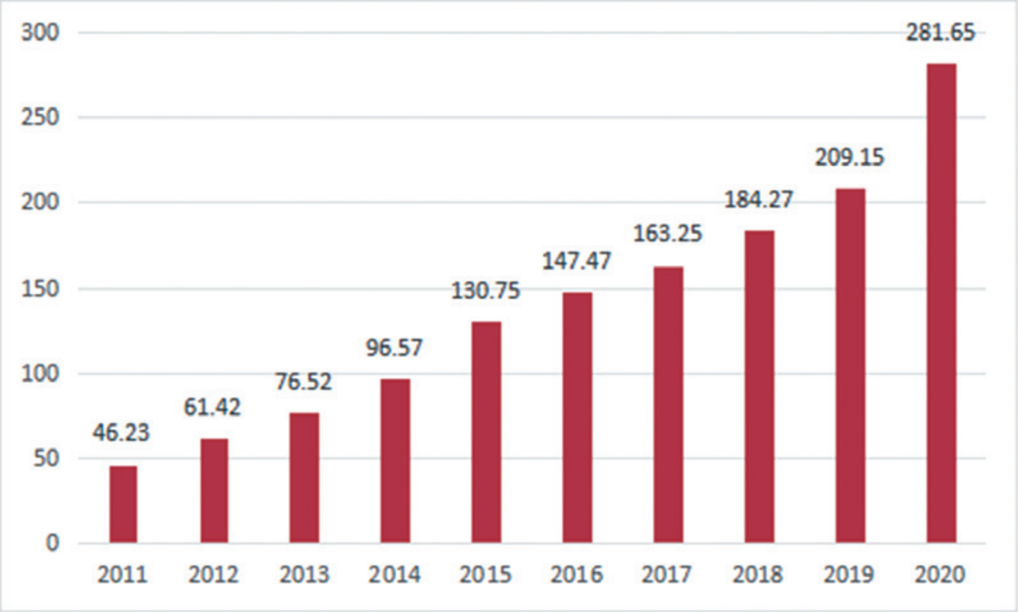

Figure 2.4 Installed capacity of wind power generation (2011-2020) (GW)

Source: China Statistic Yearbook 2021 and China Electricity Council.

China has become the world's largest wind power equipment manufacturing base as well as a key exporter of wind turbines and components. The innovation capacity of China's wind power industry technology has also been on the rise. It has been capable of manufacturing large megawatt-sized wind turbines. China is also capable of carrying out independent research, development and manufacturing of the key and core components, with a competitive wind power industrial system on the global stage.

2.1.2.3 Leading enterprises and major projects

Xinjiang Goldwind Science &Technology Co., Ltd produces large-scale wind turbines. It also builds and operate pilot wind farms. It is a leader in China's wind power equipment R&D and manufacturing industry and the world's leading wind power overall solution provider. The company is the largest manufacturer of wind power equipment in China. So far, it has delivered over 44,000 wind turbines all over the world with a global cumulative installed capacity exceeding 86 GW and an operations and maintenance (O&M) service capacity exceeding 50 GW.

According to the *14th Five-Year Plan for Renewable Energy Development* in 2022, China will:

- Promote the development and construction of tens of Gigawatts of offshore wind power bases such as the Shandong Peninsula, the Yangtze River Delta, southern Fujian, eastern Guangdong, and Beibu Gulf, promote the centralized continuous development of a number of megawatt-level key projects, and promote the demonstration of offshore wind power parity and offshore energy island demonstration projects in conjunction with the development and construction of bases.

- Support innovation and demonstration application of floating wind turbine foundation and far-sea flexible HVDC transmission technology, and plans to start construction of China's first floating commercial offshore wind power project during the "14th Five-Year Plan" period. In Guangdong, Guangxi, Fujian, Shandong, Jiangsu, Zhejiang, Shanghai and other areas with good resources and construction conditions, combined with the construction of base projects. with the construction of a number of megawatt-level far-sea offshore wind power demonstration projects, and strive to build one or two affordable offshore wind farm projects by 2025.

- Combined with the development of key wind power bases such as The Shandong Peninsula, the Yangtze River Delta, Southern Fujian, Eastern Guangdong and Beibu Gulf, the plan also includes regional energy storage, seawater desalination, marine aquaculture, etc., and build 1 to 2 offshore energy island demonstration projects in or near the base.

- Coordinate The offshore wind power projects with oil and gas fields development. Complementarities of offshore wind power and oil and gas fields will be considered for power supply model for regional power systems, and gradually the development of offshore wind power and offshore will be integrated by oil and gas industries.

2.1.3 Safe and Orderly Development of Nuclear Power

2.1.3.1 Distribution of nuclear power resources

China has been the second-largest worldwide in terms of nuclear-installed capacity and generation capacity while it has also become a pioneer in the global nuclear sector with advanced nuclear chain advantages after years of development.

From the perspective of regional proportion, nuclear power generation is mainly concentrated in East China, South China and Northeast China. In 2020, east China had the highest amount of nuclear power generation, accounting for 52.2%, followed by south China, accounting for 38.9% of nuclear power generation. Nuclear power generation in the northeast accounted for 8.9%.

According to the "14th Five-Year Plan" (2021-25) on Modern Energy System Planning released by the National Development and Reform Commission and the National Energy Administration, the government vows to step up the installed capacity for nuclear power plants in operation to 70 gigawatts by 2025, up from 51 GW at the end of 2020. The country vows to actively promote the construction and rational deployment of coastal nuclear power projects with an emphasis on security and maintenance of a stable construction pace. The plan also calls for wider promotion of the use of nuclear energy to heat residential and industrial areas and desalinate seawater. After two cities in China — Haiyang, Shandong province and Haiyan, Zhejiang province — have already successfully achieved commercial nuclear heating during the 2021-2022 heating season.

Demonstration projects of advanced reactor types including high-temperature gas-cooled reactors, fast reactors, modular small reactors and offshore floating reactors should be conducted, while the country should also step up the digitalization of the country's energy system, according to the plan.

2.1.3.2 Nuclear power generation

Since 2015, China's nuclear power generation has grown at a high rate. It grew from 170.8 billion kWh in 2015, to 348.4 billion kWh in 2019, an increase of more than 103.98% in 5 years.

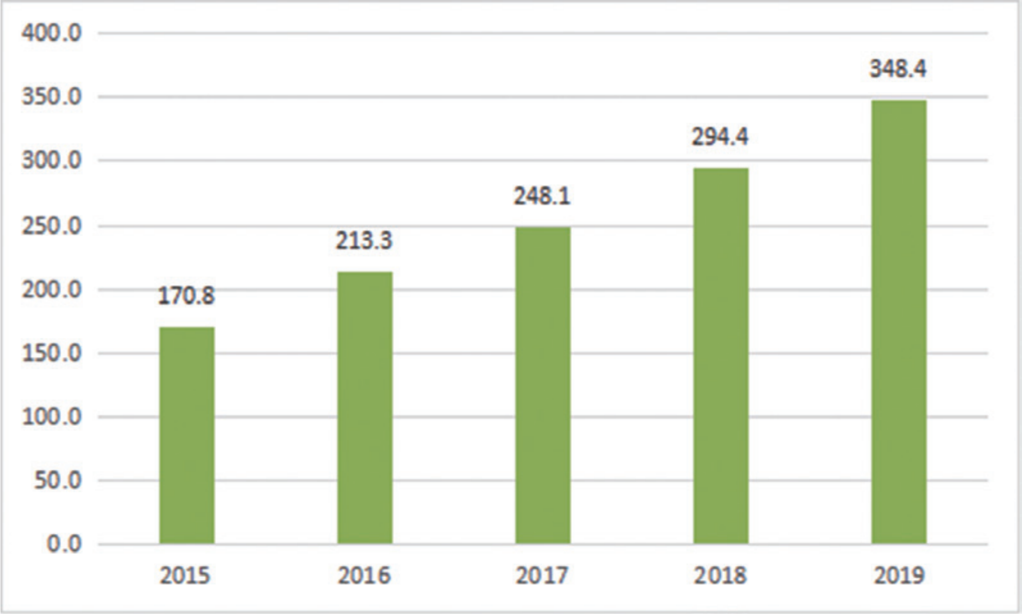

Figure 2.5 Nuclear generation (2015-2019) (TWh）

Source: China Statistic Yearbook 2021.

China's nuclear power generation market is moving towards a golden age. In 2020, China's installed nuclear power capacity reached 49.89 gigawatts, an increase of nearly 3 times from 12.57 gigawatts in 2011.

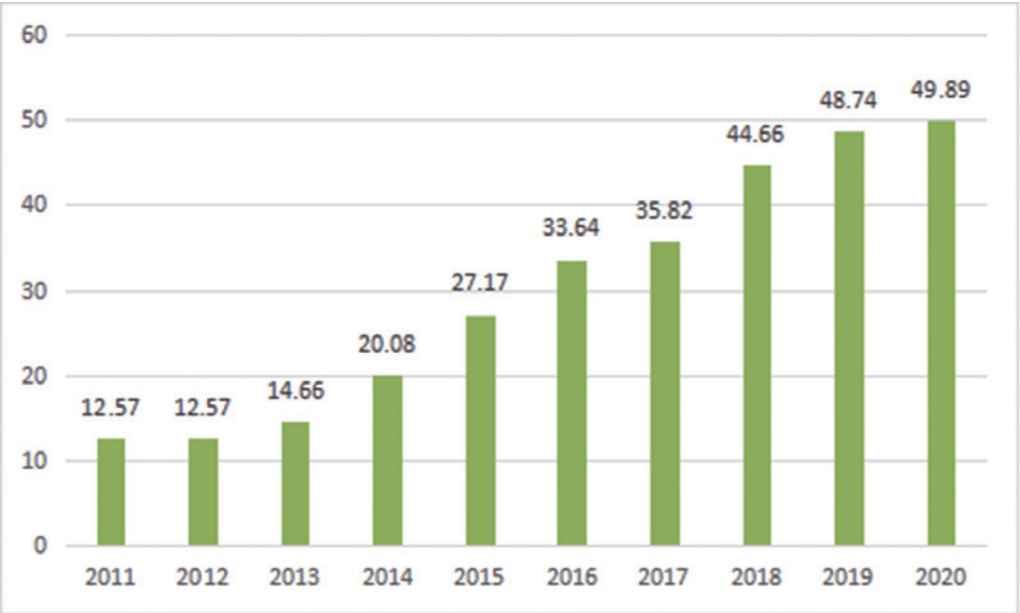

Figure 2.6 Installed capacity of nuclear power generation (2011-2020) (GW)

Source: China Statistic Yearbook 2021 and China Electricity Council.

2.1.3.3 Leading enterprises and major projects

China National Nuclear Power Co., Ltd. invests holds 7 nuclear power bases in operation and under construction, including Qinshan Nuclear Power, Jiangsu Nuclear Power, Sanmen Nuclear Power, Fuqing Nuclear Power, Hainan Nuclear Power, Zhangzhou Energy and Liaoning Nuclear Power. In 2021, electricity for commercial operations generated by the company's nuclear-power units totaled 182.637 billion kWh, an increase of 18.61% year-on-year, of which nuclear power generation was 173.123 billion kWh, an increase of 16.71% year-on-year.

China General Nuclear Power Corporation (CGN) was founded in 1994 and focused on the development of clean energies such as nuclear power, nuclear fuel, wind power, and solar power. As of the end of 2019, it has a total in-service installed capacity of 27.14 GW of nuclear power (accounting for 55.7% of the Chinese mainland), ranking first in China and in the top five internationally. CGN, boasting a total installed capacity of 5.78 GW under construction or with approval for construction (accounting for 42.2% in the Chinese mainland), is the largest nuclear power constructor in the world.

Qinshan Nuclear Power Base is the birthplace of nuclear power in mainland China and is located in the central area of the power grid load in East China. At present, Qinshan Nuclear Power Base has a total of 9 operating units, with a total installed capacity of 6.55 Gigawatts and an annual power generation of about 50 TWh, which is the nuclear power base with the largest number of nuclear power units, the richest reactor type and the largest installed capacity in China.

Sanmen Nuclear Power Co., Ltd. plans to build six 1.25 Gigawatt nuclear power units with a total installed capacity of 7.5 Gigawatts, which will be built in three phases. The first phase of the project was officially started on April 19, 2009, which is a third-generation nuclear power autonomy support project in China, and also the single project with the largest investment in the history of Zhejiang province, and its first-stadge project is the world's first AP1000 nuclear power unit, which was put into commercial operation on September 21, 2018; its second stadge was eligible for commercial operation on November 5, 2018.

"Hualong One" is China's third-generation nuclear power technology with full intellectual property rights. It is one of the most widely accepted third-generation nuclear power reactors in the current global market.

Haiyang Nuclear Power Plant located in Haiyang city, east China's Shandong province, makes Haiyang the country's first zero-carbon heating city with nuclear energy. The Haiyang Nuclear Power No.1 set has replaced 12 coal-fired boilers, reducing CO_2 emissions by 180,000 tons.

2.1.4 Diversified Utilization of Solar Energy

2.1.4.1 Distribution of solar power resources

According to the China Meteorological Administration, China's national average annual horizontal surface radiation was 1,493.4 kWh/m^2 in 2021. The solar energy resources in the western and plateau regions are higher than those in the central, eastern and plain regions. Specifically, Xinjiang, Tibet, central and western Northwest, western Southwest, central and western Inner Mongolia, northwestern North China, southeastern South China, and parts of southeastern China have a total annual horizontal plane irradiation of more than 1,400 kWh/m^2. Among them, in most of Tibet, western Sichuan, western Inner Mongolia, northwestern Qinghai and other places, the total annual horizontal irradiation exceeds 1,750 kWh/m^2; in most of Xinjiang, central and western Inner Mongolia, central and western Northwest, northern Shanxi, northern Hebei, Eastern Tibet, most of Yunnan, southern Fujian, eastern Guangdong, and most of Hainan have a total annual horizontal surface irradiation of 1,400 kWh/m^2-1,750 kWh/m^2; The eastern and southern parts of North China, most of East China, Guangxi, western Guangdong, most of Central China, central Sichuan, eastern Yunnan, and southwestern Guizhou have a total annual horizontal surface irradiation of 1,050 kWh/m^2-1,400 kWh/m^2; in eastern Sichuan, Chongqing, central and northern Guizhou, northwestern Hunan and southwestern Hubei the total annual horizontal irradiation is less than 1,050 kWh/m^2.

2.1.4.2 Solar power generation

In the past ten years, the scale of China's photovoltaic industry has continued to expand and the installed capacity of solar photovoltaic power generation has shown a rapid upward trend. In 2020, China's installed solar photovoltaic power generation capacity was 253.56 Gigawatts, an increase of 24.18% year-on-year, compared with 2.12 Gigawatts in 2011, an increase of more than 100 times.

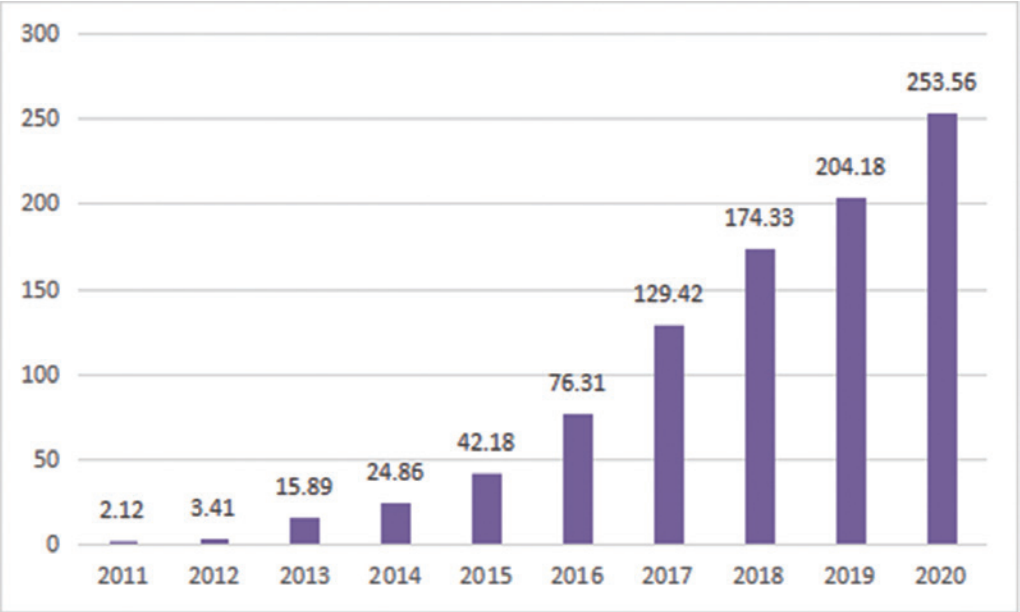

Figure 2.7 Installed capacity of solar power generation (2011-2020) (GW)

Source: China Statistic Yearbook 2021 and China Electricity Council.

2.1.4.3 Leading enterprises and major projects

According to the *14th Five-Year Plan for Renewable Energy Development in 2022:* In southern Xinjiang, China will build a new energy base of 10 gigawatts with photovoltaic as the mainstay, and explore new development methods such as photovoltaic sand control. In east Xinjiang, wind power, photovoltaic power generation and solar thermal power generation are combined to build a new energy base of 10 gigawatts.

China will give full play to the advantages of hydropower regulation in the upper reaches of the Yellow River, focusing on the overall promotion of photovoltaic power generation and wind power base development in Qinghai Haixi Prefecture, Hainan Prefecture and other areas. They include 10 Gigawatt-class wind power photovoltaic bases in Qingyang, Baiyin and other areas in Gansu province.

Focusing on the Kubuqi, Ulanbuhe, Badain Jarin and Tengger Desert areas in western Inner Mongolia, the Tarim Basin in southern Xinjiang, the Qaidam Basin in western Qinghai, the northern part of the Hexi Corridor in Gansu, and the northern Shaanxi region, China will coordinate resource conditions and consumption capacity, and build a number of photovoltaic sand control new energy power generation bases. China will also promote the development of desert governance, drought-tolerant crop planting, tourism and other related industries.

2.1.5 Scientific and Effective Development of Hydrogen

Globally, hydrogen has become an important strategic choice for major developed economies seeking to accelerate their energy transformation and upgrading. China is currently the largest hydrogen producer in the world, with an annual production output of about 33 million metric tons.

In March of 2022, Chinese authorities released a plan on the development of hydrogen energy for the 2021-2035 period as the country races toward its carbon peaking and neutrality goals[①].

According to the plan, by 2025, China will put in place a relatively complete hydrogen energy industry development system, with the innovation capability significantly improved and the core technologies and manufacturing processes basically mastered, according to the plan jointly released by the National Development and Reform Commission and the National Energy Administration.

By 2025, annual hydrogen production from renewable energy is expected to reach 100,000 metric tons to 200,000 metric tons to become an important part of new hydrogen energy consumption and enable carbon dioxide emission reduction of 1 million to 2 million metric tons per year.

By 2030, China is seeking a reasonable and orderly industrial layout and a wide use of hydrogen production from renewable energy to offer solid support for the carbon peaking goal.

By 2035, the proportion of hydrogen produced from renewable energy in energy consumption will increase significantly, which will play an important supporting role in the national green energy transformation, according to the plan.

2.2 Green Energy Development in Brazil

2.2.1 Hydropower

Seen as a mature technology, hydropower is the renewable electricity generation source with a larger share on the global energy mix, performing an important role with respect to the power system decarbonization and green development improvement. However, the expansion potential is globally limited, and its contribution is modest in long term decarbonization strategies such as the net zero carbon by 2050 (IEA, 2021; IEA, 2022a).

Furthermore, to the period from 2021 to 2030 is forecasted a decreasing of 23% with respect to the hydropower global net capacity additions when compared with the previous decade. Brazil is the world's second largest generator of hydroelectricity, large hydropower plants account for around 65% of domestic electricity generation[②]. However, several periods of drought have negatively affected the country's hydropower generation capacity (Hirons, 2020).

① http://english.www.gov.cn/statecouncil/ministries/202203/23/content_WS623ac568c6d02e53353282a4.html
② Average of the share of hydropower generation in the last 10 years (2012-2021) (EPE, 2022)

Despite its importance in the Brazilian green energy development, hydroelectric power engenders some controversies related to the construction of dams and reservoirs. They are essential to hydro plants operation, but they cause negative impacts and damages, mainly with respect to social and environmental aspects[①].

As the remaining hydro potential is majorly located in sensible environmental areas such as the Amazon region, generation capacity expansion faces strong opposition. It may threaten river ecosystems and the local biodiversity, as well as submerge landmasses in the process (Murray, 2022).

Moreover, as the highest energy demand comes from Brazilian southeast coast, hydropower expansion require costly transmission infrastructure and create reliability challenges to the system as a whole (Murray, 2022).

Due to these characteristics, hydropower should contribute little to the expansion of the Brazilian electrical system. In the ten-year plan – PDE 2031, the expansion of hydroelectric generation capacity (8.5 GW) represents only 11% of the expected expansion of generation capacity (EPE, 2022a).

2.2.2 Nuclear

Brazil began developing nuclear technology in 1951 under the National Research Council (CNPq) and accelerated its development under military rule from 1964 to 1985 (WNA, 2021). Angra 1 was the first nuclear power plant to enter commercial operation in Brazil in 1985. This first unit was a turn-key project contracted to Westinghouse which, for a certain period, presented poor operating performance (TOLMASQUIM, 2016).

The civil works of the second plant, Angra 2, started in 1976, but due to lack of financial resources and the lower-than-expected growth in demand, the unit only started to operate commercially in February 2001.

A third nuclear plant with 1,405 MWe generating capacity was planned for the same site, Angra 3. It was designed to be a twin nuclear power plant to unit 2, but incorporating the technological advances, as digital instrumentation, and control systems. Its construction began in 1984, but it was later suspended. Corruption investigations involving Eletronuclear and the difficulty of financing interrupted the work and delayed the construction schedule beyond 2026. USD 1.6 billion has already been invested in the construction of Angra 3. It is estimated that it will be necessary to invest another USD 3 billion to complete the plant. It is expected to start operating in 2027.

In Brazil, the technological option is the pressurized water reactors (PWR), the most frequently adopted technology worldwide, with more than 60% of the plants in operation. According to

① Changes in water quality, emission of greenhouse gases, people relocation, and loss of genetic patrimony have risen as a result of hydropower plants construction in Brazil.

the Ten Year Energy Plan (PDE) 2030 (EPE, 2021), after 2030, new projects may be based on PWR technologies, modular or small and medium-sized reactors (SMRs) and fourth-generation reactors, if the latter reach technological maturity and competitiveness.

The Ten-Year Energy Plan (PDE) 2031 foresees the contracting of a new nuclear plant of 1,000 MW in 2031 in addition to Angra 3. A more robust expansion was considered in the long-term National Energy Plan - PNE 2050 (EPE, 2020)[①]. It indicated an expansion from 8 to 10 GW (up to 8 new nuclear plants) in 30 years.

At the 26th edition of the United Nations Conference on Climate Change (COP26), the then Minister of Mines and Energy (MME) announced the possibility of contracting new nuclear plants from energy auctions in the short term, with the private construction of new projects from 2023, 2024, 2025.

In January 2022, the MME entered into an agreement with the Electric Energy Research Center (Cepel) to study potential locations for new Brazilian nuclear plants. The Southeast region is a strong candidate, especially Rio de Janeiro. In previous evaluations, Pernambuco appeared as the preferred region for the installation of a new plant.

Rio de Janeiro will also be the headquarters of Brazilian Holding Company in Nuclear and Binational Energy (ENBpar), a new state-owned company created in September 2021 to take control of nuclear assets after Eletrobras privatization. ENBpar is linked to the MME and has the role of ensuring the maintenance of Union control over the operation of nuclear plants.

The Brazilian nuclear sector is undergoing restructuring and is in the process of building a new strategic legal framework. To meet this objective, the National Nuclear Security Authority (ANSN) was created in 2021, with a simplified structure. The ANSN was organized from a spin-off of the National Nuclear Energy Commission (CNEN) and is linked to the MME. The intention in the future is to convert the ANSN into a regulatory agency.

The ANSN was created to separate regulatory/supervision and execution activities from nuclear activities and installations, a conflict of competences pointed out by a domestic authority (Union Court of Auditors – TCU) and by an international authority (International Atomic Energy Agency – IAEA). ANSN's competence encompasses not only the production of nuclear energy, but also activities in agriculture, such as food irradiation and nuclear medicine.

Brazil has considerable uranium resources, although a large part of the national territory has not been prospected. The known resources are in the order of 244,788 tons of contained uranium (U_3O_8), distributed among the states of Bahia, Ceará and others (INB, 2021). The

① Brazilian energy planning is developed in two time spans. The planning for the next ten years is presented in the Ten Year Energy Plan (PDE) document. Long-term planning is presented for the next 30 years in the document National Energy Plan (PNE). The latest versions are PDE 2031 and PNE 2050.

PDE 2030 (EPE, 2021) considers that there is sufficient resource to supply, for 40 years, at least 14 nuclear power plants with 1,300 MW, operating with an average capacity factor of 85%. The country also masters all the technology of the nuclear fuel cycle, from mining to assembling the fuel element.

Uranium mining in Brazil is carried out by Nuclear Industries of Brazil - INB at its Uranium Concentration Unit – URA, located in the municipality of Caetité/BA. The unit is responsible for mining and mineral processing operations that result in the product called Uranium Concentrate – or yellowcake (U3O8). Uranium production in Caetité was restarted in 2020 after a 5-year stoppage (between 2015 and 2019), after the depletion of the explored deposit.
The fuel cycle stage (conversion and part of the enrichment) has been carried out abroad for reasons of scale. URENCO, a European consortium formed by Holland, Germany and England, is the main supplier of uranium enrichment services. Thus, the uranium enrichment process produced in Brazil is carried out abroad and sent to the Nuclear Fuel Factory – Reconversion. However, Brazil already has an enrichment unit located in Resende, licensed to enrich uranium to less than 5% of U-235 (TOALMASQUIM, 2016).

The challenges to achieve the goals of PNE 2050 are numerous, especially the economic viability of nuclear projects. The construction of these new plants is only feasible after the implementation of Angra 3, which was delayed several times.

The increase in the share of nuclear energy in the country's electricity supply matrix will depend on several environmental and regulatory factors. To prevent such factors from imposing restrictions that surpass technical limitations, it is necessary to define the business model to be used in the country, as well as to update the legal framework and the regulatory framework to allow the participation of private investors in partnership with the State.

There is growing interest in modular or small to medium size reactors (SMRs), particularly in remote locations or countries with smaller grids. Small reactors have the advantages of meeting the needs of local communities, do not require high investments and do not require an expensive power transmission system.

In Brazil, the Fixed Bed Nuclear Reactor (FBNR) is under development, with the Federal University of Rio Grande do Sul as the main developer. The FBNR is a pressurized water reactor (PWR), but its fuel elements are made of TRISO-type particles. The objective of the Fixed Bed Nuclear Reactor (FBNR) Project is to develop an innovative nuclear reactor with a simple design to be small, economical, safe, strong, and sustainable. The FBNR is a terrestrial nuclear power plant, designed for urban use or in remote locations. The reactor is being designed to produce electricity on its own or to operate as a cogeneration plant producing electricity, or desalination of water and steam for industrial purposes.

The FBNR is a small reactor (70 MWe) without the need for on-site refueling due to the long fuel cycle time. Each module is replenished at the factory and then transported to the site. No on-site refueling is necessary because the fuel elements are contained in the sealed fuel chamber and are transported to the factory for refueling under inspection conditions. The

FBNR is evaluated by the IAEA's INPRO Methodology which evaluated the project as having the potential to reach a total safety level.

Current efforts are being made to bring potential investors together with industrial partners to build the FBNR reactor prototype.

The different designs of small advanced modular reactors (SMRs) that are approximately one third the size of a typical nuclear power plant, with shorter construction time can represent cost savings in relation to traditional designs. SMRs can reduce project costs and mitigate business risks.

With advanced reactor designs comes the possibility of an expanded role for nuclear power. There is a wide variety of other non-electrical applications for which the new generation of reactors may be suited. These innovations include heat production and cogeneration for heavy industry, hydrogen and synthetic fuel production, desalination and off-grid applications. Taken together, the potential for large-scale construction using existing nuclear technologies (long-term operation), SMRs, hybrid nuclear power and hydrogen systems begin to reveal the full extent of the potential for nuclear power and nuclear innovations to play a role.

For nuclear power to reach the audacious target of 1,160 gigawatts of electrical capacity, 87 gigawatts of accumulated emissions would be avoided between 2020 and 2050. By 2050, nuclear power could displace 5 gigawatts of emissions per year, which is more than the entire US economy emits annually today (NEA, 2021a).

2.2.3 Biomass

Biomass is very relevant in the Brazilian energy mix. Biomass products represents 31% of the primary energy consumption in Brazil (EPE, 2022). The main energy uses of biomass in Brazil are biofuels, ethanol and biodiesel, and electricity generation.

Ethanol

The use of ethanol has been promoted in Brazil since 1975, when Proálcool was created. Initially, ethanol was used only mixed with gasoline, in the form of anhydrous ethanol: in 1977, Brazilian legislation required a mixture of 4.5% ethanol with gasoline. The first Brazilian cars fueled exclusively with hydrated ethanol appeared in 1978.

After a rapid diffusion in the early 1980s, ethanol vehicles came to represent 96% of light car sales in 1985. However, the withdrawal of incentives coupled to the fall of oil price discouraged the supply of the fuel. In the second half of the 1980s, there were episodes of shortages and sales of ethanol vehicles plummeted. Even so, ethanol consumption remained relevant due to the hydrous ethanol fleet already in circulation and the mixture of anhydrous ethanol in gasoline.

A new moment for the Brazilian ethanol market began with the emergence of the flex-fuel car in 2003, which can use ethanol or gasoline in any proportion. Hydrous ethanol sales in Brazil increase as the flexible fleet spreads. Today, flexible models represent 73% of the Brazilian car fleet (Sindipeças, 2022).

According to current legislation, the ethanol mixture can vary from 18% to 27.5% and is currently set at 27% (E27) for the final gasoline sold in gas stations. Regular gasoline is the official term used for gasoline blended with anhydrous ethanol.

RenovaBio, established by Law No. 13.576/2017, is a government policy that seeks to promote the use of biofuels. It is based on the establishment of annual targets for reducing carbon intensity, in units of gram of CO_2 per mega joule (gCO_2/MJ) of the transport energy matrix for a minimum period of ten years. The targets give rise to obligations for fossil fuel distributors to acquire Biofuels Certification and Decarbonization Credit (CBIO) from biofuels producers. Its effective operation began in 2020. ANP has authorized[①] 267 ethanol plants, 30 biodiesel plants and 3 biomethane plants to provide CBIOs, (EPE/PDE 2031).

Established through CNPE Resolution No. 7/2021, the Fuel of the Future Program aims at increasing the share of sustainable and low-carbon fuels, integrating various public policies, such as RenovaBio, the National Program for the Production and Use of Biodiesel (PNPB), the National Vehicle Labeling Program and Route 2030. The Program will also study the use of aviation biokerosene and sustainable alternatives in the maritime sector, measures to capture carbon in the production of biofuels and ways of using hydrogen as fuel.

Currently, the Brazilian government has different tax policies for ethanol in relation to gasoline, both in CIDE and PIS/COFINS[②]. In addition, governments of several states offer different treatment for ethanol, using different ICMS[③] rates for ethanol and gasoline. It is also worth mentioning that the IPI[④] on flex-fuel cars is lower compared to vehicles powered only by gasoline.

In 2021, Brazilian ethanol production was estimated at 30.43 billion liters, down 13% from the revised figure for 2020 (35.08 billion liters), mainly because sugarcane production was severely harmed and favored the production of sugar.

The Ministry of Agriculture, Livestock and Supply registered, in December 2020, 361 ethanol and sugar production units in Brazil, whose effective installed crushing capacity was 745 million tons of cane (Mtc) (capacity factor of 90% of the nominal).

According to the ANP, the units authorized to produce ethanol had annual anhydrous and hydrated production capacity of 23 billion liters and 43 billion liters, respectively (considering an average of 180 days of harvest).

① Until November 2021.

② Contributions for Intervention in the Economic Domain – CIDE and Social Integration Program -PIS/ Contribution to Social Security Financing – COFINS are federal taxes.

③ Tax on the Circulation of Goods – ICMS is state level tax.

④ Tax on Industrialized Products – IPI is federal tax.

Ethanol can also be produced through other inputs, such as bagasse, straws and tips (E2G) and corn. Brazil has two commercial second-generation ethanol plants (Granbio and Raízen), with nominal production capacity of 60 and 42 million liters per year, respectively.

Biodiesel

The Brazilian experience with biodiesel is the most recent of the programs to stimulate energy use of biomass. The National Biodiesel Production and Use Program (PNPB) was established by Law No. 11.097/2005. Since then, more than 52 billion liters of this biofuel were produced by September 2021. Comparatively, Brazil is among the three largest consumers of biodiesel, after Indonesia and the USA. But unlike other major markets in Europe and the United States, Brazil only uses biodiesel mixed to fossil diesel. In relation to exports, the Brazilian share has never been significant, with only 3.8 million liters exported in 2020. The national biodiesel sector registered a total of 50 production plants in August 2021, concentrated in the Central-West and the South regions (USDA, 2021).

Initially the addition of biodiesel to fossil diesel in the percentage of 2% was authorized, becoming mandatory in 2008. The percentage reached 5% in 2010 and, since then, there has been rapid evolution, reaching 13% in March 2021, with a schedule to advance to 15% in 2023. Law No. 11,097/2005 provides a broad definition for biodiesel, as any fuel derived from renewable biomass for use in Diesel cycle engines.

About 75% of the biodiesel produced is made from soybean oil and 6.5% comes out from animal fat. Other raw materials are palm oil (2%), cottonseed oil (1.7%) and cooking oil (1.4%). Raw materials represent around 75% to 80% of the cost of producing biodiesel, while other inputs such as methanol and additives represent 10%.

As of January 2022, a new model of commercialization of biodiesel has begun. It promotes free negotiation between biodiesel producers and distributors and requires that 80% of the supply come from plants with the Social Biofuel Label (SBS), maintaining the current rule of priority participation of family farming (EPE/PDE 2031).

Bioelectricity

Biomass thermal generation accounts for 16 GW of power capacity, about 9% of the Brazilian electrical matrix. Sugarcane bagasse is the most used fuel, with 73% of the power generation by biomass (ANEEL/SIGA, 2022).

The extraction of sugarcane juice generates bagasse as residue, and the production of ethanol and sugar gives rise to filter cake and, in the case of biofuel, vinasse. In addition to these, the sugarcane harvest also generates residual biomass composed of straw and tips (EPE, 2022).

The cogeneration of heat and power by sugar and ethanol producers is very traditional in Brazil. In 2004, the Incentive Program for Alternative Sources of Electric Energy (PROINFA) created new stimulus.

In addition to energy self-supply, sugarcane biomass plants sell electricity in the regulated (ACR) and free (ACL) contracting environments. In the ACR, energy purchase and sale operations are made through auctions. The auction model was structured to ensure greater transparency and competition in energy trading by distribution companies. In the ACL, the agents of generation, commercialization, import, export, and free consumers act in freely negotiated bilateral energy purchase and sale contracts, with distributors not being allowed to purchase energy in this market.

To increase the competitiveness of sources derived from biomass and stimulate the growth of bioelectricity in the Brazilian electricity matrix, the federal government created regulatory mechanisms and incentive policies, such as specific auctions. In 2008, the first reserve energy auction (LER 2008) was held, focused exclusively on biomass. On this occasion, more than 590 MWmed were contracted at maximum value, with start-up scheduled for the years 2009 and 2012.

Among the 369 sugarcane plants in operation in 2021, about 220 units sold energy and approximately 40% of these did so through energy auctions. By August 2021, 60 contests had been held, with energy sales from sugarcane plants in 30 of them (CCEE, 2021). Over the last few years, the commercialization of bioelectricity in the ACR has decreased, despite reducing its participation in the national electricity matrix. In this sense, even with the realization of future events, in which this amount can be increased, the tendency is that the ACL and the settlement of energy in the spot market (PLD) are configured as the majority for the sale of energy in this segment. Thus, the total energy contracted from these units in the ACR will reach approximately 1 GWaverage by the end of 2025, in addition to the extra amount of 530 MWavg, which can be sold by the sugarcane biomass plants in the ACL or PLD in the same year. Included in the amount contracted in the ACR, there is energy from PROINFA projects, of 278 MWavg (ELETROBRAS, 2021).

Sugarcane biomass in electricity generation has a seasonal behavior and the increase in bioelectricity generation occurs during the harvest. The generation from other biomasses is more controllable and deterministic, mainly due to the possibility of storing the fuel. This is an important attribute for the electricity sector, contributing to increased energy security and systemic reliability.

The power granted for generation through other biomass (except sugarcane) represents 2.51% of the electrical matrix. Black liquor stands out, largely driven by the growth in production in the cellulose sector, biogas and forest residues. Despite the lesser participation, elephant grass, charcoal, rice husks, auto oven gas and firewood (ANEEL/SIGA) also contribute.

2.2.4 Solar

Photovoltaic solar energy is the main technology to produce electricity from the sun. The energy is obtained through the direct conversion of light into electricity, and the photovoltaic cell, manufactured with semiconductor material, is the fundamental unit of this conversion process.

As it is located almost entirely in the region limited by the Tropics of Cancer and Capricorn, with a vertical incidence of solar rays, Brazil has a high level of solar radiation in almost all its territory, even in winter. This condition gives the country significant potential for generating electricity from photovoltaic solar sources. In the 2010s, its use began to spread in Brazil due to new regulation of distributed generation connected to the grid and through auctions for contracting of centralized power plants.

Centralized Photovoltaic Generation

Centralized generation is characterized by large electric power production plants, requiring transmission and distribution lines for the energy to reach the final consumer. The contracting of energy can be carried out both in the Regulated Contracting Environment (ACR) and in the Free Contracting Environment (ACL). In ACR the energy is sold through public auctions to distribution companies. In ACL, large consumers buy energy through freely negotiated bilateral contracts.

The solar power auctions initiated in 2014. Initially, solar power was only negotiated in auctions designed to renewable sources. In 2017, solar power projects were first selected in general (technology neutral) power auctions as cost reductions made the technology more attractive. To date, 4.7 GW of solar installed capacity has been contracted in 10 public auctions (figure 2.8).

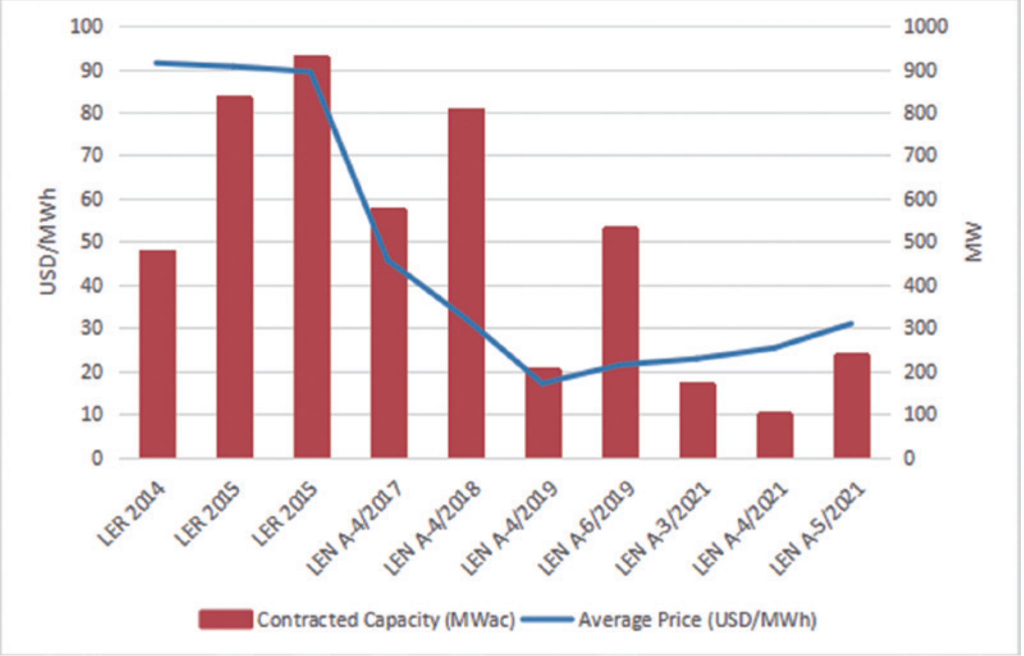

Figure 2.8 Solar power in ACR auctions - Brazil (Average price and Generating Capacity)

Note: LER – Renewable Oriented Auctions; LEN – General (Technology neutral) Auctions. A – X means that plant operation must start in X years.

Source: Greener (2022).

Recently, a significant volume of solar energy projects has been oriented to the free market. Law 14,120/2021 gives a 3-year deadline for granting discounts on transmission and distribution tariffs for renewable projects. Thus, renewable plants that enter after this period will pay full tariffs. This sparked a race for permits for solar energy projects. Licenses were issued for a total of 38 GW of solar generation aimed at the free market, although part of these projects might not be carried out.

Solar PV Distributed Generation

In 2012, a net metering system for renewable distributed generation was introduced in Brazil through the ANEEL Resolution 482/2012. This incentive mechanism for distributed generation (DG) consists of measuring the net flow of energy by bidirectional meters. If the distributed generation is bigger than the consumption, the excess is supplied to the grid and the consumer receives an "energy credit" that can be used when consumption is bigger than generation. Therefore, the distribution network works as a "battery" to distributed generation systems.

Initially, few consumers chose to install distributed generation systems in the metering scheme. However, as electricity prices increased after 2015 and the rules were amended DG became more attractive.

The net metering scheme is under review. The current method does not remunerate grid costs (as 1 KWh consumed can be compensated by 1 KWh generated). A new law (14,300/2022) reduces progressively the amount of consumption that can be compensated by new distributed generation. It stimulated a rush to install PV panels before the change in the rule of compensation (see figure 2.9).

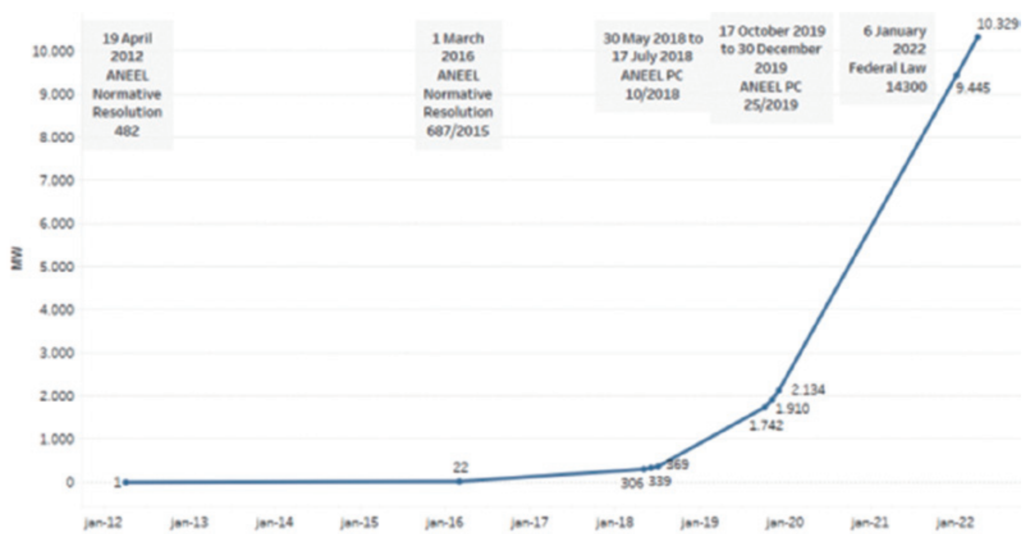

Figure 2.9: Evolution of accumulated installed capacity (MW) of Solar photovoltaic distributed generation - Brazil

Source: Elaborated by the authors using ANEEL data.

Law 14,300/2022 also created the Social Renewable Energy Program (PERS) which provides funds for the installation of solar panels in low-income consumers. However, its effectiveness will depend on the voluntary adhesion of the distribution companies. Losekann and Abuche (2022) indicates that it is necessary to complement its institutional design and financial resources to obtain a significant result.

In 2020, distributed photovoltaic technology led to the addition of installed capacity in Brazil, with almost 2.8 GW installed, surpassing all other technologies, including centralized generation. Since then, photovoltaic DG continues to develop at a fast pace, totaling 966 thousand installations and having surpassed the 10 GW mark in the first quarter of 2022 (see Figure 2.9).

Of the 10.3 GW of installed capacity in photovoltaic DG, the residential segment accounts for 4.7 GW, followed by commercial with 3.3 GW and rural with 1.4 GW. However, there is still only 1% of households with photovoltaic DG in Brazil. The high electricity tariff and remote work in the period of the Covid-19 pandemic contributed to greater adoption of DG in households. The solar energy boom resulted in the multiplication of integrator companies and equipment suppliers (there are 21,200 active photovoltaic integrators).

The disorganization of the global supply of solar panels because of the logistical restrictions resulting from the pandemic opens an opportunity for national suppliers to replace imports that are very significant today.

PV modules represent around 38% of the final price of a PV system. The main input of the module is metallic silicon (which represents 60% of the cost structure of inputs and is the raw material for polysilicon), so its price directly impacts the final price of PV modules. In 2021, the price of polysilicon increased by more than 200%, mainly due to production restrictions in China due to the Covid-19 pandemic, generating an imbalance between supply and demand for modules. The FOB price of the Mono PERC module increased by an average of 26%. International freight, which represented about 3% of the CIF price, reached 16% in 2021due to the lack of containers and congestion in ports.

Semiconductors and electronic components account for most of the total cost of photovoltaic inverters (48% and 30%, respectively). In 2021, demands for these components had increased due to the digitization process that was accelerated by the Covid-19 pandemic. This scenario culminated in global supply problems for these components and consequent increases in prices and freight, influencing the cost of inverters.

The structures are made of aluminum or steel to ensure material flexibility and longer useful life and are produced in Brazil.

2.2.5 Hydrogen

IEA (2019) identifies hydrogen as one of the sources that can facilitate decarbonization, especially in segments where electrification is not possible or too expensive (airlift and shiping). Hydrogen makes it possible to store and deliver energy in large amounts without emitting CO_2 during combustion. Hydrogen (H2) is an energy carrier and vector, being converted from other fuels, enables end-users to be less dependent on specific energy resources and increases the resilience of the energy supply. However, hydrogen is a green fuel only when produced from a renewable source such as wind, solar, or hydropower.

Brazil has a prominent position to become a big exporter of green hydrogen, due to its favorable conditions for generating electricity through wind, solar and hydro sources. Hydrogen production is currently concentrated in the refining and fertilizer sectors using processes with high CO_2 emissions. Brazil follows the global trend and produces it through the reform of natural gas, also called gray hydrogen. The Brazilian government transition strategy is to initially promote the production of blue hydrogen, that is, hydrogen produced from fossil fuels with carbon capture, utilization, and storage (CCUS) using emission reduction technologies that can be applied throughout the power system. Then, as production costs decrease, green hydrogen will be promoted.

The investments announced for the construction of plants producing green hydrogen (H2V) in Brazil reach more than US$ 27 billion, most concentrated in ports like Pecém in Ceará state, Suape in Pernambuco state, and Açu in Rio de Janeiro state. These ports combine strategic factors for developing the new H2V chain, such as logistics for exports due to their proximity to industrial centers, and abundant renewable energy sources like solar and wind. The port of Rotterdam, in the Netherlands, plans to supply 4.6 million tonnes/year of hydrogen to northwest Europe by 2030, with most of this volume coming from other continents. The distances between the port of Rotterdam and potential H2V exporters (Table 2.1) evidence the strategic location of Brazilian ports.

Table 2.1 - Distances between Rotterdam and potential H2V exporters

Harbor	km
Australia (New Castle)	16,250
Chile (Valparaiso)	12,400
Brazil (Fortaleza)	7,390

Source: Elaborated by the authors

The Ceará state has more than 22 signed intent memoranda for green hydrogen (H2V) projects. These include an agreement with the Australian Enegix Energy to set up a green hydrogen plant in the Pecém Industrial and Port Complex, located in the Fortaleza metropolitan region, with an estimated investment of US 5.4 billion, in addition to projects with other companies like Portuguese EDP for the installation of solar plant with a capacity of 3 megawatts (MW) for the hydrogen production. Porto Suape in Pernambuco state signed an investment agreement with companies such as the Neoenergia and Qair for the combined electrolysis processes, pumping, and liquefaction, allowing the product to be shipped over long distances, in addition to the reform of natural gas.

The Municipality of São Carlos (SP) signed an understanding memorandum with R20 (Regions of Climate Action) for the feasibility study of implementing a hydrogen production plant.

Unigel company inaugurated a nitrogen fertilizer unit that produces ammonia and urea and intends to build the first green ammonia plant expected to be operational by the end of 2022 in Camaçari, Bahia. In 2019, Brazil demanded around 36.2 million tons of fertilizers, of which 81.5% (29.5 million tons) were imported.

Fortescue Future Industries Pty Ltd and Porto do Açu have signed a Memorandum of Understanding (MOU) to develop a green industrial project hydrogen electrolyzer of 300 MW to produce 250,000 t/year of green ammonia in Rio de Janeiro. Rio Grande do Norte and Piauí states already have memoranda of understanding with the private initiative to produce H2V. And Minas Gerais state presents a green steel production project.

There are wide regional variations in hydrogen production costs today, and its future economy depends on fossil fuel, electricity, and carbon prices. Natural gas is currently the most cost-effective option for hydrogen production in most parts of the world, with costs as low as USD 1/kgH2 in the Middle East. Brazil is one of the most competitive countries to green hydrogen production. The Levelized Cost of green Hydrogen (LCOH) produced in Brazil would be around USD 1.50/H2kg in 2030 (Figure 2.10). Although other countries have competitive costs, a cleaner energy matrix can be an advantage for Brazil.

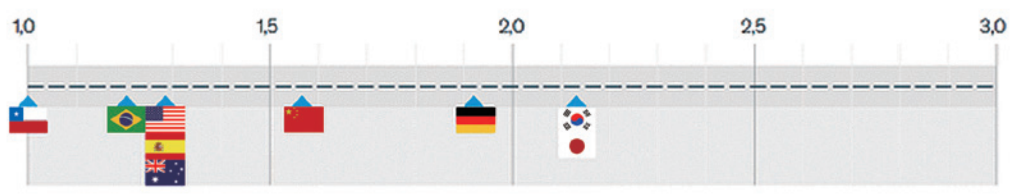

Figure 2.10 - LCOH Benchmark, 2030 USD/kgH2.

Source: Gurlit et al. 2021.

The research, development, and innovation strategy for hydrogen in Brazil does not start in recent. In 2002, the Ministry of Science, Technology, and Innovation (MCTI) launched the science, technology, and innovation program in the hydrogen economy, which promoted the formation and training of human resources, with an emphasis on graduate studies, in addition to the implementation of demonstration of different fuel cell systems and hydrogen production technologies.

In 2005, the Ministry of Mines and Energy (MME) launched the roadmap for structuring the hydrogen economy in Brazil, with a focus on evaluating different technological routes in which Brazil could have competitive advantages, such as water electrolysis, ethanol, and other biomasses. In addition to recognizing the natural gas role in the transition to the green hydrogen phase and the market diffusion logic definition for hydrogen with distributed energy generation.

① Now MCTIC, as 'Communication', became also the responsibility of this Ministry.

In 2010, the Ministry of Science, Technology, and Innovation (MCTI ①) and Management and Strategic Studies Center (CGEE) presented as the main national bottlenecks the small volume of investment in the area, the need for continuity of investments in R&D programs in hydrogen, and the lack of incentives to technology-based companies (CGEE, 2010). With so many challenges, it was only in 2018 that the MCTIC published the science, technology, and innovation plan for renewable energies and biofuels, aiming to promote studies on the potential of oceanic, heliothermal, offshore wind, and hydrogen (MCTIC, 2018).

In 2020, the MME presented the national energy plan (PNE 2050). The renewable energy potential in Brazil will be more than 17 times its demand in 2050, among the disruptive technologies, with emphasis on hydrogen, with the main challenges in the elaboration guidelines for their use, transport, and storage, as well as recommendations for designing regulatory improvements related to quality, safety, transport infrastructure, storage, and supply (MME/EPE, 2020).

The National Energy Policy Council (CNPE) Resolution No. 2 of February 2021 established guidelines on research, development, and innovation in the energy sector in Brazil, prioritizing the allocation of research resources to the following topics: (i) hydrogen; (ii) nuclear energy; (iii) biofuels; (iv) energy storage; (v) technologies for a sustainable thermoelectric generation; (vi) digital transformation; and (vii) strategic minerals for the energy sector.

The Brazilian government launched the Brazilian Hydrogen Energy Pact as part of the "United Nations High-Level Dialogue on Energy" which was the first global meeting on energy under the aegis of the UN since 1981. Ministry of Mines and Energy (MME) launched the guidelines (CNPE Resolution No. 6/2021) for the construction of the Brazilian National Hydrogen Program (PNH2). EPE developed technical bases for the consolidation of the Brazilian hydrogen strategy, with the main challenges and opportunities, emphasizing that in addition to green hydrogen, blue hydrogen and CCUS are important to make the process costs viable (EPE, 2021).

In August 2021, the MME launched the National Hydrogen Program (PNH2) whose principles are to value the national potential of energy resources; be comprehensive; align with the economy's decarbonization ambitions; value and encourage national technological development; aim for the development of a competitive market; seek synergies and articulation with other countries; and recognize the contribution of the national industry (MME, 2021). In 2022, EPE released a series of studies for gray (reform of natural gas), blue (reform of natural gas with CCUS) and turquoise (natural gas pyrolysis) hydrogen (EPE, 2022, 2022a, 2022b):

Regarding financing for renewables and low-carbon hydrogen, Brazil has have research, development, and innovation financing funds; and lines of financing at BNDES, FINEP, the private sector, and capital markets. Brazil has several research groups in universities and maintains laboratories of international standards to make technologies applicable to the national reality in the hydrogen sector, such as the Alberto Luiz Coimbra Institute of Graduate Studies and Engineering Research, of the Federal University of Rio de Janeiro (COPPE-UFRJ) with the Hydrogen Laboratory (LabH2), developing solid oxide fuel cells and electric-powered heavy vehicles, among others. At the initiative of LabH2 and with the collaboration of several research and development institutions, government agencies, and companies related to the subject, the Brazilian Association for Research, Development, and Innovation of Hydrogen was founded in April 2017 (ABH2) which is a non-profit association dedicated to hydrogen research in Brazil (GIZ, 2021).

The Hydrogen Laboratory (LH2) of the State University of Campinas (UNICAMP) studies: 1) hydrogen production through the processes of reforming natural gas, ethanol, and water electrolysis and hydrogen purification, 2) applications of hydrogen in projects of distributed generation of electric energy, using fuel cells and 3) applications of hydrogen in mobility, where the construction of the first vehicle powered by hydrogen and fuel cells of the type Polymeric Electrolytic Membrane (PEM) in the southern hemisphere stands out (GIZ, 2021).

Unicamp has a project with Nissan to study bioethanol as an option for electric mobility, having developed a prototype vehicle with a solid oxide fuel cell (SOFC) that runs on energy generated by ethanol. Hytron was created in 2003 as a spin-off from the University of Campinas and acquired in 2020 by NEUMAN ESSER GROUP of Aachen, Germany (NEA GROUP) and develops solutions in the engineering area and systems integration for energy and gas systems with a focus on in hydrogen.

The Hydrogen Research Center (NUPHI) of the Itaipu Technological Park (PTI) was an agreement signed with Itaipu Binacional and Eletrobras. The experimental hydrogen production plant makes it possible to analyze the entire cycle of obtaining and applying hydrogen, involving the production, purification, compression, storage, and subsequent use in fuel or combustion cells in mixing with other fuels, such as biomethane. The EMTU and USP study hydrogen buses in São Paulo in 2021; the Laboratory of Materials and Renewable Energy (Labmater) of the Federal University of Paraná, National Institute of Technology of the Ministry of Science, Technology, and Innovation; and the Technological Park of the Federal University of Ceará (UFC), which has more than twenty studies in progress focused on developing solutions for the green hydrogen hub (H2V), including hydrogen production study from sewage, without using electric energy.

Among the current initiatives it is worth mentioning the Brazil-Germany Energy Partnership for a Sectorial Mapping Study of Green Hydrogen in Brazil; the special study commission on hydrogen technologies ABNT/CEE 067 for the Standardization of H2 technologies; and the Public Policies for Renewable Energies Strategic Call for Hydrogen R&D Projects.

2.2.6 Petrobras Initiatives about green energy

Since 1975, when Proálcool was created, Brazilian public policies have stimulated the use of biofuels. The mandatory blending of biodiesel with fossil diesel (10%, with a forecast increase) and of ethanol with gasoline (27%) formed the basis for the great expansion of consumption and production of biofuels in Brazil.

Petrobras investments in renewable energy

The worldwide interest in renewable fuels in the 2000s motivated Petrobras to start new projects in the biofuel segment. In biodiesel, Petrobras started investing after the approval of the legal framework for the production and sale in Brazil. In December 2004, the federal government launched the National Program for the Production and Use of Biodiesel (PNPB), with the tax model for the new fuel and the mechanisms for including family farming in the production of raw materials. In the following year, Law No. 11,097/2005 introduced biodiesel into the Brazilian energy matrix. The mandatory addition of biodiesel to diesel oil came into effect in January 2008, with an initial percentage of 2%.

To achieve the biodiesel production target, Petrobras made investments in 2006 in three biodiesel production plants in the states of Ceará, Bahia and Minas Gerais. In July 2008, the first refinery was inaugurated, in Candeias (BA). The second biodiesel plant started producing in Quixadá (CE) in August 2008. In January 2009, the Montes Claros Plant (MG) started production. The three refineries were designed with the same production capacity, with a total of 170 million liters of biodiesel/year. In 2008, Petrobras created the company Petrobras Biocombustível to consolidate all initiatives related to biodiesel and ethanol and to establish partnerships with biofuel manufacturers. In this context, Petrobras created a program for the development of the regional agricultural market, with the objective of guaranteeing raw materials to produce biodiesel, which mainly uses soybean oil. Contracts for the purchase of vegetable oils were signed with small farmers and industrial producers[①].

In 2010, Petrobras produced around 11 thousand barrels/day, 10% of the Brazilian consumption. In the following year, the biodiesel production capacity increased, with the acquisition of 50% of the company BSBIOS Marialva Biodiesel Sul Brasil[②]. In 2012 Petrobras was one of the five largest biodiesel producers in Brazil. Petrobras has also started to use Residual Oils and Fats (OGR - used cooking oil), in its biodiesel plants[③].

Investments in ethanol were made in 2010, taking advantage of the company's available infrastructure for the distribution of ethanol in Brazil and for export. The first investment was made in association with Tereos International, a Brazilian subsidiary of the Tereos Grupo, from France, with investments of US$ 909 million in the acquisition of a 45.7% stake in Açúcar Guarani S.A., the fourth largest sugarcane processor in Brazil. Investments of US$ 244 million followed in the acquisition of a 49% stake in Nova Fronteira Bioenergia S.A., in partnership with Grupo São Martinho, to operate and expand production at the Boa Vista and SMBJ Agroindustrial S.A. plants. Petrobras also invested in Bioóleo Industrial e Comercial (production of castor oil, semi-refined cotton, and soybean oil), Bambuí Bioenergia and Total Agroindústria Canavieira S.A.[④]

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① Petrobras. Relatórios anuais Form 20F, 2007 a 2018. Available in: < https://www.investidorpetrobras.com.br/apresentacoes-relatorios-e-eventos/relatorios-anuais/>. Accessed May 03 2022.

② Petrobras. Relatório anual Form 20F, 2009, p. 69. Acesso em: 03 maio 2022.

③ Petrobras. Fatos e Dados, 02.07.2014. < https://petrobras.com.br/fatos-e-dados/petrobras-biocombustivel-produzira-mais-biodiesel-a-partir-de-oleo-de-cozinha-usado.htm>. Accessed: May 02 2022.

④ Petrobras. Relatórios anuais Form 20-F, 2009/2010.

Petrobras also invested in five wind farms (Mangue Seco 1, Mangue Seco 2, Mangue Seco 3, Mangue Seco 4 and Macau) in Rio Grande do Norte, with 106 MW of generating capacity, two small hydropower plants and one solar power plant, UFVAR[①].

Withdrawal from the renewable energy segments

In the 2014-2018 Petrobras Business Plan, the expansion of ethanol and biodiesel production was one of its main goals. In 2014, the company produced 17% of the total biodiesel consumed in Brazil. However, the financial crises following the corruption scandals forced the company to adjust its plan in 2015, focusing investments on pre-salt oil projects.

The state-owned company defined a broad program of asset sales to reduce debt and to focus on Exploration and Production of oil and gas. In 2016, it decided to exit from the biofuels production, a segment in which it had been making losses since 2013[②].

In December 2016, Petrobras sold its share (46%) in Guarani ethanol plant for US$202 million. It was followed by the sales of Nova Fronteira in 2017. In 2019, Petrobras has made four sales operations of its participation in: Belém Bioenergia, sold to Galp Bioenergy; BSBios Biodiesel Sul Brasil S/A; Bioóleo Industrial e Comercial S.A. (Bioóleo) held by PBio (6.07%); and Complexos Bioenergéticos S.A. (PCBios). In 2020, Petrobras sold Bambuí Bionergia. With the divestments, the state-owned company reduced its participation in the Brazilian production of biodiesel to 6%.

In April 2021, it finalized the sale of its stakes in the 4 Mangue Seco wind farms.

Perspectives for Petrobras in Renewable Energy

Petrobras exit from renewable energy production was motivated by the need to adjust debt indicators, after the credibility crisis in 2014-2015. Due to the portfolio adjustment and the increase in oil prices, the current financial situation is significantly better. The company gross debt reduced from US$ 132.2 billion, in 2014, to US$ 58.7 billion, in 2021[③]. In 2021, Petrobras profit reached US$ 21.2 billion.

The new financial context allows the company to review the role of renewable energy on its strategy, to reposition the company in the energy transition process. Most if not all the international oil companies are transforming themselves into energy companies and Petrobras should follow the same trajectory.

Some recent actions indicate a return of Petrobras to renewable energies, focusing on new technology segments such as renewable diesel, Bio Jet Fuel and Hydrogen. Renewable diesel is an alternative to Biodiesel. It is produced from vegetable oil, to be used in higher

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① Petrobras. Relatório anual Form 20F 2015, p.6-74. . Accessed: May 06 2022.
② Petrobras, Relatório Form 20-F, 2016, p. 113. Accessed: May 07 2022.
③ Petrobras. Relatórios Form 20F 2015/2021. . Accessed: May 06 2022.

concentrations in the mix with traditional diesel and even as a standalone fuel for diesel engines ① . Bio Jet fuel is considered an essential way to advance in decarbonization of transport, and the International Civil Aviation Organization (ICAO) requires its use from 2027②. Renewable diesel and Bio Jet fuel are mentioned as part of Petrobras strategy in the 2020-2024 Business Plan.

In the 2022-2026 Business Plan, Petrobras has planned US$ 600 million of investment on biorefinery, to produce renewable diesel, bio jet fuel. The company also started R&D projects for biobunker (fuel for ships) and other new renewable energy technologies ③.

The company is considering investing in the hydrogen segments and in nuclear, wind and solar energy generation, to improve its positioning during the energy transition.

① Petrobras. Fatos e Dados < https://petrobras.com.br/fatos-e-dados/petrobras-se-prepara-para-futuro-do-mercado-de-refino-e-gas-natural.htm#:~:text=O%20BioQAv%20ou%20bioquerosene%20de,obrigatoriamente%20a%20partir%20de%202027>. Accessed: May 09 2022.

② Petrobras. Fatos e Dados. “Petrobras se prepara para futuro do mercado de refino e gás natural”. 23.09.2020.< https://petrobras.com.br/fatos-e-dados/petrobras-se-prepara-para-futuro-do-mercado-de-refino-e-gas-natural.htm#:~:text=O%20BioQAv%20ou%20bioquerosene%20de,obrigatoriamente%20a%20partir%20de%202027>. Accessed: May 04 2022.

③ Petrobras. Plano Estratégico 2022-2026. <https://api.mziq.com/mzfilemanager/v2/d/25fdf098-34f5-4608-b7fa-17d60b2de47d/6d98b296-503c-53cc-1f9e-153a904e8066?origin=1>. Relatório anual Form 21, p. 15/164. Accessed: May 04 2022.

III. Green Energy Development: Strengths and Weaknesses

3.1 Chinese Perspective

3.1.1 Positive Policy Environment Guarantee the Development

In the 1990s, the Chinese government formulated an outline for the development of renewable energy and also started to promote renewable energy through legal means and economic incentive policies, but the country was still in the initial stage of exploration.

Until the period of the "Eleventh Five-Year Plan"(2006-2010), with the profound evolution of the global energy situation, China's energy policy was adjusted to "adhering to the priority of conservation, based on domestic, diversified development, relying on science and technology, protecting the environment, strengthening international mutually beneficial cooperation, and striving to build stability, economy, a clean and safe energy supply system supports sustainable economic and social development with sustainable energy development"[①].

In order to standardize and promote the development renewable energy, China has further improved its energy policy system and listed renewable energy as one of the priorities of energy construction during the "Eleventh Five-Year Plan" period. China's energy consumption per unit of GDP decreased by 19.1% during that period, and the utilization rate of non-fossil energy increased to 8.3%. At the same time, the national Chemical Oxygen Demand (COD) emissions decreased by 12.5% and sulfur dioxide emissions decreased by 14.5%. Since then, the Chinese central government's "Twelfth Five-Year Plan" has clearly put forward the goal of "green development, building a resource-saving and environment-friendly society", pointing out that "in the face of increasingly intensified resource and environmental constraints, it is necessary to strengthen the concept of low-carbon development, focus on energy conservation and emission reduction, improve the incentive and restraint mechanism, accelerate the construction of resource-saving and environment-friendly production and consumption models, enhance sustainable development capabilities, and improve the level of ecological civilization". [②]

As China has entered the stage of accelerated heavy industrialization, sustainable energy use has become the key point to safeguarding the interests of national development. Since the 18th National Congress of the Communist Party of China, various regions and relevant departments have formulated a series of policies and measures on green energy and low-carbon development, and have achieved remarkable results in promoting the development and utilization of clean energy[③].

The main goals and directions of the development of the energy industry provide important references for relevant institutions and enterprises to formulate development policies. In 2019, the National Development and Reform Commission of China issued the 2019 Catalogue for

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① "China's Energy Situation and Policy", http://www.nea.gov.cn/2011-08/22/c_131065968.htm

② http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm

③ http://www.gov.cn/zhengce/2020-12/21/content_5571916.htm the Guidance of Industrial Structure Adjustment①, which clearly proposed to encourage the utilization of solar energy, wind energy, ocean energy and geothermal energy. It emphasizes technology development and equipment manufacturing and encourage the development of production in the field of related machinery and equipment②.

In May 2020, based on the "Renewable Energy Law" and drawing on international experience, China's National Energy Administration issued the "Instructions on Establishing and Improving a Long-term Mechanism for Clean Energy Consumption and Consumption", trying to establish and improve a guarantee mechanism for renewable energy power consumption and to solve the problem of the delivery and consumption of hydropower, wind power and photovoltaic power during the utilization. In 2021, the NEA issued "Instructions on Accelerating the Development of New Energy Storage"③, proposed that it is necessary and important to build a clean, low-carbon, safe and efficient energy system to archive the goal of the carbon peaking and carbon neutrality. By 2025 China will realize the transformation of new energy storage from the initial stage of commercialization to large-scale development.

In order to implement the relevant requirements of the "Guidance on the Complete, Accurate and Comprehensive Implementation of the New Development Concept and the Carbon Neutralization of Carbon Peaking" and the "Carbon Peaking Action Plan before 2030", the NEA released in 2022 the “On Improving Energy Green and Low-Carbon Transformation Institutions, Mechanisms and Policies”④, which proposes to improve the coordinated promotion mechanism for the implementation of the national energy strategy and plan, to improve the system and policy system to guide green energy consumption and to establish a green and low-carbon-oriented new mechanism for energy development and utilization, especially to complete the construction of new operation mechanism for Power Systems, to improve the Clean and Efficient Development and Utilization Mechanism of Fossil Energy, to improve the safety and supply system for green and low-carbon of energy, and to establish a scientific and technological innovation system to support green and low-carbon transformation of energy, to establish a fiscal and financial policy guarantee mechanism to support the transformation of energy, to promote International cooperation on green energy and low-carbon transition.

The "Energy Technology Revolution Innovation Action Plan (2016-2030)", jointly issued by the National Development and Reform Commission and the other relevant departments indicated that to promote technological innovation in energy intelligent production, focusing on the three major sectors of renewable energy transmission, consumption and supervision.

In the field of energy industry planning, the Chinese government has formulated a number of specific plans and put forward development requirements for various fields involved in

① https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=18453, effective in 2020 and revised in 2022
② http://www.gov.cn/xinwen/2019-11/06/content_5449193.htm
③ http://zfxxgk.nea.gov.cn/2021-07/15/c_1310079331.htm
④ http://zfxxgk.nea.gov.cn/2022-01/30/c_1310464313.htm

green energy. In June 2014, the state issued the "Energy Development Strategic Action Plan (2014-2020)", which clearly stated that by 2020 the installed capacity of nuclear power should have reached 58 Gigawatts, and the capacity under construction would reach more than 30 Gigawatts; Conventional hydropower installed capacity reaches 350 million kilowatts; the installed capacity of wind power would reach 200 million kilowatts, and the on-grid price of wind power and coal power is similar; the installed capacity of photovoltaics would reach about 100 million kilowatts, and the price of photovoltaic power generation would be equivalent to the sales price of the grid; the scale of geothermal energy utilization would reach 50 million tons of standard coal.

The “Thirteenth Five-Year Plan for Electric Power Development" proposes specific development goals for six aspects: supply capacity, power supply structure, power grid development, comprehensive regulation capacity, energy conservation and emission reduction, and electricity guarantee for people's livelihood. The installed capacity of solar power generation should reach more than 110 Gigawatts, the installed capacity of Biomass energy generation should be about 15 gigawatts, and the installed capacity of nuclear power should reach 58 gigawatts. In addition to those comprehensive policies, the government has also issued a series of implementation plans and guidelines for wind energy, nuclear energy, solar energy, biomass energy, etc., and has basically covered the energy industry, especially green energy industry development policies.

In the field of international cooperation in promoting green and low-carbon transformation of energy, the Chinese government proposed to actively promote green and low-carbon transformation and development cooperation in global energy governance. Build and operate the "Belt and Road" energy partnership and the International Energy Transformation Forum, and strive to play a better role in the global green and low-carbon transformation process. Relying on cooperation platforms such as China-Arab League, China-AU, China-ASEAN, China-Central and Eastern Europe, and the Asia-Pacific Economic Cooperation (APEC) Sustainable Energy Center, China will continue to support clean and low-carbon energy such as renewable energy, nuclear power, and hydrogen energy cooperative training of relevant technical talents, carrying out capacity building, policy, planning, standard docking and talent exchange. Improve the level of cooperation with international organizations such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), and actively participate in and guide multilateral organizations such as the United Nations, G20, APEC, the BRICS, and the Shanghai Cooperation Organization. Cooperation on green energy and low-carbon transformation will make full use of international factors to promote the green and low-carbon development of domestic energy. Implement the catalogue of industries that encourage foreign investment, improve relevant support policies, and attract and guide foreign investment in clean and low-carbon energy industries. The Chinese government will continue to improve the incentive mechanism to encourage foreign investment to integrate into China's clean and low-carbon energy industry innovation system, strictly protect intellectual property rights, promote the establishment of an international cooperation platform for clean and low-carbon energy technology innovation, support multinational companies to set up clean and low-carbon energy technology joint R&D centers in China, and promote clean and low-carbon energy technology.

The Chinese government always attaches great importance to and supports the coordinated development with other countries, seeks common benefits, explores the establishment of multilateral and bilateral green energy economic development cooperation mechanisms, and realizes cooperation in green energy projects on the basis of "co-consultation, co-construction and sharing", and realizes energy advantages.

3.1.2 Technologies Innovation Brings New Impetus

In recent years, China has actively developed solar energy and wind energy, which has achieved certain scale effects. With the development of a new generation of information technology, the integration and application of new energy will further promote the development of China's new energy industry and bring stronger technical support for the promotion and application of green energy. China's nuclear energy and hydrogen energy have formed a relatively complete industry chain, which is conducive to promoting intensive cultivation in depth on the basis of stabilizing industrial development. China has gradually established a nuclear power industry system that matches the pressurized water reactor nuclear power plant, and has a number of large and professional nuclear power equipment, manufacturing enterprises and many large and medium-sized nuclear power plant auxiliary equipment manufacturing enterprises of different scales. In the field of hydrogen energy, more than 190 special policies for the hydrogen energy and fuel cell industries have been issued by 25 provinces, municipalities and autonomous regions across the country. The main technologies and production processes such as hydrogen energy preparation, storage and transportation, fuel cell system integration, and hydrogenation facilities have been continuously improved. Hydrogen energy has gradually moved from demonstration applications to large-scale promotion, and the industrial chain has been continuously improved. The hydrogen energy industry in the three major regions of the Yangtze River Delta, the Pearl River Delta and the Bohai Rim has begun to take shape. Suzhou, Foshan, Wuhan, Chengdu and other places have gathered many hydrogen energy companies and R&D institutions, and the development of the entire industry chain is in good shape. In general, China has basically built a relatively complete hydrogen energy industry chain covering hydrogen production, storage and transportation, filling and application.

Since 2020, China has accelerated the deployment of 5G networks. The major operators have successively released 5G construction plans, building a total of 500,000 5G base stations, covering all cities above prefecture level[①] in the country. With the 5G communication technology, more intelligent upgrades and transformations can be achieved in the electric power field and new formats will be presented in terms of applications, while big data applications can collect, store, analyze and process a large amount of information data, and process power transmission more efficiently. China's cloud computing market is in a stage of rapid development, and the continuous maturity of technologies such as containers and micro services is driving the transformation of cloud computing. With the continuous expansion of application scenarios of cloud computing, the application of cloud computing

① In terms of China's administrative divisions, cities directly under the jurisdiction of provincial administrative regions and at the same level as the regions.

has penetrated into traditional industries such as new energy, government, finance, industry, transportation, and logistics. The Internet of Things is an important foundation for the national strategy and it plays an important role in promoting the upgrading and optimization of the national industrial structure. The Internet of Things is a highly integrated and comprehensive application of a new generation of information technology, which is of great significance to a new round of industrial transformation and the green, intelligent, and sustainable development of the economy and society; the smart new energy platform integrates the new generation of information technology with energy production, transmission, and storage, consumption and the energy market are deeply integrated and developed.

In April 2015, the Central Committee of the Communist Party of China and the State Council issued the "Guidelines of the Central Committee of the Communist Party of China and the State Council on Accelerating the Construction of Ecological Civilization", proposing the establishment of systems such as energy conservation and carbon emission trading. The "Overall Plan for the Reform of Ecological Civilization System" issued in September 2015, and clearly proposed to establish a green financial system and promote green credit. In March 2016, the outline of the "13th Five-Year Plan" clearly stated that a green financial system should be established, green credit and green bonds should be developed, and a green development fund should be established. China has made new progress in green funds, green stock indices, green bond indices, green bond certification and disclosure, green rating methods, environmental stress tests, carbon financial products, and international cooperation. The scale of the green financial market is growing, the participants in the market are becoming more diversified, and various green financial products and their derivatives are constantly developing and innovating. In August 2016, the "Instructions on Building a Green Financial System" issued by the People's Bank of China and other seven ministries and commissions. It provides financial services for project investment and financing, project operation, risk management and etc in the fields of environmental protection, energy conservation, clean energy, green transportation, and green buildings. Therefore, 2016 is also known as the first year of green finance in China and the green finance mainly includes investment loans and loan guarantees, low-interest loans, industrial financial replication, industrial development funds, and green funds. Relevant entities are not limited to large entities such as banks and fund companies. Some institutions have tried to accurately identify green projects through various new channels, and provide unsecured credit loans to small and micro enterprises. By accurately and scientifically identifying whether the upstream and downstream core enterprises of the industry are green, small and micro enterprises and green enterprises are encouraged to carry out economic activities, and the downstream of the industrial chain is guided to focus on the circulation or manufacturing of green commodities.

3.1.3 Characteristic Economy Boosts the Demand

In 2018, China and 17 countries issued the Joint Ministerial Declaration on Building the “Belt and Road” Energy Partnership ①, which provides a new way to build a closer energy

① Brazil has not yet joined the Belt and Road Energy Partnership community with a shared future and promote the green and sustainable development of international energy. Since then, it has successfully held two “Belt and Road” energy partnership forums and several senior officials’ consultations, building a high-quality platform for bilateral and multilateral project cooperation and technical exchanges for member states. In 2019, the member states jointly released the Belt and Road Energy Partnership Cooperation Principles and Practical Actions. At the same time, the partnership was also officially included in the Joint Communiqué of the Roundtable Summit of the Second Belt and Road Forum for International Cooperation [①]. The mentioned Communiqué focuses on green energy project investment, and to strengthen capacity building and technology in the green energy field.

In February 2022, China successfully hosted the 24th Winter Olympic Games. The Beijing Winter Olympics relies on the comprehensive management and bold application of green energy. It shows a new look of green, inclusive, open and clean. The successful experience of the Green Winter Olympics is inseparable from China's vigorous development of new energy and circular economy, as well as the promotion and application of low-carbon technology research and development. All competition venues of the Beijing Winter Olympics are powered by 100% clean energy, and it is the first time in the world that hydrogen fuel cell buses are used in large quantities to serve sports events. "Micro-fire" has become the main torch of the Winter Olympics, "green electricity" lights up the Winter Olympics venues, new ice-making technology creates the "fastest ice", and temporary facilities can still be reused after dismantling; green finance runs through the preparation and holding of the Winter Olympics. The Beijing Winter Olympics' pursuit and efforts towards clean energy demonstrate the confidence and attitude of the Chinese government to vigorously develop the clean energy industry and actively fulfill its responsibility as a major country in reducing carbon emissions. Taking the Winter Olympics as an opportunity, it will focus on technological breakthroughs and explore new energy sources. The new integrated path of large-scale transmission, grid connection and consumption fully demonstrates the potential of new energy applications, and is also conducive to promoting the industrialization of new energy, accumulating valuable experience for low-carbon energy transformation.

3.1.4 Unbalanced Development of Chinese Energy Industry

China's resource endowment, the regional distribution and the energy mix is unbalanced. High-quality energy sources such as oil and natural gas are scarce, with a low ranking of proven reserves and high external dependence insufficient supply while coal resources are abundant. Renewable energy potential is abundant but on a low exploitation standard.

At present, China’s energy mix is still seriously unbalanced. Data from the China Statistical Yearbook shows that in 2020, coal accounted for 68% of primary energy consumption, while oil accounted for 7%, and natural gas accounted for 6%. Compared with the world average, the data show that China’s over-reliance on coal has not been alleviated, and the development and utilization of clean energy such as nuclear energy is still in the primary stage.

① https://bremc.obor.nea.gov.cn/

Despite the continuous increase in production of oil and gas in recent years, there is still a large gap relative to China's large demand. In 2019, China's foreign dependence on crude oil and natural gas exceeded 70% and 45% respectively. In 2020, affected by the epidemic, China's oil and gas production failed to meet expectations. At present, China's gas storage capacity is about 5.7% of annual consumption, far below the world level of 12% to 15%. Gas storage facilities still have problems such as generally small scale of LNG receiving stations, scattered layout, low utilization of land and shoreline resources, and increased costs in supporting facilities and operating. China is the world's largest energy consumer. With the continuous economic development, China's energy demand is still growing. From 2010 to 2020, China's energy consumption increased by 54.6%. Energy consumption in 2017 was 3.132 billion tons of oil equivalent, accounting for 23.2% of the total global energy consumption. [①]

So far, China's energy consumption has never recorded negative growth, and primary energy consumption has maintained continuous positive growth. According to the BP World Energy Statistical Yearbook 2022, China's total primary energy consumption in 2021 was 157.65 Exajoules, ranking first and accounting for 26.5% of the world, followed by the United States with 92.97 Exajoules, India and Russia ranked third and fourth with 35.43 and 31.3 Exajoules, respectively, and Europe totaled 82.38 Exajoules. Crude oil consumption maintained a rapid growth of 7.2%, and natural gas consumption increased by 12.8%. Electricity consumption increased by 10%, consumption capacity was slightly higher than production capacity, and energy dependence was high. [②]

Energy supply and demand are mismatched [③] . According to data released by the National Bureau of Statistics of China, for the energy production structure in 2019, raw coal accounted for 68.8%, crude oil accounted for 6.9%, natural gas accounted for 5.9%, and hydropower, nuclear power, and wind power accounted for 18.4% [④]. In 2019, China imported 505.72 million tons of crude oil, with a year-on-year increase of 9.5%, and 96.56 million tons (about 133.3 billion cubic meters) of natural gas, with a year-on-year increase of 6.9%.

As the productivity of China's energy resources is gradually highly concentrated in the advantageous resource areas, the pattern of energy supply and demand mismatch will be further manifested. In the distribution of energy resources, coal production capacity is highly concentrated in Shanxi, Xinjiang, Inner Mongolia and Shaanxi provinces, accounting for more than 70% of the country's total production capacity; oil and gas, coal power, and hydropower resources are concentrated in the western region; new energy such as wind power and photovoltaics concentrated in the northern region. In terms of demand, the eastern region has a large energy demand, and the most economically developed coastal areas, including provinces with large GDP such as Hunan, have a very high industrial demand for thermal coal. However, these areas lack energy resources and require coal transportation from north

① BP, World Energy Statistics 2019 , 2020.
② BP, World Energy Statistics 2019 , 2022
③ Energy development trends and challenges, Chinese Energy. July 2021, Y. Jing Zhu.
④ http://www.cinic.org.cn/sj/sdxz/shengchanny/817661.html

to south, cross- regional energy resource allocation such as West-to-East Power Transmission and West-to-East Gas Transmission to meet load demand. Under the energy "dual control" and total coal consumption control, limited by transportation capacity, these areas with scarce energy resources and high load demand are prone to "power cutoff" during peak energy consumption hours. On the other hand, there are obvious problems of coordination among various energy sources, which are not conducive to the construction of an effective modern energy system, and there are institutional mechanisms and policy support problems in coordinating and optimizing the development of coal, oil and gas, electricity and new energy.

3.1.5 Green Energy Development Level Needs to be Improved

As the second largest energy producer and consumer in the world, China has adjusted its energy consumption structure to a certain extent, but there are still many problems. For a long time, coal has been the main energy source. The proportion of total consumption of crude oil and natural gas is relatively small. In the process of transition from coal to oil, there are problems such as low utilization rate.

Legislative support needs to be further improved. In pursuit of high-quality energy development, China must establish a comprehensive energy market system integrated with the auxiliary service market. China's current energy system still has the contradictions of low quality, and the supervision system is not yet perfect. The energy price mechanism and fiscal and taxation policies need to be improved, and the resource consumption tax is not comprehensively set.

China has a large green trade deficit and a high dependence on the European and American markets. Take the production of photovoltaic modules in China as an example, 95% of the production orders are still from foreign manufacturers. In addition, after the financial crisis, the demand in important markets such as Germany, Spain and Japan dropped sharply, and trade protectionism began to appear. To a certain extent, financial subsidies from these countries for new energy have been reduced, and green trade barriers have been set up in many ways, affecting the development of domestic new energy industry.

Insufficient technological innovation capability. The level of energy research, especially basic research, is still weak, and the investment and research of cutting-edge technologies such as hydrogen energy and fuel cells are limited, which is not enough to realize the leap-forward development of green transformation.

3.1.6 Remaining Obstacles for Integration with International Standards

Although China has formulated the "Renewable Energy Law of the People's Republic of China" and "Interim Measures for the Administration of On-grid Electricity Price and Expense Allocation for Renewable Energy Power Generation", the legal system is still incomplete and the legal design is relatively rough. China should improve the strategic, forward-looking and operability of energy green development, and provide solid legal guarantee for China's energy transition.

The government should lead the formulation of new energy strategies, overall plans for new energy development, new energy legislation, and new energy development support systems, especially in the early stages of new energy development. The governments of the United States and Japan have launched state-led new energy technology and technology promotion projects. The EU has also set relatively unified new energy development goals for member states, striving to establish a unified new energy market in the EU. China should strengthen the role of the government in the process of transition to new energy, and coordinate the development of new energy in various regions, so as to improve China's comprehensive competitiveness in the transition to green energy.

The new energy industry will probably lead the development direction of the world economy and drive new changes in human society. Most of the G20 countries have set targets for the proportion of green energy in electricity consumption. China should actively integrate the resources of enterprises, research institutions and government, formulate and implement medium and long-term R&D plans for green energy technology, launch large-scale national scientific research projects, and carry out extensive international cooperation, and strive to be in line with international standards in new energy technology.

Another key issue is how renewable energy can adapt to the development trend of energy digitalization and intelligence. From the perspective of energy, there is a global trend from resource dependence to technology dependence; technological progress has given renewable energy a competitive advantage. At present, the technical development of China's green energy industry is insufficient, which limits the application of renewable energy and the richness of application scenarios. Although China has made a lot of achievements in digital development, it still lacks experience in international operations, especially in the field of localization. China can consider promoting the scientific and efficient development of the energy industry, while meeting the needs of the international market.

3.1.7 Strength and Weakness in Industries

In 2011, China and Brazil signed a joint communiqué covering cooperation in a variety of fields, especially in the energy sector, and expressed their willingness to further deepen cooperation in the fields of oil trade financing, oil and gas exploration and development, electric power, energy equipment, peaceful use of nuclear energy, biofuels and other new energy sources, and further explore new areas of energy cooperation. In February 2012, the two sides signed the Joint Action Plan and officially launched the 10-year cooperation plan. At the same time, with the blessing of the BRICS energy cooperation mechanism, the energy cooperation between China and Brazil has achieved remarkable results. Most of the Chinese companies' investment in Brazil is concentrated in the renewable energy sector, which is related to the investment opportunities and market potential in Brazil, as well as the strength of China's supply chain and financing.

Solar energy

China is rich in solar energy resources, and the annual radiation in more than two-thirds of the country is more than 5.02 million kilojoules / square meter. Although most of China's solar photovoltaic enterprises are small and medium-sized enterprises, they have a high technical level and strong comprehensive strength, and have trained a large number of chemical and energy professionals, and have reserved sufficient human resources for the development of new energy. At present, the main difficulty of development is the technical bottleneck in the technical level, which is still at the low end of the international photovoltaic industry. Most of the raw materials for photovoltaic power generation still depend on imports, the level of polysilicon production technology is not high, and the technological breakthrough has not yet been realized.

Despite its late start, Brazil has unique strengths in this sector. Most of Brazil's territory is located in the tropics, with long hours of sunshine and great potential for solar power generation. As an important photovoltaic raw material, Brazil is also rich in reserves. In addition, Brazil attaches great importance to environmental protection and the relevant regulations are very strict. As a clean energy, photovoltaic power generation has a small impact on the environment and is easy to promote. On the other hand, with the rapid development of global photovoltaic power generation in recent years, more new technologies and new materials have been used, and the cost has gradually decreased, which has also created conditions for the development of photovoltaic power generation in Brazil. Because of the advantages of high production efficiency, low cost and convenient logistics, Chinese companies are currently in a leading position in the field of solar energy manufacturing. Chinese companies can provide cost-effective all-round services for PV projects in Brazil.

Hydrogen energy

Hydropower occupies an important position in China's power structure, and has obvious advantages. It is mainly characterized by clean and environmental protection, priority access to the power grid, low electricity price, relative stability, low cost, strong competitiveness, easy peak shaving and energy saving. The world's largest hydropower station - the Three Gorges Hydropower Station is located in China, in addition to various types of hydropower stations of different scales, it is also unique in the international hydropower field, with a high-level management and operation team and rich and skilled construction experience, with a total of 18,900 hydropower station-related enterprises in the country, mostly concentrated in the southern coastal provinces and cities.

China is developing pumped storage power stations with an installed capacity of more than 20 million kilowatts and an investment scale of more than 100 billion yuan. Pumped storage is the most mature large-scale energy storage mode at present, which has the advantages of peak regulation, frequency modulation, phase modulation, energy storage, multi-function, super capacity, simple system, economic reliability, ecological protection, and etc. It can effectively ensure the safe and stable operation of power system and improve the level of new energy utilization.

Nuclear Energy

Nuclear power, like solar and wind power, does not produce a large amount of greenhouse gas emissions during operation, and the carbon emissions of nuclear power are even lower than those of other clean energy power generation. However, solar power and wind power generation are affected by seasonal and weather factors, with the characteristics of intermittent power generation, the stability of power supply is relatively poor, compared with them, nuclear power can almost perfectly avoid factors such as seasons and weather, and has obvious advantages of all-weather power generation. In addition, as a low-carbon and efficient large-scale base-load power source, nuclear power has a high utilization hour, low cost of electricity, and does not emit atmospheric pollutants such as sulfur dioxide, nitrogen oxides and soot particles. Since nuclear power has the above clean and low-carbon characteristics, nuclear power will inevitably become one of the important options for the world's energy transition from high emissions and high pollution to clean and low-carbon energy.

However, the safety of nuclear power is one of the most important issues for the development of the industry, so the nuclear power industry has high administrative entry barriers, technical barriers and financial barriers. There have been many major nuclear accidents in history, but the main causes are basically caused by improper human operation and flaws in the design of nuclear power plants. In 2021, CNNC and China General Nuclear Power Corporation developed the Hua Long NO.1 based on 30 years of experience and lessons learned from the Fukushima nuclear accident in Japan, and like the United States (AP1000) and France (EPR2), they also mastered the third-generation nuclear power technology. Due to the particularity of the nuclear power industry, China's nuclear power projects (except demonstration projects and research reactors) officially approved by the State Council are all operated by China Nuclear Power, China General Nuclear Power and State Power Investment Corporation before 2020. Among them, the market share of China's installed nuclear power capacity reached 42.3%, and the market share of CGN installed capacity reached 42.5% (excluding joint ventures), and the above two companies are the two leading nuclear power operations in China.

Biomass

Although China's biomass energy is rich in resources and has great development potential, it accounts for a very low proportion in the energy consumption structure, and it is difficult to become a "mass energy". At present, China's biomass energy utilization methods mainly include biomass power generation, bio-liquid fuel, biomass molding fuel, biomass gas and biological hydrogen production technology. Biomass energy resources are relatively abundant, but the proportion of total energy consumption is relatively low. From the perspective of installed capacity, by the end of 2021, the cumulative installed capacity of biomass power generation in China reached 37.98 million kilowatts, accounting for 1.6% of the total installed power generation capacity. In China's biomass power generation structure in 2021, waste incineration accounted for about 61.2%, agricultural and forestry biomass power generation accounted for about 35.5%, and biogas accounted for about 3.3%.

In addition to the fact that biomass energy cannot be widely used in China, there are also disadvantages of uncontrollable costs, for agricultural and forestry biomass power generation enterprises, fuel costs account for more than 60% of their operating costs, and the production and operation conditions are indeed difficult to maintain. Briefly, in China, the ecological and environmental value of bio-power generation has not yet been fully reflected, the industrial structure has not reached a basic balance. Brazil is a global pioneer in promoting the development of the bio-fuel industry, and has solved a series of key technical and industrialization problems in the development and utilization of bio-liquid fuels such as fuel ethanol. In the future, China can increase cooperation with Brazil in the field of biomass liquid fuels, such as breakthroughs in second and third-generation fuel technologies, to achieve complementary advantages and promote mutual benefit and win-win results.

3.2 Brazilian Perspective

This session presents the strengths and weaknesses for the development of green sources in Brazil. The main Brazilian strength for the promotion of green energy sources is the availability of resources. Natural conditions imply stable and frequent winds for wind generation, high solar insolation and diversity of biomass sources. The main weakness stems from late development in relation to the pioneering countries. In this way, the country sought to structure the production chain and develop technology compared to countries that already have a consolidated industry.

3.2.1 Solar Energy

Strengths

Solar energy experiences some advantages in Brazil. They result from weather features and from the industrial capacity:

(i) Wide network of integrator companies and equipment suppliers;

(ii) High incidence rates of solar radiation, including during winter, in practically the entire national territory;

(iii) Panels are ease to operate and the need for operation and maintenance is low.

Weakness

(i) One usual weakness of solar power is intermittence and the required infrastructure. Hybrid plants with existing projects (Ex.: photovoltaic solar energy in hydroelectric reservoirs or wind farms), minimizing the need for new works and reducing associated socio-environmental impacts are recommended;

(ii) The equipment supply industry in Brazil does not provide more sophisticated parts what implies high import levels. It is interesting to stimulate local suppliers to develop new capabilities on PV module assembly, micro inverters and inverters and batteries;

(iii) The dissemination of DG took place in the higher income classes, due to the financing capacity. Develop adequate financing conditions for the cash flow for low-income consumers is a significant challenge;

(iv) Articulation between environmental agencies and government institutions for the recycling of PV system components is required, encouraging the development of an industrial chain focused on the logistics of disposal and recycling of such components;

(v) There is a need to regulate the sale of distributed generator surpluses in the free market, the entry of the hourly price, the possibility of competition in electricity retail and the participation in ancillary services markets.

3.2.2 Hydrogen

Strengths

The main competitive strengths identified that show the potential for green hydrogen production in Brazil are:

(i) Availability of natural resources used for hydrogen production (natural gas, ethanol and water) at lower costs due to favorable climatic and geographic conditions for large-scale green H2 production;
(ii) Growth of production of photovoltaic and wind energy that can be used to develop green hydrogen and boost distributed generation in the country, observing the potential for using green hydrogen as renewable energy storage;
(iii) Ease of production flow (extension of the coast) and geolocation considering the distances between the port of Rotterdam and other potential H2V exporting countries;
(iv) Existence of sectoral representation (ABH2);
(v) Brazil's evolution of natural gas market, from the perspective of the extension of the pipeline network with the potential for injection or mixing of H2 with natural gas;
(vi) The increasing cost reduction of energy generation from renewable sources with a forecasted leveled cost of Brazilian green hydrogen would be around ~1.50 USD/kg of H2 in 2030.

Weakness

(i) Lack of pipeline and supply infrastructure to ensure transportation. The current infrastructure is limited to natural gas and is concentrated in the coastal region;
(ii) Existence of regulatory barriers and bureaucracy. Further definition is needed on which functions will be assumed by which public authorities related to the regulation and use of H2V, with the development of technical standards on, for example, the mixing of H2 with natural gas in pipelines;
(iii) Brazil needs to regulate its carbon market to encourage private sector investment in sustainable energy projects. The Brazil natural gas market evolution occurs without regulatory provisions that allow the injection of H2 into the network.
(iv) Low growth of the Brazilian economy and high fiscal disequilibrium, with impact on the volume of public and private investments in H2.

3.2.3 Nuclear

Strengths

Nuclear energy can contribute to complementing the intermittent energy produced in Brazil. As Brazil has large hydroelectric reservoirs, the production of nuclear energy at the base of the load curve (with high frequency and low operating costs) helps to keep the reservoirs full to face periods of low rainfall.

Weakness

(i) As the cost of capital is high in Brazil and the level of investment is low in the country, the high capital intensity of nuclear power projects is challenging. On average, the portion

referring to the fixed costs of new nuclear projects is between 73% and 85% of total costs. Barkatullah and Ahmad (2017) point out that the scale of nuclear energy projects can reach US$ 9 billion;
(ii) There is a history of delays in large electricity generation projects in Brazil, which penalize capital-intensive sources in Brazil. The case of the Angra 3 project is emblematic;
(iii) Although the country has experience in nuclear energy, the country is not considered a technological leader in the sector. International partnerships are very important to overcome this barrier.

3.2.4 Biomass

Strengths

(i) Biofuels contribute to security of supply of fuels, that is a critical issue nowadays;
(ii) Biofuels have a long history in Brazil. Its productive chain is already organized and with high capability;
(iii) Biomass offers an opportunity for reuse of waste, helping to solve an urgent urban problem (waste disposal) ;
(iv) Cogeneration by sugarcane biomass is complementary to hydroelectric generation, since the increase in bioelectricity generation occurs during the harvest, a period concomitant with river dry periods.

Weakness

(i) Brazilian capability in biofuels is mainly focused on traditional technologies. There is a challenge to migrate to advanced technologies;
(ii) Supply varies with seasonality and price volatility;
(iii) Precarious working conditions in the sugarcane production.

IV. Potential Areas of Bilateral Green Energy Cooperation

4.1 Hydropower

China and Brazil stand out in the use of hydroelectricity and are, respectively, the first and second countries with the largest hydroelectric capacity in the world. Of the 10 largest hydroelectric plants in the world, a list that is headed by the Three Gorges and Itaipu plants, only two are not located in China or Brazil.

Brazil, which consolidated the hydroelectric segment before, and China have a history of cooperation in the technologies of large dams for the production of electricity and long-distance transmission lines, essential to enable the use of plants far from consumption centers.

In the 1980s and 1990s, Brazilian companies that already had a long experience in the construction of dams participated in the construction of hydroelectric plants in China. In the Three Gorges hydroelectric plant, Brazilian service companies cooperated with the Chinese companies that led the construction (BIATO Júnior, 2010).

To better understand the recent Sino-Brazilian cooperation in hydro power issues, it is essential to address the Chinese presence in the Brazilian electricity sector that encompasses three important aspects: loans, investments and construction projects. As a result, one can identify the Chinese presence in activities related to energy transmission, local generation, and distribution.

According to Barbosa, "Brazil's rich resource endowment, necessity to expand installed capacity and power grid, and favorable market, legal, and policy conditions, aligned with China's financial might and technological capabilities, have created an ideal situation for Chinese firms' arrival" (2020, p.3). Moreover, it is worth mentioning that Chinese companies have invested in the sector in which Brazil has abundance of resources and natural advantage, what justifies the fact that hydro power has received 81% of all generation investments done in the country.

Notwithstanding the presence of several Chinese firms in the Brazilian energy sector, two of them stand out: China Three Gorges (CTG) and State Grid. Both address a paramount importance in the bilateral cooperation efforts that aim to developing the Brazilian hydro power sector, mainly State Grid due to its presence in Belo Monte, one of the most important Brazilian hydroelectric, with more than 11 GW of installed capacity.

Due to large geographical distances between supply and demand of energy, long distance transmission lines are essential to hydro power projects. Both countries developed productive and technological capacity in this field. Recently, State Grid signed the operation license of Phase II of the Brazilian Belo Monte Hydropower ±800kV UHV DC Transmission Project, which has a total length of 2,539 Km and crosses 81 cities in five states in Brazil, being the longest ±800kV UHV DC project in the world and an important innovation applied in the hydro power sector.

The transfer of technology to the Brazilian hydro sector by State Grid is a relevant aspect and it also shows how the cooperation between Brazil and China can be deepened. The installation of Ultra High Voltage (UHV) transmission lines and smart metering systems can enhance Brazil's transmission sector. (Cote, 2014).

In addition, given some negative environmental and social effects generated by the construction of hydro power plants - changes in water quality, emission of greenhouse gases, people relocation, and loss of genetic patrimony – Brazil and China could, together, engender new ways to mitigate these undesirable effects commonly associated to the building of new dams. Thus, Brazil and China could also cooperate by sharing solutions to environmental challenges regarding hydropower projects.

4.2 Solar Energy

Solar power has the advantages of simple construction process, strong regional adaptability, and inexhaustible resources. It is currently a rapidly developing clean energy around the world. Both China and Brazil have the potential to further development of solar power.

In terms of climate resource, Brazil is a country rich in solar energy, with almost 80% of territory located in the tropics and more than 50% of the territory being 500 meters above sea level. The average annual sunshine time in the country is over 3,000 hours and the total solar radiation on the horizontal surface of the country is between 1,534 kWh/m^2 and 2,264 kWh/m^2, with an average of about 1,700 kWh/m^2, which means a very high development potential. The central and northeast parts of Brazil are especially abundant in sunlight with a potential installed capacity of onshore centralized photovoltaic of about 28,519 Gwp[①].

In terms of the domestic demand, with the adjustment of energy mix in Brazil, solar energy has broad prospects for development. A critical problem in Brazil's renewable energy matrix is that it shows an over-reliance on hydropower, which implies a heavy dependence on the stable precipitation during the year, especially in rainy season from November to March. As climate change is altering the distribution of global temperature and precipitation, the country's renewable energy supply is facing more uncertainty and risks causing by extreme weather events. Taking May 2021 for instance, Brazil has experienced the worst drought in its history. Extreme weather without precipitation severely impacted the country's electricity system, forcing the authorities to switch to the use of higher-cost thermal power and to import electricity from neighbors such as Argentina and Uruguay. In addition, due to the increase of environmental protection around the world, it is becoming more and more difficult to build new hydropower stations in tropical rainforest areas. But on the other hand, Brazil's urbanization process and industrial development is requiring more and more power supply. Therefore, for Brazil it is necessary and urgent to adjust its energy mix to meet the increasing demand. As Brazil's solar resources is abundant while currently occupied small share of the renewable energy matrix, it may have great potential for development.

① http://com.gd.gov.cn/go/article.php?typeid=38&contentId=21450.

In terms of construction efficiency and cost, according to Brazilian Association of Photovoltaic Solar Energy (Absolar), in Brazil solar is recognized as a champion in the speed of new generation plants. It only takes one day of installation to transform a home or business into a small plant that generates clean, renewable and accessible electricity due to the versatility and agility of solar technology. And for a large-scale solar plant, it takes less than 18 months from the auction to the start of electricity generation. As for power generation cost, large solar plants generate electricity at prices up to ten times lower than emergency fossil thermoelectric plants or electricity imported from neighboring countries, which are two of the main factors responsible for the tariff increase on Brazilian consumers[①].

In policy terms, according to the 2030 Ten-Year Energy Expansion Plan (PDE 2030, in the Portuguese acronym) launched by the Ministry of Mines and Energy (MME) of Brazil and the Brazilian Energy Research Company (EPE), from 2021 to 2030, Brazil plans to achieve an installed power generation capacity of 236 Gigawatts by 2030, greatly increasing the installed capacity of distributed power generation, wind power, natural gas, and solar energy, and reducing the installed capacity of fossil energy power generation, including coal, diesel and fuel oil[②]. In addition, in order to encourage the development of photovoltaic industry, the Brazilian government has also provided financial support for the import and production of related modules. In 2020 Brazil government removed import duties on goods including photovoltaic modules, inverters and solar trackers. Before that, most PV equipment imported into Brazil was subject to a 12% tariff. The Resolution also stipulated that if "Made in Brazil" modules are used in photovoltaic power plants, financial support could be obtained from the national development bank BNDES and other government bodies[③]. In addition, in order to support the development of the local distributed photovoltaic market, the Brazilian government has also abolished the taxation of small-scale solar power generation systems, and photovoltaic power plants with an installed capacity of less than 1 MW are also exempt from turnover tax (ICMS)[④].

From the Chinese side, as mentioned above, it is also a country rich in solar energy resources. Besides, China has accumulated experience and mature techniques through decades of exploration. The country began to plan the development of the solar energy industry in 2000. Subsequently, a series of supporting projects such as “Power transmission to the countryside” and the “Luminosity Plan” were launched to solve the electricity shortage problem of more than 700 townships in seven western provinces (Tibet, Xinjiang, Qinghai, Gansu, Inner Mongolia, Shanxi and Sichuan) by way of promoting photovoltaic and wind power. As mentioned above, these provinces are extremely rich in solar energy resources. And at the same time, they are also the most underdeveloped regions in China. Therefore, the promotion of solar power generation in these provinces not only solved the problem of local rural

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① https://www.invt.com/news/brazil-top-15-pv-power-113
② https://portal.apexbrasil.com.br/regulatory_report/the-ministry-of-mines-and-energy-mme-and-the-brazilian-energy-research-company-epe-launched-the-2030-ten-year-energy-expansion-plan-pde-2030-in-the-portuguese-acronym-it-will-support-federal-d/
③ https://www.pv-magazine.com/2020/07/22/brazil-eliminates-import-duties-for-cells-modules-inverters-and-trackers/
④ https://www.imsilkroad.com/news/p/460447.html

electricity consumption, but also drove the economic development of the entire region through making full use of its resource advantages. The success of these projects have also made China's annual installed solar PV capacity transform from kW to MW （Wang Jie et al.,2022） At present, China is the country with the fastest growing photovoltaic industry and largest solar photovoltaic industry scale in the world. In some key core technologies of solar power generation, China has also achieved global leadership. Therefore, the experience of China's solar energy industry development could be shared with Brazil, and advanced technology research could be a focus of cooperation between the two countries.

In terms of domestic demand and policy orientation, China has a huge market of 1.4 billion people, and is in the transitional stage of state-driven clean energy to replace traditional fossil energy. Therefore, the Chinese market will have huge demand for solar energy and other clean energy in the next few decades. In 2020, China proposed its carbon peak and neutrality goals, that is, carbon dioxide emissions will strive to peak by 2030, and strive to achieve carbon neutrality by 2060. Power industry is the sector with most carbon emissions (about 4 billion tons of carbon dioxide emitted in 2020) in China. Thus, controlling carbon emissions in power industry will be the key to achieve the country's "30-60 goals" (Deng Yue, 2021). In 2021, at the ninth meeting of the Central Financial and Economic Affairs Commission, the requirements for building a new power system in China with renewable energy as the mainstay were proposed. According to the "14th Five-Year Plan for Renewable Energy Development" jointly issued by 9 departments including China's National Development and Reform Commission and National Energy Administration, from 2021 to 2025 China will accelerate the green and low-carbon transformation of energy and implement the goals of Nationally Determined Contribution (NDC). The incremental renewable energy power generation will account for more than 50% of the total increase in electricity consumption, and the solar power generation will double[①].

Based on the above analysis, China and Brazil could carry out in-depth cooperation in the following two key areas:

Firstly, key technology research to improve the stability and power generation efficiency of solar power. The advantages of solar power are outstanding. For instance, solar energy resources are endless and widely distributed and solar power can be used wherever there is light; solar cell modules are simple in structure, small in size, light in weight, and easy to transport and install; the photovoltaic power generation system has a short construction period, and can be large or small according to the power load capacity. However, the disadvantages of solar power are also prominent. First of all, solar power is greatly affected by climatic and environmental factors. The energy comes directly from sunlight. Long-term changes in rainy and snowy days, cloudy days, foggy days and even cloud layers will seriously affect the status of the power system. Air pollution can also affect its efficiency. If the particulate matter (such as dust) in the air settles on the surface of the solar cell

① http://www.gov.cn/zhengce/2022-06/08/content_5694539.htm module, blocking part of the light irradiation, this will reduce the conversion efficiency of the cell module, resulting in reduced power generation and even damage to the solar panel. Secondly, the energy density of solar and the conversion efficiency of power generation are low. Although the total amount of energy thrown by the sun to the Earth is huge, because most of the earth's surface is covered by oceans, the solar energy that can really reach the land surface is only about 10% of the solar radiation energy that reaches the Earth. The conversion efficiency of photovoltaic power generation refers to the rate at which light is converted into electricity. At present, the conversion efficiency of crystalline silicon photovoltaic cells is 13% to 17%, while that of amorphous silicon photovoltaic cells is only 5% to 8% [①]. The low conversion efficiency of solar cells is the bottleneck hindering the large-scale promotion of photovoltaic power generation. Finally, the production process of crystalline silicon, the raw material of photovoltaic modules, is not environmentally friendly. The main raw material for crystalline silicon cells is highly pure silicon. In the process of transforming silica sand into crystalline silicon, it has to undergo multiple chemical and physical processes, which not only consumes a lot of energy, but also causes environmental pollution. Therefore, scientists from China and Brazil have a broad space for cooperation in key technical issues such as improving the stability and efficiency of solar power generation, reducing energy consumption and pollution in the production of parts and components.

The second area can be photovoltaic related product trade and production capacity investment. Driven by favorable policy environment, Brazil's photovoltaic industry has achieved rapidly growing installed capacity, which provides opportunities for the two countries in photovoltaic related product trade. China is an important supplier of photovoltaic products in the global trade market. According to statistics from the China Photovoltaic Industry Association, in 2021, its polysilicon, silicon wafer, cell, and module output reached 505,000 tons, 227 GW, 198 GW, and 182 GW respectively, and the output value of these four parts exceeded 750 billion yuan. The export value of China's photovoltaic products was 28.43 billion US dollars with a year-on-year increase of 43.9% [②]. In the first quarter of 2022, China's photovoltaic module exports were about US$10.6 billion, with a year-on-year increase of 122.9%. Among them, exports to Brazil were 1.33 billion US dollars, accounting for 12.6%, ranking third after India and the Netherlands [③]. For China, Brazil is a critical market. With the implementation of Brazil's domestic renewable energy plan, the future PV trade between the two countries will continue to expand.

In addition, since the photovoltaic industry is a capital and technology-intensive industry, the investment cooperation between China and Brazil relying on their respective advantages will help to improve the efficiency of green energy utilization in the two countries. At present, low-carbon and environmentally friendly development has become a global trend. China and Brazil have also introduced relevant policies to support their photovoltaic industry. There are historical opportunities for the two countries to deeper investment cooperation in solar energy.

① https://solar.in-en.com/html/solar-2326665.shtml
② http://www.gov.cn/xinwen/2022-02/24/content_5675307.htm
③ http://www.xinhuanet.com/energy/20220510/6abd571f3b5740a784af22ad41bb1585/c.html

The Chinese government proposed in the Action Plan for the Innovation and Development of the Smart Photovoltaic Industry (2021-2025) that will actively encourage enterprises to cooperate with advanced international institutions and enterprises in technology, talent, capital, and standards in the field of smart photovoltaics, and support enterprises to contribute to the world's poverty alleviation and desertification control through the development of smart photovoltaic power station projects [①]. Brazil is an important destination for Chinese PV investment in Latin America. The Chinese company BYD has already set up photovoltaic power plants in Brazil. The two countries should continue to carry out integrated investment and cooperation in the whole industry chain including power station investment, construction and operation. This will not only help make up for the local electricity supply gap and reduce electricity prices, but also help create new employment opportunities and promote the green recovery of economy in the post-epidemic period.

4.3 Wind Power

Wind energy has been one of the fastest-growing renewable energy sources in the world, driven strongly by discussions of climate change and the consequent reductions in greenhouse gas and other polluting gas emissions. Both Brazil and China take wind energy as a promising clean energy source. According to the Ten-Year Energy Expansion Plan issued by the Energy Research Company (EPE in its Portuguese acronym), a subsidiary of the Brazilian Ministry of Mines and Energy, the Brazilian government plans to attract more than 300 billion reais of investment between 2020 and 2030 for the construction of power points, including new investment in wind and photovoltaic power accounted for more than 50% [②]. By 2029, Brazil aims to generate a third of its new generation capacity from wind. As of 2019, Brazil's installed wind power capacity reached 15.4 gigawatts. And a recent assessment predicts that the local wind power potential is as high as 880 gigawatts [③]. According to the 14th Five-Year Plan for Renewable Energy Development issued by the Chinese government, China pledged to strive to peak carbon dioxide emissions by 2030 and to achieve carbon neutrality by 2060. The total installed capacity of wind power and solar power will reach more than 1.2 billion kilowatts in 2030. Wind and photovoltaic power generation, with advantages of large resource reserves, flexible construction sites and economic efficiencies are expected to become the new pillars in China's future power market [④]. China and Brazil both have strong will to accelerate the development of wind power, which provides important cooperation opportunities for the two countries.

The first field can be offshore wind power, which has globally become a new trend in the development of clean energy. According to the Global Wind Energy Council (GWEC), in 2021, investment in offshore wind surpassed offshore oil and gas for the first time. A report by Windpower Monthly, the world's leading wind power magazine, also indicated that between 2021 and 2025, more than 70 gigawatts of offshore wind power capacity is expected to be installed globally, meaning its share in wind energy will surge from the current 6.5% to 21% [⑤].

① http://www.gov.cn/zhengce/zhengceku/2022-01/05/content_5666484.htm
② http://com.gd.gov.cn/go/article.php?typeid=38&contentId=21450
③ https://www.investgo.cn/article/yw/tzyj/202104/538945.html
④ http://www.gov.cn/zhengce/2022-06/08/content_5694539.htm
⑤ https://ocean.cctv.com/2022/03/23/ARTIAi2y5lbzjYlF8fClwtdE220323.shtml

Ⅳ. Potential Areas of Bilateral Green Energy Cooperation

With nearly 8,000 kilometers of coastline, Brazil has great potential to develop offshore wind power, one of the most modern renewable energy sources. However, due to obstacles of finance, technology and infrastructure, the construction of offshore wind power plants in Brazil has been very slow. The current wind expansion in Brazil is mainly onshore projects. Building offshore wind farms is more technically complex, more expensive and slower to build than onshore wind farms. Generally, it takes two to three years from inception to implementation to build an onshore wind farm with cost from $1 million to $2 million, while the construction of an offshore wind farm takes between five and ten years with costs from $10 million to $50 million. China's investment and technology will be helpful for Brazil's offshore wind power project. In the past two decades, with the rapid development of China's wind power technology, a complete offshore wind power technology industry chain has been formed and the construction of wind power plants in the country is gradually shifting from land to sea. By the end of 2020, the cumulative installed capacity of China's offshore wind power ranked third in the world, accounting for 21.6% of the global installed capacity (Xv Bin et al., 2022). In 2021, the world added about 13.4 gigawatts of new offshore wind power capacity, with the largest contribution coming from China, accounting for three-quarters, about 10.8 gigawatts[①] The experience in design, R&D, manufacturing, installation and operation of China's offshore wind farms can be taken as reference by Brazil. The two countries have broad prospects for exchanges and cooperation in improving the techniques and reducing cost of the construction of offshore wind power.

The second is trade and investment cooperation of wind power equipment. China is the largest wind turbine manufacturer in the world with production accounting for more than two-thirds of the global market share[②]. According to the statistics of the Chinese Wind Energy Association, as of the end of 2020 China's wind turbines had been exported to 38 countries including the United States, the United Kingdom, France, and Australia, covering six continents with a total of 2,728 units exported and a cumulative capacity of 6.374 million kilowatts. As the world's largest wind power equipment manufacturing base, China's output of generators, hubs, racks, blades, gearboxes, bearings and other components accounts for 60%-70% of global production[③]. As the main source of imports of Brazil's wind power equipment, China has always been an important trading partner in Brazil's wind power supply chain. As Brazil's economy ushered in a green recovery after the COVID-19 pandemic, its domestic wind power scale is expected to accelerate, providing a good opportunity for the two countries to deepen green trade in the wind power sector. In addition, for China and Brazil investment cooperation related to the wind power supply chain will also be a win-win choice. Brazil's domestic policy encourages local production of wind power equipment: since 2013, Brazil requires local production rate of wind turbines to reach 80%[④]. At present, China's wind power generation technology and equipment (long blade, high tower application) and industrial chain have reached an international advanced level. For Chinese companies,

① http://www.nea.gov.cn/2022-01/21/c_1310437803.htm
② https://news.bjx.com.cn/html/20220104/1197316.shtml
③ http://tradeinservices.mofcom.gov.cn/article/yanjiu/hangyezk/202204/133031.html
④ http://br.mofcom.gov.cn/article/jmxw/202205/20220503315415.shtml

building a supply chain in Brazil will also help improve the local competitiveness of wind turbine products.

Thirdly, cooperation in land and sea transportation and logistics. According to Brazil's National Energy Plan 2050, transportation is a major obstacle to the development of wind power due to its equipment, such as towers, generator cabins and blades are ultra-long, overweight, ultra-wide, and ultra-high components. The transportation infrastructure in most parts of Brazil (including in the northeastern region with rich wind energy resources) at present cannot provide stable logistic for wind farm construction. In the future, with the scale upgrade of wind farms, the size and weight of wind power equipment might continue to increase, which would make the problem of transportation more prominent. Obstacles to the transport of wind power equipment have become a major concern for Brazilian manufacturers and entrepreneurs. Apart from land transportation, even by sea, the problem cannot be completely solved. In Brazil, the progress of wind energy project may be delayed due to the inability of ships to conduct cabotage. For onshore wind projects, the country's existing port infrastructure is considered insufficient or too small compared to the size of the wind components. For offshore wind projects with larger physical dimensions, the process of transporting components from the manufacturing site to the wind turbine assembly area is more complex and difficult. The cooperation between China and Brazil in sea and land transportation can help solve the logistics problems in Brazil's wind power construction. The two countries can not only strengthen cooperation in road and port infrastructure construction with the goal of improving transportation carrying capacity, but also strengthen exchanges on the transportation methods of large-scale wind power equipment—for instance, China has solved the problem of transporting large wind turbine blades in mountainous areas and narrow roads. Innovative transportation methods will help Brazil solve the logistics problems of wind power.

4.4 Nuclear Power

Nuclear energy is an important part of international energy cooperation, especially in the context of human fighting with the challenges of climate change. The development of nuclear power as clean technology plays an important role in reducing carbon emissions.

Nuclear power can be obtained from nuclear fission, nuclear decay and nuclear fusion reactions. Presently, the vast majority of electricity from nuclear power is produced by nuclear fission of uranium and plutonium in nuclear power plants. There has always been a debate about nuclear power. Supporters believe that, first, nuclear energy is a clean and efficient energy source. In a technologically advanced country like the United States, nuclear energy has become the country's largest source of clean energy. Nuclear power plants can generate nearly 800 billion kilowatt-hours of electricity each year, producing more than half of the country's zero-emission electricity. This allows the United States to avoid more than 470 million metric tons of carbon emissions each year, the equivalent of taking 100 million cars off the road. Thermal energy from nuclear reactors can also be used as the most reliable source of energy on the grid today. Also, the development of nuclear energy can create more jobs. Workers in nuclear power plants generally enjoy remuneration packages that are much higher than the local average. They also pay taxes and contribute to local economic development. Furthermore, the peaceful development and utilization of nuclear energy is crucial to a country's national security. A strong civilian nuclear sector is conducive to the national peace and stability.

However, the voices against nuclear energy development have not stopped. The safety use of nuclear energy is the most contentious issue. In March 2011, an earthquake measuring 9 on the Richter scale occurred in the Pacific Ocean in northeastern Japan, which triggered a nuclear leakage accident at the Fukushima Daiichi Nuclear Power Plant. In the following 10 years, the treatment of nuclear wastewater has always been a major problem that plagued Japan. When the Japanese government announced its decision to discharge the nuclear waste water stored at the Fukushima Daiichi nuclear power plant into the ocean, it received controversy around the world, including the Japanese public. In Belarus and Ukraine, the consequences of nuclear accident are still being dealt with today—monitoring radiation levels, cleaning up soil of contaminants, and providing rehabilitation for irradiated people. In addition, as an electricity commodity, the cost of nuclear power is an important factor affecting its competitiveness and long-term development. Nuclear power plants are expensive to build and operate. The initial investment of nuclear power is big, and its construction cost can account for 50% to 70% of the total cost. In contrast, the construction cost of thermal power is only 20% to 30%. The construction period of nuclear power is also longer. Nuclear-grade equipment has higher requirements on design, materials, and manufacturing processes than conventional equipment, so it usually takes 5-7 years for a nuclear power plant to go from pre-planning to put into operation[①]. High capital costs, permitting and regulatory approvals, combined with long lead times and construction delays, are detrimental to nuclear power's competitiveness in the electricity market.

Based on the above discussion, the cooperation between China and Brazil in the field of nuclear energy should mainly focus on two issues: First, how to improve the safety of nuclear energy use? Second, how to reduce the construction and operation costs of nuclear power generation?

From perspective of technology, China and Brazil should actively carry out third-and fourth-generation nuclear power technology exchanges. The nuclear power plant technology can be mainly divided into four generations. Among them, the first is the experimental nuclear power plant, with the main purpose to verify the feasibility of its nuclear power in engineering implementation through the form of test demonstration. This experimental plant has basically been decommissioned today; the safety of the second generation nuclear power technology is better than that of the first generation but its measures to deal with serious accidents are still weak; the third-generation nuclear power technology is the current mainstream, with higher safety, shortened construction period and extended life; the fourth-generation nuclear power technology designed to prevent nuclear proliferation, is the technology with least nuclear waste and the highest safety and economic performance.

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① https://news.bjx.com.cn/html/20180619/906674.shtml

At present, through independent research and development of key raw materials and equipment, China has mastered the third-generation nuclear power technology with completely independent intellectual property rights and realized the export of nuclear power. Hualong One (HPR 1000) has a total of 4 units at home and abroad to achieve grid-connected power generation, which has been recognized by domestic and foreign users. China National Nuclear Corporation (CNNC) has also established cooperation intentions on nuclear power projects with more than 20 countries and regions, including Brazil and Argentine in Latin America. China's fourth-generation nuclear power technology has also made breakthroughs. With the successful implement of the world's first pebble bed modular high temperature gas-cooled reactor project, China has developed its fourth-generation nuclear power units with independent intellectual property rights.

Brazil is also an important country in the development and utilization of nuclear energy technology in the world. In 2000, under the initiative of the U.S. Department of Energy, Brazil, the United States, the United Kingdom, Switzerland, South Africa, Japan, France, Canada, South Korea and Argentina, and ten other countries interested in the development of nuclear energy, jointly formed the Generation IV International Forum (GIF), agreed to cooperate in research and development of the fourth-generation nuclear energy system. Brazil has accumulated rich experience in cooperation with the world's traditional leading country in nuclear technology. The enhanced exchanges and cooperation between China and Brazil in nuclear use will help to learn from each other's experience and jointly contribute to the world's low-carbon development addressing the challenges of global climate change.

From an economic perspective, China and Brazil have potential opportunities for cooperation in the construction and operation of nuclear power plants, as well as in nuclear fuel mining and trade. Although Chinese companies are not Brazil's traditional nuclear plant constructors and operators, with the 3rd and 4th generation of nuclear energy technologies, which possess higher power generation efficiency and lower cost, they may have a place in the future Brazilian market.

The Covid-19 pandemic has delayed the construction of Brazil's Angra 3 project until 2027. According to Eletronuclear, Brazil will find a suitable constructor and operator for the unit by 2023, and potential partners include Chinese companies[①].

In addition, China and Brazil have great opportunities in uranium mining and trade. Brazil is a country rich in uranium resources, with proven reserves of about 309,000 tons in spite of a small amount of exploitation, whereas China is a country with high dependent on uranium import. Currently the main suppliers for China are Kazakhstan, Uzbekistan, Canada, Namibia, Niger and Australia.

With the expansion of China's nuclear power industry, the demand for high-quality uranium will continue to increase. Expanding uranium trade with Brazil will help diversify China's energy

① https://www.cnnpn.cn/article/19686.html imports. Furthermore, the 3rd-generation green uranium mining technology developed by China, marked by the "CO_2 + O_2" in-situ leaching uranium mining process, possesses leading advantage of low cost, high efficiency and environmental friendliness. The complementary resources and technologies provide the possibility for China and Brazil to deepen the exploitation and utilization of uranium resources.

4.5 Biomass

Brazil is the second largest producer of ethanol in the world, after the United States, and is home to the world's largest fleet of cars that use ethanol as fuel. China is the largest automotive fuel market in the world.

As previously highlighted, Brazil has a long history of promoting biofuels. The sugarcane ethanol and biodiesel industries are consolidated and Renovabio can set a new impulse. The country already has important advanced biofuels initiatives.

Even though China's main choice for decarbonizing transport is electric vehicles, biofuels may have relevance. In 2017, the Chinese government announced the adoption of a mandate to add ethanol to gasoline, which would reach 10% in 2022. However, concerns about the pressure on the price of corn, the main ethanol input in the country, made the mandate unfeasible. Today the ethanol blend reaches 2% of gasoline in the country.

The potential for international partnerships in biomass involves the intensification of international trade. Brazilian ethanol has environmental advantages as CO_2 emissions from sugar cane are lower than corn ethanol. Another advantage is that the impact on food supply is less significant. Today, China's ethanol imports are predominantly corn ethanol from the United States (Pratt, 2021).

The technological area offers important cooperation opportunities for Brazil and China in the biofuels segment. Advanced biofuels would make it possible to increase productivity and overcome barriers currently posed to the use of biofuels, especially competition with food production. Brazil has a leading position in the development of biofuels and Chinese technological capacity can allow the country to maintain its relevance in advanced fuels. The biofutures platform, in which the two countries participate, could be a starting point for cooperation.

4.6 Hydrogen

China is the world's largest hydrogen producer and has large-scale green hydrogen projects. The cooperation between Brazil and China in the development of the green hydrogen energy industry may encompass renewable energy systems integration projects, including grid integration; development of the electricity market; flexibility options for the electricity system; and mechanisms to promote energy efficiency for the industry. By signing a Memorandum of Understanding on Cooperation in Bioenergy, the two sides can cooperate in the research and development of renewable energy. Brazil and China already participate in the BRICS Energy Research Cooperation Platform, and the research groups that develop technologies applicable to the hydrogen sector can develop partnership projects.

V. Suggestions

Green energy is a crucial issue for both China and Brazil. If more bilateral cooperation could be carried out, the people from these two countries can benefit and spillover effect may be observed to accelerate the transition to a greener economy.

Establish the corresponding entity in the bilateral green energy cooperation. Both China and Brazil should try to establish such authorized entity to setup the basic frame of green energy, integrate the resources and share information with each other. This could take place under the structure of COSBAN – Chinese-Brazilian High-Level Concertation and Cooperation Commission. The responsibility of the entity is to plan the development route of green energy in both countries and to send a clear signal that the whole system is under transition to a greener one. The entity would be one of the promoters or advocates in the improvement of the laws and regulations for defining appropriate administrative environment, better reflecting the demands of the businesses and consumers and stating the privileges and obligations more accurately, which is one of the factors to support the decision-making process for the domestic and foreign investors.

As important participants, the actions of China and Brazil are observed carefully and the voices of China and Brazil on green energy should be heard in the international community too. Even if the deployment of electricity equipment on different parts of the supply chain is the domestic affair of each country, cooperation is needed to make the respective advantages of each country reduce the cost and improve the efficiency to transfer from the original mode.
Develop forums to bring together institutions for research and technological development of renewable and clean energies. Both countries have institutions (such as universities and research centers) with solid experience in green energy. Sharing experiences would help to identify common technological challenges and complement each country's knowledge base.

Bridge the gaps among different stakeholders of green energy for decisions-making. Green energy has quite wide range of areas, which develop very quickly. Fully understanding the progress and judging the future development trend will benefit the society. Timely exchange of intentions and opinions is very important for coordination and calibration of actions. There are gaps between the government intention and the reaction by the market. Regulations and policies to reduce the frictions and cost of the related policies might help to fill the gap between government and market. In fact, there is a two-ways interaction between government and market. To better design the policies, it is necessary for the government to listen to the suggestions from the market. Mechanisms should be established to collect the willingness and demands of the market, especially on the bilateral cooperation of green energy of Chinese and Brazilian companies. Green energy life cycle includes education, finance, basic research and even laws and consultation. Mobilizing and integrating these stakeholders requires the recognition of the importance and efficiency of cooperation, which first involves the exchange of information, so that decisions may be made in a more efficient way.

Coordinate the development of green and traditional energy ecosystem for more resilience. The transition from traditional energy to green energy needs more support. Raising social awareness of the importance of transformation will help in the transition to green energy.

V. Suggestions

In certain circumstances, the supply of energy exceeds the demand, which may cause competition among companies. With the impact of COVID-19, the global supply chains have been hit hard. The current high prices of oil and gas is an important drive for green energy to flourish. Coordination can be necessary to generate space for the new-born green energy development. China and Brazil are both big countries, which means a lot of different situations in different areas. It is possible and necessary to establish some pilot zone (s). Infrastructure like the electricity grids in these pilot zones could be modified and improved so as to reduce the cost of implementation of energy transition. With more companies involved in the green energy, the advantage will become more prominent, which may not only reduce the cost of transition from traditional energy by more applications with lower cost, but also set good example for other areas to follow. From these pilot zones, transition will be more smoothly propelled.

Educate the consumers on the choices on family equipment and facilities using green energy. Generally speaking, Chinese consumers are willing to accept new life mode, Brazilian consumers enjoy the interaction of different culture. But it is still necessary for the systematic work to help the transition from the traditional energy. Like other issues, consumers need reasons to change their habits. Both China and Brazil could advocate the responsibility of green energy and provide the guide on the transition. Published standard and criteria of green energy may establish a rule-based system to give the consumers more confidence on the choices of the green energy products and services. Actions of the idols or superstars can also be important to lead the fashion. Usually at the beginning, the consumers may pay more for using new products. To provide a complete system to support the after-sale services and speedup the evolution process would reduce cost and barrier for those consumers using the green energy products. Platforms such as social media could be used to provide more communication channels for Chinese and Brazilian consumers to share their experience or even complaints, so that the green energy equipment manufacturers may have better ideas on designs and functions to attract consumers.

Encourage the research on more advanced and adaptable technology for more efficient deployment of green energy. The key points of promoting green energy include the development of technology and its commercialization. These two processes can be strengthened in two-ways. Commercialization is not only the test field of technology, but also provides guide and demand for better technology. Although the companies do have incentives to do research, the basic research may be nonprofitable and need the support from the government. China and Brazil both have the capability on certain kinds of green energy. The research cooperation can also be important driving forces in the promoting of green energy in these two countries. There could be different forms of cooperation: for example, research institutions in Brazil can work with Chinese investors or companies or research institutions in both countries to identify important topics and work together to find solutions to their problems. China has a whole set of manufacturing system, which could be very important to transfer the products from the laboratory to the real market. As the new ideas, materials and technology integrated into the life-cycle of products, the efficiency of green energy applications can be improved by bigger market and more consumers, which could be the advantage of China-Brazil cooperation.

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新兴经济体绿色能源发展与合作
——以中国和巴西合作为例

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引言

由于资本和运营成本下降，可再生能源部署战略得以广泛实施，新兴经济体比以往更加致力于能源产业转型。

建立绿色、低碳的经济体系和能源体系 ，实现碳达峰、碳中和，是中国政府作出的重大战略决策。中国计划到 2060 年全面建立绿色低碳循环发展的经济体系和清洁低碳安全高效的能源体系。根据联合国可持续发展目标（SDGs），巴西致力于确保人人都能获得可负担、可靠的能源服务，同时扩大可再生能源使用，提高能源效率。

长期以来，中国和巴西都在制定各项政策，推广绿色能源。对两国而言，国际合作是促进能源转型和确保可持续能源供应的重要且常用的方式。

在过去十年中，中国建立了完备的可再生能源技术工业体系，可再生能源已成为中国新增装机容量的主要来源。生物质能在巴西的能源结构中占据重要地位。生物质能产品在巴西一次能源消费中的占比高达31%。自1975年推出“国家乙醇计划”(PROALCOOL)以来，巴西制定了一系列公共政策促进生物燃料使用。巴西生物燃料消费与生产迅速扩大的基础是强制推行的生物柴油与化石柴油混合（柴油中生物柴油的比例为 10%，预计这一比例还要增加）以及乙醇与普通汽油混合（汽油中乙醇的比例为 27%）。

中国和巴西在可再生能源领域具有广阔的合作前景。巴西拥有丰富的资源、扩大装机容量和电网的强烈需求以及有利的市场、法律和政策条件，中国则拥有雄厚的金融实力和技术能力，这种互补性为两国合作创造了理想条件。水电、核能、生物质能、太阳能和氢能是最具合作潜力的领域。中国和巴西可以充分发挥各自比较优势，广泛开展合作，进一步提高绿色能源发电量，促进两国能源结构优化。原材料与设备相关的前沿技术、贸易和投资将成为双方合作的抓手。此外，双方还可以加强陆上和海上物流，从而促进贸易，提高电力设备的可及性。

本报告包括引言和五章内容。第一章介绍了绿色能源的背景和定义，以及中国和巴西各自的目标与政策。第二章重点介绍了两国的绿色能源发展历程和成就。第三章论述了两国绿色能源发展的优势与不足。第四章讨论了中巴绿色能源合作潜在领域，第五章提出了开展进一步合作的建议。

一、新兴经济体绿色能源发展与合作概述

1.1 绿色能源概述

1.1.1 背景

能源是经济、社会和环境可持续发展的关键因素。不断增长的人口以及更高的收入和消费水平扩大了能源需求，给环境带来了越来越大的负担，对全球气候的影响尤为严重（GIBSON，WILMAN，LAURANCE; 2017）。

化石燃料（煤、石油和天然气）是主要的能源来源，约占当今世界一次能源需求的 85%（BP，2021）；能源生产占全球温室气体排放的 76%（WRI，2022）。为了缓解气候变化，需要实现能源重大转型，转向可再生和可持续能源（SEN，GANGULY; 2017）。截至 2016 年，已经有 176 个国家制定了发展一定比例“绿色” 能源的目标（GIBSON，WILMAN，LAURANCE; 2017）。

根据政府间气候变化专门委员会（IPCC）的数据，2020 年全球约有 28% 的电力来自低碳能源（包括水力发电和可再生能源），到 2050 年时，这一比例应增加至 80%（BP，2021）。为了实现第 21 届联合国气候大会（COP21）提出的目标和将全球气温升高控制在 1.5° C 的目标，需要根据气候变化的情况，调整能源的商业模式和投资等各个方面，发展低碳能源结构成为必然。

在过去十年中，得益于光伏太阳能和风能的迅速发展，在全球电力需求增长 25% 的情况下，发电产生的二氧化碳排放量仅增长了 9%。十年来，各类可再生能源技术满足了近 65% 的电力需求增长（IEA，2021）。由于这些来源提供的电力不断增加，很多传统发电厂（例如煤和天然气）被取代。

2008 年金融危机之后，创造“绿色”就业机会的政策首次出台，成为减少失业的一种手段（Markandya 等，2016）。2009 年，《美国复苏和再投资法案》（ ARR Act）获得通过，这项经济刺激方案包含了 670 亿至 1120 亿美元的 “清洁能源” 或 “绿色” 计划，约占 GDP 的 0.7%。除了该刺激计划，奥巴马总统还宣布了美国的清洁能源目标，其中一个目标是，到 2012 年时将可再生能源发电装机容量增加一倍，并创造 300 多万个就业机会；另一个目标是提高可再生能源的国内生产能力，创造可再生能源供应链就业机会。但是，要提供更多的绿色工作机会，还需要开展大量的宣传教育。此外，该计划还包括了支持可再生能源和其他绿色就业机会的培训计划（MUNDACA，RICHTER; 2015）。

欧盟最近发起了“绿色就业计划”，该机制为成员国提供资金，帮助其向绿色经济过渡，把握就业机会，并应对相关挑战。除此之外，欧盟还通过了2030年能源和气候框架，旨在将温室气体排放量减少40%，该框架提出将能源消耗中可再生能源的比例提高至不低于27%的约束性目标，使能源效率提高27%（MARKANDYA等，2016）。

国际能源署（IEA, 2021a）认为，发展新能源经济需要适当的政府政策和技术创新，新能源已成为投资和就业的重要新兴部门。国际能源署（IEA, 2021a）还强调，需要加强国际合作，加快知识转让，支持新技术快速传播。

总的来说，政府支持政策一直是全球可再生能源投资增长的核心。世界各地都在加速出台可再生能源支持政策，目前几乎所有国家都至少设定了一个可再生能源目标。此外，通过直接支持政策促进可再生能源发展的国家数量增加了三倍，从2004年的至少48个国家增加到了2017年的至少147个国家，更多的发展中国家和新兴国家制定了可再生能源目标和政策。可再生能源目标是公共和私营机构能源转型承诺的主要方式，具体形式包括政府官方公告和包含详细指标与合规措施的书面计划。这些目标的重点可能各不相同，既有单一的技术或部门目标，也有涵盖整个经济领域的目标（IRENA，REN 21，IEA; 2018）。

然而，由于人们未能充分理解可再生能源技术所带来的总体好处，在评估此类技术时，一般认为其成本效益不及传统技术。因此，要全面评估可再生能源技术，必须综合考虑其益处。例如，许多可再生能源技术可以在较短周期内小规模提高现有能源体系的容量增量，相比核电站等大型设施，新能源技术的发电机组通常在增量供应方面具有更大的灵活性（DINCER，ROSEN; 2005），这些都应成为重点考虑的因素。

总体而言，过去十年中，得益于各方扩大可再生能源使用以及提高能源效率的努力、各类支持政策和目标的陆续出台，可再生能源的应用已显著增加，但它们还远未完全融入更大层面的能源体系（IRENA，REN 21，IEA；2018）。

随着资本和运营成本下降以及可再生能源部署战略的广泛实施，新兴经济体加大了能源产业转型的力度。例如，2009年中国成为全球最大的可再生能源和热力开发国（IRENA，REN 21，IEA; 2018）。

联合国贸发会议（2017）强调，可再生能源对新兴经济体的发展具有重要意义。具体而言，对依赖于大宗商品的国家来说，对大宗商品进行可持续管理，可以促进经济增长、扩大就业、增加财政收入和推动基础设施发展。与此类议程相关的一些目标是：（1）确保粮食和能源安全；（2）提高资源效率和可再生能源的使用；（3）促进工业多样化和商品增值，支持国内技术开发、研究和创新。为了实现这些目标，政府、私营部门和民间社会之间必须开展协同合作，这一点至关重要。

1.1.2 定义

气候变化可能是当今人类面临的最大挑战，能源行业排放了将近四分之三的温室气体，是影响气候变化的关键因素，通过能源转型能够避免气候变化带来的最差影响。（IEA，2021a）。

Zarnikau（2003）将绿色能源定义为利用可再生能源所产生的电力，包括光伏电池板、生物质能项目、地热项目和风电场等技术。采用绿色能源发电，温室气体排放为零，因此可以成为持久的气候变化解决方案。Chernysheva（2019）认为，绿色能源包括所有有助于减少二氧化碳排放的行业。根据该定义，绿色能源既包括太阳能、风能、水能等主要行业，也包括地热能和潮汐能生产以及与此相关的基础设施建设。

Mohanty（2012）区分了三代绿色能源技术。第一代技术包括水电、地热和生物质燃烧等；第二代技术包括太阳能加热和冷却、光伏发电和风力发电等；第三代技术包括生物质气化、生物炼制、地热和海洋能（潮汐能、波浪能、海洋温差能）等。

根据 Omer（2008）的说法，可持续性被定义为“既满足当代人的需求，又不对后代人满足其需求的能力构成危害的发展”，但是所有能源都会对环境产生某种影响，因此，提高能源效率可以在一定程度上减少人们对排放及其所带来的负面影响的担忧。对于同等级别的服务或产品级，如果使用的资源更少，带来的污染程度更低，那么能源效率就更高（DINCER，ROSEN; 2005）。

国际能源署（2021a）认为，若要在全球范围内减少因电力供应而产生的排放，可再生能源技术是关键所在。几十年来，水电一直在低排放源中位居前列，但可再生能源发电若要在 2030 年增加两倍，并在净零排放情况下到 2050 年增加八倍以上，则主要有赖于风能和太阳能的发展。此外，可再生能源在减少建筑、工业和运输排放方面也发挥着重要作用，可再生能源产生的电力可以通过区域供暖间接使用，也可以直接用于热力生产。在运输中，可再生能源通过发电为电动汽车提供动力，在减少排放方面起着重要的间接作用。它们还通过使用液体生物燃料和生物甲烷来直接减少排放。

国际可再生能源署（IRENA）、21 世纪可再生能源政策网络（REN 21）和国际能源署（2018）指出，生物燃料主要用于公路运输，但也可用于铁路、海上和航空运输。生物燃料可与常规能源基础设施和陆路运输燃料低级混合使用，为现有运输体系提供动力，高级混合通常需要在发动机和燃料分配基础设施方面进行调整。

1.1.3 文献综述

Sen 和 Ganguly（2017）认为能源质量是影响发展的重要因素。在可持续发展过程中，清洁、

安全能源的持续供应可降低能源对环境的影响。Midilly、Dincer 和 Ay(2006)也从这个角度出发，认为实现可持续发展的关键是能持续获得成本合理的的能源供应，而且这种能源供应不会对社会造成负面影响，或带来的负面影响很小。

Dincer 和 Rosen（2005）认为绿色能源资源和技术是可持续发展的关键要素，他们列出了三个主要原因。首先，相比其他能源，绿色能源对环境的影响通常更小，其多样性也为人们提供了灵活的选择。其次，绿色能源不会枯竭。在适当谨慎使用的情况下，绿色能源几乎可以无限期保证可靠且可持续的能源供应。最后，绿色能源有利于能源体系分散化，有助于实施在某种程度上独立于国家能源网络的本地解决方案，从而增强了系统灵活性，保障了少数偏远地区人口的经济利益。此外，绿色能源设备规模较小，能够减少从设计到操作所需的时间，从而具有更强的适应性，可以有效应对无法预测的能源需求增长和变化情况。

Sen 和 Ganguly（2017）从社会经济发展的角度出发，强调人均收入与人均能源使用量呈正相关，人类发展指数也与人均能源使用量呈正相关。经济增长是过去几十年能源需求和消费上升的最重要因素。随着经济增长，人类对更先进、灵活性更强的能源的需求也在增加。因此，经济增长是从常规燃料向现代能源转型的推动因素之一。发展中国家已经强烈感受到这种转型需求，可靠的能源是人类发展的必要条件之一，因为这类能源可以增加收入，提高健康和教育质量，降低贫困水平。此外，现代能源技术可以分散使用，因而能在农村发展中发挥重要作用，也能够创造新的就业机会，不管是对发展中国家，还是对发达国家，这些都是新能源技术最积极的长期影响。

Dincer 和 Rosen（2005）认为，可再生能源技术可以为传统能源体系提供兼具成本与环境效益的替代性方案。基于可再生能源的能源转换系统具有多种优势，因此极具吸引力，其中一个明显优势是，这种能源体系的供应成本不太容易受到化石燃料价格波动的影响。具体而言，可再生能源体系的优势包括：成本估算结果可靠，采用这种系统有助于减少全球不可再生能源的消耗；系统实施相对简单；通常不会造成环境过度退化，有助于解决重大环境问题，所以可再生能源体系的广泛使用必然会降低污染水平；通常对发展中国家有利。事实上，在发展中国家不断追求更高生活水平的推动下，可再生能源技术市场需求可能会进一步增长（DINCER，ROSEN; 2005）。

国际能源署（2021a）强调政府在出台、实施适当政策以促进可再生能源使用方面所起的作用。此外，诸如国际开发银行之类的公共金融机构可以在投融资方面发挥关键作用，尤其是面向新兴经济体国家的投融资。

1.2 目标

1.2.1 中国

建立绿色、低碳的经济体系和能源体系，实现碳达峰、碳中和，是中国政府作出的重大战略决策。根据中国发布的《中共中央、国务院关于完整准确全面贯彻新发展理念做好碳达峰碳中和工作的意见》[①]，其主要目标是：

到 2025 年，绿色低碳循环发展的经济体系初步形成，重点行业能源利用效率大幅提升。单位国内生产总值能耗比 2020 年下降 13.5%；单位国内生产总值二氧化碳排放比 2020 年下降 18%；非化石能源消费比重达到 20% 左右。

到 2030 年，单位国内生产总值二氧化碳排放比 2005 年下降 65% 以上；非化石能源消费比重达到 25% 左右，风电、太阳能发电总装机容量达到 12 亿千瓦以上。

到 2060 年，绿色低碳循环发展的经济体系和清洁低碳安全高效的能源体系全面建立，能源利用效率达到国际先进水平，非化石能源消费比重达到 80% 以上，碳中和目标顺利实现，生态文明建设取得丰硕成果，开创人与自然和谐共生新境界。

1.2.2 巴西

水力发电是巴西发电量的主要来源，在该国总发电量中的占比高达 60%（ANEEL，2022）。在过去十年中（2012-2021），水力发电占该国总发电量的 64%（EPE，2022）。巴西大型水力发电厂水库的总发电量可达 213 太瓦时（ONS，2022），相当于 2021 年全国用电量的 43%（EPE，2022）。

在巴西，轻型车辆已广泛使用生物燃料：可以使用任何比例乙醇或汽油的灵活燃料汽车约占新车销量的 95%；2016 年，灵活燃料汽车在轻型车辆中的占比为 72%，共有 2400 万辆车可以使用纯（未混合）乙醇燃料（IRENA，ren21，IEA; 2018）。

如前所述，巴西电量大部分来自可再生能源，其中最为重要的是水力发电。然而，Losekann 和 Hallack（2018）强调，由于成本不断增长，管控日趋严格，水力发电量的增加受到限制。因此，巴西必须投资新的可再生能源，以便在不扩大化石能源发电的情况下满足其用电需求。

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① 中国国家发展和改革委员会（简称“发改委”）：
https://en.ndrc.gov.cn/policies/202110/t20211024_1300725.html

相比发达经济体，巴西对风能和太阳能的开发要晚一些，但是，该国的风能和太阳能发电量已在过去十年中大幅提升。风力发电量从 2012 年的 1.9 吉瓦增加到 2021 年的 20.7 吉瓦；太阳能发电量从 2012 年的 7 兆瓦增加到 2021 年的 13.7 吉瓦。

在风能方面，巴西制定了含有当地成分才能获得资助的工业政策，吸引了几家供应商向巴西供货。新制造商的到来刺激了风电行业的竞争，减少了每兆瓦风电装机容量的投资，降低了能源生产成本。2013 年，巴西共有有 12 家风力涡轮机制造商，其产品供应给欧洲、美国、阿根廷和巴西当地。巴西在风力涡轮机和风电场设备方面已实现自给自足。整合可再生能源，尤其是与风能有关的可再生能源，对于长期融资的连续性至关重要。此类融资为包括资本货物行业在内的能源和工业部门提供支持，推动前景乐观之技术的发展（DA SILVA 等，2013）。

根据联合国可持续发展目标，巴西致力于确保人人都能获得可负担、可靠的能源服务，同时扩大可再生能源使用，提高能源效率。实现这些目标需要开展国际合作，尤其要加强合作提高清洁能源研究和技术的可及性，扩大能源基础设施投资。

Miranda 等（2021）指出，绿色技术已成为巴西可持续发展和经济发展的替代性战略。总体而言，Miranda 等（2021）认为，巴西的大多数研究都集中在绿色技术应用方面，如产品、流程或原材料等。采用这些做法的目的是改善可持续流程，扭转以往的情况。这些绿色技术的好处还包括：可以获得水和能源的替代性资源，实现预期目的；有望将环境立法、创新引领的工业改进及各机构的环境绩效提升相结合；可以采用生产性较低的流程，减少对环境、社会和经济的影响。

1.3 政策

1.3.1 中国

1.3.1.1 相关法律法规

中国现行的能源相关法律法规主要有：《安全生产法》(2002)、《环境影响评价法》(2003)、《特种设备安全法》（2014）、《可再生能源法》（2006）、《矿产资源法》（1986）、《环境保护法》（2015）、《电力法》（1996）、《煤炭法》（1996）和《节约能源法》（2008）[①]。

中国将清理现行法律法规中与绿色能源工作不相适应的内容，加强法律法规间的衔接协调。

① 中国国家能源局：http://www.nea.gov.cn/nyflfg/index.htm.

除了研究制定碳中和专项法律外，抓紧修订《节约能源法》《电力法》《煤炭法》《可再生能源法》《循环经济促进法》等法律，增强相关法律法规的针对性和有效性。

中国还将完善绿色能源标准计量体系。加快节能标准更新升级，抓紧修订一批能耗限额、产品设备能效强制性国家标准和工程建设标准。加快完善地区、行业、企业、产品等碳排放核查核算报告标准，建立统一规范的碳核算体系。积极参与相关国际标准制定，加强标准国际衔接。

1.3.1.2 财政政策

中国将有序推进绿色低碳金融产品和服务开发，设立碳减排货币政策工具，将绿色信贷纳入宏观审慎评估框架，引导银行等金融机构为绿色低碳项目提供长期限、低成本资金。鼓励开发性政策性金融机构按照市场化法治化原则为实现碳达峰、碳中和提供长期稳定融资支持。支持符合条件的企业上市融资和再融资用于绿色低碳项目建设运营，扩大绿色债券规模。研究设立国家低碳转型基金。鼓励社会资本设立绿色低碳产业投资基金。建立健全绿色金融标准体系。

根据中国国家发改委、国家能源局 2022 年 1 月共同发布的《关于完善能源绿色低碳转型体制机制和政策措施的意见》[①]，中国将完善支持能源绿色低碳转型的多元化投融资机制。加大对清洁低碳能源项目、能源供应安全保障项目投融资支持力度。国家绿色发展基金和现有低碳转型相关基金要将清洁低碳能源开发利用、新型电力系统建设、化石能源企业绿色低碳转型等作为重点支持领域。推动清洁低碳能源相关基础设施项目开展市场化投融资，研究将清洁低碳能源项目纳入基础设施领域不动产投资信托基金（REITs）试点范围。中央财政资金进一步向农村能源建设倾斜，利用现有资金渠道支持农村能源供应基础设施建设。

1.3.1.3 税收优惠

2022 年 5 月，国家税务总局发布《支持绿色发展税收优惠政策指引》[②]。为助力经济社会发展全面绿色转型，实施可持续发展战略，国家从支持环境保护、促进节能环保、鼓励资源综合利用、推动低碳产业发展四个方面，实施了 56 项支持绿色发展的税费优惠政策。

以助力经济社会发展全面绿色转型，实施可持续发展战略，国家从支持环境保护、促进节能环保、鼓励资源综合利用、促进低碳产业发展。税收优惠政策包括：对于风力发电项目所缴纳的增值税，实行增值税即征即退 50% 的政策；对于水电站、核电站，部分免征城镇土地使用税。

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① http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/47673/48000/xgzc48006/Document/1721203. htm.
② 中国国家税务总局：
http://www.chinatax.gov.cn/chinatax/n810341/n810825/c101434/c5175740/content.html.

1.3.1.4 补贴政策

可再生能源电价附加补助资金是按照《可再生能源法》要求，通过从电价中征收基金附加的形式筹集资金设立，支持电网企业收购光伏、风电、生物质等可再生能源发电量的政府性基金。享受可再生能源电价附加补助资金的可再生能源发电项目，需符合国家规划并纳入国家规模管理，符合电价政策，并按要求发电上网。目前，中国风电、光伏发电等可再生能源发电技术水平不断提升，成本持续下降，具备了与传统能源竞争的基础，逐渐成为中国能源结构转型的重要力量。中长期来看，补贴呈逐步下降趋势。2019 年，中国在风电、光伏发电行业开展无补贴平价上网试点，其他可再生能源发电行业的补贴也逐步有序减少。根据财政部等三部委下发的文件，自 2020 年起，新增海上风电和光热项目不再纳入中央财政补贴范围，自 2021 年起新备案的集中式光伏电站、工商业分布式光伏项目和新核准陆上风电项目，中央财政不再补贴。

1.3.1.5 科技政策

中国将制定科技支撑碳达峰、碳中和行动方案，编制碳中和技术发展路线图。采用“揭榜挂帅”机制，开展低碳、零碳、负碳和储能新材料、新技术、新装备攻关。加强气候变化成因及影响、生态系统碳汇等基础理论和方法研究。推进高效率太阳能电池、可再生能源制氢、可控核聚变、零碳工业流程再造等低碳前沿技术攻关。培育一批节能降碳和新能源技术产品研发国家重点实验室、国家技术创新中心、重大科技创新平台。建设碳达峰、碳中和人才体系，鼓励高等学校增设碳达峰、碳中和相关学科专业。

中国将深入研究支撑风电、太阳能发电大规模友好并网的智能电网技术。加强电化学、压缩空气等新型储能技术攻关、示范和产业化应用。加强氢能生产、储存、应用关键技术研发、示范和规模化应用。推广园区能源梯级利用等节能低碳技术。推动气凝胶等新型材料研发应用。推进规模化碳捕集利用与封存技术研发、示范和产业化应用。建立完善绿色低碳技术评估、交易体系和科技创新服务平台。

根据《关于完善能源绿色低碳转型体制机制和政策措施的意见》[①]，建立清洁低碳能源重大科技协同创新体系。建设并发挥好能源领域国家实验室作用，形成以国家战略科技力量为引领、企业为主体、市场为导向、产学研用深度融合的能源技术创新体系，加快突破一批清洁低碳能源关键技术。支持行业龙头企业联合高等院校、科研院所和行业上下游企业共建国家能源

① http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/47673/48000/xgzc48006/Document/1721203/1721203. htm.

领域研发创新平台，推进各类科技力量资源共享和优化配置。围绕能源领域相关基础零部件及元器件、基础软件、基础材料、基础工艺等关键技术开展联合攻关，实施能源重大科技协同创新研究。加强新型储能相关安全技术研发，完善设备设施、规划布局、设计施工、安全运行等方面技术标准规范。

1.3.1.6 人才政策

根据国家发改委、国家能源局等九部门于 2022 年 6 月联合印发的《“十四五”可再生能源发展规划》[①]，中国将完善人才评价和激励机制，造就一批具有国际竞争力的科技人才与创新团队。中国将加大高水平人才培养与引进力度，鼓励各类院校开设可再生能源专业学科并与企业开展人才培养合作，完善可再生能源领域高端人才引进机制。

1.3.2 巴西

巴西长期致力于将绿色能源推广到发电和运输行业，并制定了多项相关政策。在初期阶段，由于巴西化石能源储量有限，这些政策的目标是保障能源安全。

从这个角度出发，巴西在 20 世纪 70 年代推出“国家乙醇计划”（PROALCOOL），以应对石油危机的影响，减少石油产品进口。在该计划的推动下，1975 年巴西的轻型车辆开始大量使用乙醇燃料。近年来为了保护环境，巴西恢复了鼓励使用生物燃料的政策。2004 年该国通过了支持生物燃料发展的新法规和法律框架。根据巴西的生物燃料要求，2019 年标准汽油需含 27% 的乙醇，标准柴油需含 10% 的生物柴油；生物燃料的缴税额低于化石燃料。巴西是世界第二大乙醇生产国，每年产量约为 300 亿升。

巴西于 2018 年推出“国家生物燃料政策计划”（RenovaBio），为国家燃料供应设定了减排目标。燃料分销商可以通过提高生物燃料（乙醇、生物柴油和生物甲烷）的销售量来实现这些目标，此举有望显著扩大生物燃料的生产和使用。此外，生态区划、工业活动、森林保护和农业实践方面的补充法律也促进了可持续性政策的实施。

2002 年巴西推出了“替代电能激励计划”（Proinfa），成为可再生能源电力激励政策的起点。该计划承诺以激励性价格购买太阳能、风能和生物电力。随后，促进可再生能源发展的拍卖体系开始生效。

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① http://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202206/t20220601_1326719.html.

促进家庭和企业广泛使用太阳能电池板的激励机制是分布式发电的净计量制度。净计量方案制定于 2012 年，由于电池板价格不断下跌，2016 年出现了大范围使用太阳能的热潮。

2022 年巴西修订了分布式发电的激励制度，同时宣布将逐步取消补贴。

巴西军政府执政期间，核能计划得到加强，在里约热内卢州的安格拉杜斯雷斯市（Angra dos Reis）修建了两座核电站。根据最新的扩建计划，将在安格拉（Angra）修建第三座核电站，还将在其他地方建造新的核电站。

1.3.2.1 绿色能源相关法律

目前，与鼓励可再生能源直接相关的规定包括：强制添加生物燃料的规定、国家生物燃料政策、分布式发电框架、受管制的可再生能源电力市场拍卖以及可再生能源发电在配电和输电电价方面享受的折扣。

1997 年，巴西出台了第 9.478 号法律，规定在汽油中强制添加乙醇。根据该法，政府规定乙醇需以 18%~27.5% 的比例强制混入汽油使用。目前的混合比例为 27% （即汽油中含 27% 的乙醇）。2022 年颁布的第 10.940 号法令规定，由国家能源政策委员会（CNPE）确定具体的混合比例。

2004 年，巴西推出了“国家生物柴油生产和使用计划”（PNPB），确立了从 2% 的比例开始，逐步将生物柴油与矿物柴油混合的时间表。2016 年第 3.263 号法律规定，生物柴油在全国燃料消费中的比例需每年增加 1%，到 2018 年时达到 10%；该法还授权国家能源政策委员会确定未来的的增长比例，直至达到 15% 的目标。根据国家能源政策委员会确定的新计划，生物柴油的比例将每年增加 1% ，到 2023 年时达到 15%。但是，由于柴油价格不断上涨，能源政策委员会委员会在其 2021 年第 16 号决议中确定，将这一比例从 13% 降到 10%，并推迟了实现新目标的时间表。

2017 年第 13.576 号法律提出了“国家生物燃料政策计划”，作为一项政府政策，该计划旨在通过向化石燃料分销商出售碳信用额度的方式，扩大生物燃料的使用。

在太阳能领域，2022 年第 14.300 号法律修订了巴西国家电业局（ANEEL）2012 年 482 号决议，正是该决议确定了净计量方案。根据新法规定，可以用新增分布式发电量来补偿的用电量将逐步减少。在新规则生效之前，巴西出现了安装光伏板的热潮。

根据 2021 年第 14.182 号法律，受管制市场将采取拍卖模式来满足电力分销商的需求。该法包含了专门针对可再生能源拍卖会的内容，这与风能和太阳能的扩张直接相关。

1998 年第 9.648 号法律规定，小型水力发电厂的输配电电价适用 50% 的折扣。2002 年第 10.438 号法律和 2003 年第 10.762 号法律将折扣扩大到风能、生物质能和太阳能。

2021 年第 14.120 号法律规定，新增可再生能源项目的输配电电价折扣只能再实施三年，到期后新增项目将与传统资源享受同等政策。需要指出的是，到期之前投入运行的可再生发电机在整个使用年限内，仍然可以享受折扣。巴西国会提议将新增项目的折扣延长两年。

1.4 国际合作

1.4.1 中国

中国坚定维护以联合国为核心的国际体系，遵循《联合国气候变化框架公约》及其《巴黎协定》的目标和原则，努力落实 2030 年可持续发展议程。中国将力争 2030 年前实现碳达峰、2060 年前实现碳中和。这是中国基于推动构建人类命运共同体的责任担当和实现可持续发展的内在要求而作出的重大战略决策。此外，中国已决定接受《〈关于消耗臭氧层物质的蒙特利尔议定书〉基加利修正案》，并加大对非二氧化碳排放的管控。

中国将与国际社会深化伙伴关系，提升合作水平，在实现全球碳中和新征程中互利共赢[①]。中国已经在绿色 “一带一路” 建设方面取得积极进展，未来将继续努力挖掘绿色 “一带一路”建设潜力，促进全球低碳转型。近年来，中国对 “一带一路” 沿线国家和地区可再生能源项目的投资不断增长，积极帮助发展中国家和地区推广绿色能源技术的应用。中巴经济走廊重点项目卡洛特水电站就是一个例子，该项目总投资为 17.4 亿美元，2021 年底已投入商业运营，每年可为巴基斯坦提供约 32 亿千瓦时的清洁电力，覆盖 500 万人口，每年将减少二氧化碳排放 350 万吨。中国还依托“一带一路”环境大数据平台和一带一路环境技术转让中心，促进“一带一路” 国家共享绿色发展信息，扩大绿色技术应用。

中国将加快 “一带一路” 投资与合作实践绿色转型，支持“一带一路”国家开发和使用清洁能源。根据《关于完善能源绿色低碳转型体制机制和政策措施的意见》[②]，中国将鼓励金融产品和服务创新，支持“一带一路”清洁低碳能源开发利用。推进“一带一路”绿色能源务实合作，探索建立清洁低碳能源产业链上下游企业协同发展合作机制。引导企业开展清洁低碳

① 中国国家主席习近平在“领导人气候峰会”上的讲话 , 2021 年 4 月 22 日。
http://language.chinadaily.com.cn/a/202104/23/WS6082197fa31024ad0bab9c28.html

② http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/47673/48000/xgzc48006/Document/1721203/1721203.htm.

能源领域对外投资，在相关项目开展中注重资源节约、环境保护和安全生产。推动建设能源合作最佳实践项目。中国将建设更紧密的绿色发展伙伴关系，让绿色切实成为共建“一带一路”的底色。

中国将积极推动全球能源治理中绿色低碳转型发展合作。创建于 2019 年的“一带一路”能源合作伙伴关系旨在促进成员在能源政策方面开展合作，提供技术交流平台。依托中国—阿盟、中国—非盟、中国—东盟、中国—中东欧、亚太经合组织（APEC）可持续能源中心等合作平台，持续支持可再生能源、电力、核电、氢能等清洁低碳能源相关技术人才合作培养，开展能力建设、政策、规划、标准对接和人才交流。提升与国际能源署和国际可再生能源署等国际组织的合作水平，积极参与在联合国、二十国集团（G20）、APEC、金砖国家、上合组织等多边框架下的能源绿色低碳转型合作。

1.4.2 巴西

国际合作是促进能源转型和确保两国可持续能源供应的重要且常用的方式。合作可以通过国际组织（如联合国）、国家集团（如二十国集团、南方共同市场、金砖国家）或双边方式开展。

近年来，巴西在能源领域的国际合作有所加强。巴西外交部 Concordia 平台记录了 30 年来巴西参与的 608 项能源国际行动[①]。其中，120 项行动涉及可再生能源[②]。

Santos 和 Silva（2018）指出，20 世纪 90 年代，由于巴西与毗邻南美国家之间实施电力联通和天然气管道项目，巴西国际能源合作的主要对象是南美国家，尤其是阿根廷和玻利维亚。在此期间，核领域的国际合作也很突出。

21 世纪头十年，巴西的国际合作伙伴变得更加多样化，可再生能源方面的合作开始增多。来自非洲、亚洲以及欧洲和美洲的国家开始与巴西开展能源领域合作。此时，生物燃料已在国际展现出成功前景，推动了巴西制定这方面的国际合作计划。

在过去十年中，可再生能源领域合作取得了蓬勃发展。金砖国家与巴西签订的相关国际合作协议增多。近期比较突出的合作成果是“生物未来平台”和 2020 年与印度签署的《生物能源谅解备忘录》。

“生物未来平台”是巴西发起的一项倡议，共有 20 个国家参与。该平台创建于 2016 年，

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①通过网站搜索引擎，以关键词“能源”搜索 1990 年 1 月 1 日至 2022 年 1 月 7 日期间的相关国际行动。国际行动包括条约、协定、谅解备忘录、协议、联合声明、公报、计划、交易等。

② Número de atos internacionais que resultaram do mecanismo de busca para as palavras chaves Solar, Eólica, Etanol e Biodiesel no período 01/01/1990 a 01/07/2022.

旨在促进生物经济尤其是生物燃料的发展。平台合作对象既有政府部门，也有国际能源机构，例如国际能源署、国际可再生能源署和全球生物能源伙伴关系（GBEP）。

巴西和印度之间的合作旨在加强可持续的交通运输，重点合作领域是生物燃料和可使用灵活燃料技术的车辆。印度计划在 2022 年底使乙醇在汽油中的含量达到 10%； 2025 年之前达到 20%。巴西和印度之间确立了 9 个关键合作领域，其中包括第二代乙醇的开发①、航空可持续燃料以及沼气和生物甲烷方面的政策和激励措施。

①第二代乙醇可以利用第一代乙醇生产过程中丢弃的生物质废物，提高了能源生产力和二氧化碳封存能力。

二、中国和巴西的绿色能源发展

2.1 中国的绿色能源发展

中国绿色能源在过去几十年里取得了跨越式的发展，装机容量突破 10 亿千瓦大关，占全国发电总装机容量的 40% 以上。其中，水电、风电、光伏发电、生物质发电装机容量分别连续 17 年、12 年、7 年和 4 年居世界第一，光伏、风电等产业链具有突出的国际竞争优势。在过去十年里，中国还发展了完备的可再生能源技术工业体系，可再生能源已成为中国新增装机容量的主要来源。2022 年前 5 个月，中国可再生能源发电新增装机容量增至 4349 万千瓦，占全国发电新增装机容量的 82.1%。中国的风能、太阳能、生物质能和水力发电装机容量继续位居全球首位。

2.1.1 水电迅速发展

1904 年中国建设了第一个水电站，此后，中国水电发展迅速，装机容量和年发电量连续多年位居世界第一。

中国制定了碳达峰和碳中和目标，出台了一系列减少污染、降低二氧化碳排放的重要政策措施，为包括水电行业在内的清洁能源高质量发展提供了重大机遇。在加快建设以新能源为主体的新型电力体系的过程中，抽水蓄能电站的建设和发展将迎来新一轮机遇，作为一种非常规水电站，这种电站具有强大的调峰和调频功能。

2.1.1.1 水电资源分布

水力发电资源集中在中国西南部，西藏、四川和云南占全国水力发电资源的三分之二以上。从区域分布来看，2020 年西南地区水电发电量占 58.51%，华中地区占 18.5%，西北地区占 10.9%。华南、华东、东北和华北水电发电量占比较小，分别为 5.9% 、4.2% 、1.1% 和 0.9%。

2.1.1.2 水力发电

根据《中国统计年鉴 2021》，中国水电发电量从 2015 年的 1130.3 太瓦时稳步上升至 2019 年的 1304.4 太瓦时，五年间增长了 15.40%。

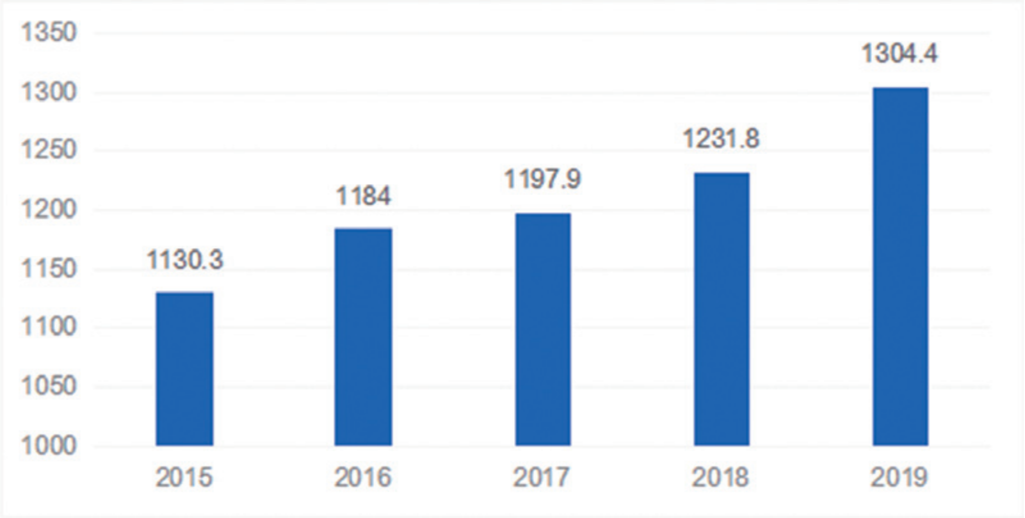

图 2.1 水力发电（2015–2019）（TWh）

来源：《中国统计年鉴 2021》

在过去十年里，中国的水电装机容量从 2011 年的 232.98 吉瓦增至 2020 年的 370.28 吉瓦，十年间增长了 58.93%。

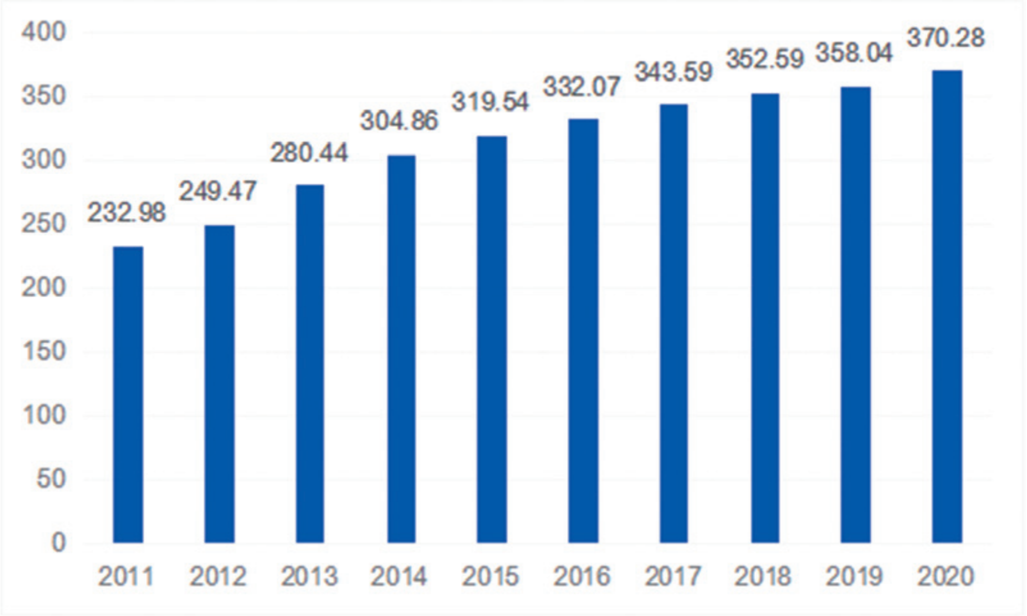

图 2.2 水力发电装机容量（2011–2020）（GW）

来源：《中国统计年鉴 2021》、中国电力企业联合会

中国正在提高抽水蓄能水电产能，以促进新能源开发并确保电网稳定运行。截至 2021 年底，中国抽水蓄能水电装机容量达到 3639 万千瓦，同比增长 15.6% 。

中国政府发布了支持抽水蓄能水电发展的政策。2014 年，国家发改委和国家能源局先后发布了《关于促进抽水蓄能电站健康有序发展有关问题的意见》和《关于完善抽水蓄能电站价格形成机制有关问题的通知》，促进了抽水蓄能电站的健康发展，形成了新一轮水电建设高潮。2021 年 4 月，国家发改委和国家能源局发布了一系列完善抽水蓄能价格形成机制的建议。2022 年 9 月，国家能源局发布了《抽水蓄能中长期发展规划（2021-2035 年）》，其中包括促进中小型项目和加强技术创新的内容。该规划设定的目标是到 2025 年，抽水蓄能投产总规模达到 6200 万千瓦以上，到 2030 年达到 1.2 亿千瓦左右。

2.1.1.3 龙头企业和重大项目

中国长江电力股份有限公司（以下简称“长江电力”）主要从事水力发电、配售电、智慧综合能源以及投融资业务，在中国、葡萄牙、秘鲁、巴西、巴基斯坦等多个国家开展相关业务。长江电力是中国最大的电力上市公司和全球最大的水电上市公司。公司总装机容量为 4559.5 万千瓦，其中国内装机容量为 4549.5 万千瓦，占中国水电总装机容量的 12.3%。2021 年，长江电力的发电量为 2628.8 亿千万时。公司现拥有三峡、葛洲坝、溪洛渡和向家坝四座大型水电站，并代为管理乌东德和白鹤滩两座水电站。

国投电力控股有限公司（以下简称“国投电力”）是中国领先的电力公司。国投电力拥有多元化的水电、风电和光伏发电项目组合。在目前中国上市的所有电力公司中，就综合水电装机容量而言，该公司排名第三。水电项目主要分布在四川、甘肃、云南、新疆等省区。国投电力持有雅砻江水电基地 52% 的股份，该基地是雅砻江流域唯一的水电开发主体，在全国 13 大水电基地中排名第三。雅砻江流域的装机容量为 1470 万千瓦，2019 年末正在建设的水电容量为 450 万千瓦。

三峡水电站位于湖北省宜昌市三斗坪，地处长江西陵峡中段。三峡水电站是世界上最大的水电站，主要功能包括防洪、发电、航运和水资源利用。电站的总装机容量为 2250 万千瓦，其中 32 台单机容量为 70 万千瓦，另外两台单机容量为 5 万千瓦。截至 2021 年 12 月 31 日，三峡水电站累计发电量达到 1502.8 亿千万时。

白鹤滩水电站位于金沙江下游的四川省宁南县和云南省巧家县境内，电站以发电为主，兼有防洪、拦沙、改善下游航运条件和发展库区通航等综合效益。电站左右两岸的地下厂房分别安装了八组单机容量 100 万千瓦的水轮发电机组，总装机容量为 1600 万千瓦。白鹤滩水电站

2011 年开工建设，第一批发电机组在 2021 年 7 月开始发电。全面建成后，将是仅次于三峡水电站的世界第二大水电站。

葛洲坝水电站位于湖北省宜昌市境内长江三峡段末端河段上，是长江干流上建设的第一座大型水电站，具有发电和改善航道等综合效益。葛洲坝水电站共有 22 台机组，总容量为 273.5 万千瓦。首台机组 1981 年 7 月 30 日投产，1988 年工程全面竣工。截至 2021 年 12 月 31 日，累计发电量达到 6054 亿千瓦时。

溪洛渡水电站位于位于四川省雷波县和云南省永善县境内金沙江干流上，主要供电华东和华南地区。电站总共安装了 18 台单机容量为 77 万千瓦的水轮发电机，总装机容量为 1386 万千瓦，坝高为 285.5 米。溪洛渡水电站是世界上第一座具有千万千瓦容量的高拱巨型水电站，于 2016 年获得了菲迪克（FIDIC）工程项目杰出奖。电站工程于 2005 年底正式启动，首批机组于 2013 年 7 月开始发电。2014 年 6 月底，18 台机组全部投产。截至 2021 年 12 月，累计发电量达 4754 亿千瓦时。

向家坝水电站位于四川省宜宾市与云南省水富市交界的金沙江下游河段上。电站以发电为主，兼有防洪、改善通航条件、灌溉和拦沙等综合效益。电站安装了 8 台单机容量为 80 万千瓦水轮发电机组，拥有世界上最大的垂直升船机，最大提升高度为 114.2 米。向家坝水电站于 2006 年 11 月正式开工建设，2012 年 11 月首台机组投产，2014 年 7 月全面投产。2018 年 5 月 26 日，升船机在试验基地通航。到 2021 年底，电站累计发电量超过 2600 亿千瓦时。

乌东德水电站位于云南省和四川省交界的金沙江干流上。电站以发电为主，兼有防洪、改善通航条件、促进当地经济和社会发展等综合效益。电站总装机容量为 1020 万千瓦，左右岸地下厂房均安装了 6 台单机容量为 85 万千瓦的水轮发电机组。2011 年项目开工，2021 年 6 月全部机组正式投产。

长龙山抽水蓄能电站是华东地区最大的抽水蓄能水电设施，于 2022 年 6 月实现全面投产。电站安装了 6 台抽水蓄能发电机组，总装机容量为 210 万千瓦，每年发电量近 25 亿千瓦时（kWh）。在充满电的情况下，发电量能达到 600 万千瓦时以上，相当于近 100 万户家庭的每日生活用电量。预计在全部机组投产后，每年可减少约 42 万吨的二氧化碳排放和 2800 吨的二氧化硫排放。

2.1.2 风电协调发展

2.1.2.1 风电资源分布

中国风能资源主要分布在三大区域：北方地区（内蒙古、东北、西北）；东部、东南

沿海和近海岛屿；湖南衡山、湖北九宫山、安徽黄山、云南太华山和青藏高原北部等内陆地区。

根据《“十四五” 可再生能源发展规划》，中国将有序推进海上风电基地建设，重点建设山东半岛、长三角、闽南、粤东、北部湾五大海上风电基地。

2.1.2.2 风力发电

根据《中国统计年鉴 2021》，中国风电产业近年来发展迅速，发电量从 2015 年的 1858 亿千瓦时增至 2019 年的 4060 亿千瓦时，五年间增长了 118.51%。

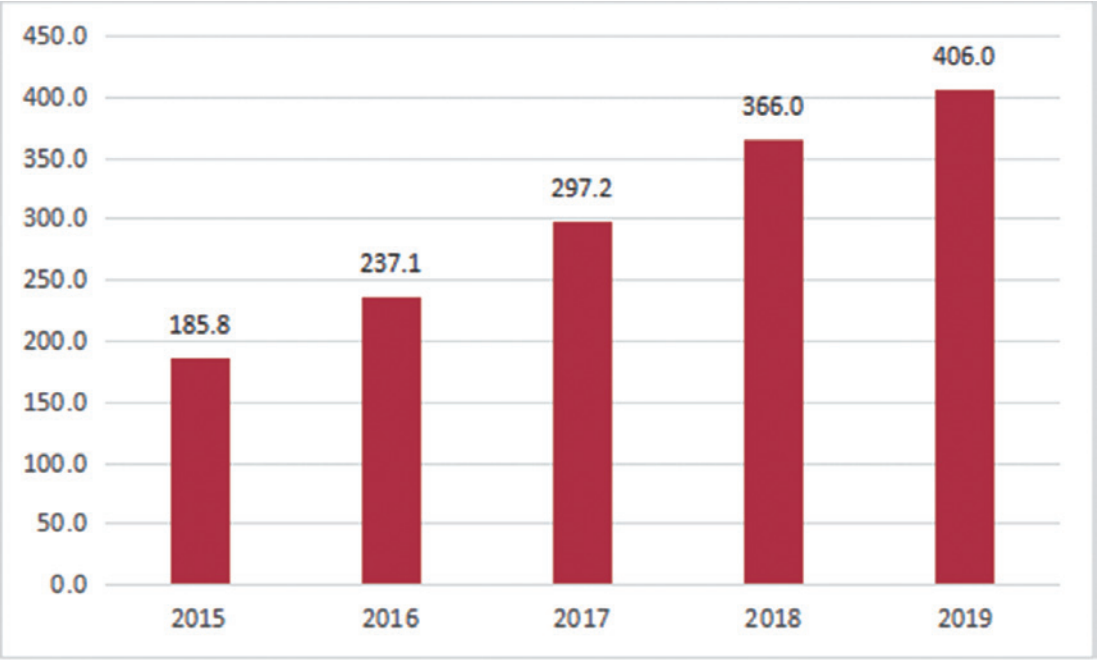

图 2.3 风力发电（2015–2019）（TWh）

来源：《中国统计年鉴 2021》

近十年来，中国风电装机容量呈上升趋势，从 2011 年的 46.23 吉瓦增至 2020 年的 281.65 吉瓦，五年间增长了 5 倍以上。国家能源局的数据显示，2021 年，中国并网风电装机容量达到 300.15 吉瓦，是 2016 年的两倍，已连续 12 年排名全球第一。风电对国家电力供应的贡献不断增加，目前风电占全国电力总装机容量的 13%，风力发电量占全国总用电量的 7.5%，分别比 2020 年提高了 0.3 个百分点和 1.3 个百分点。

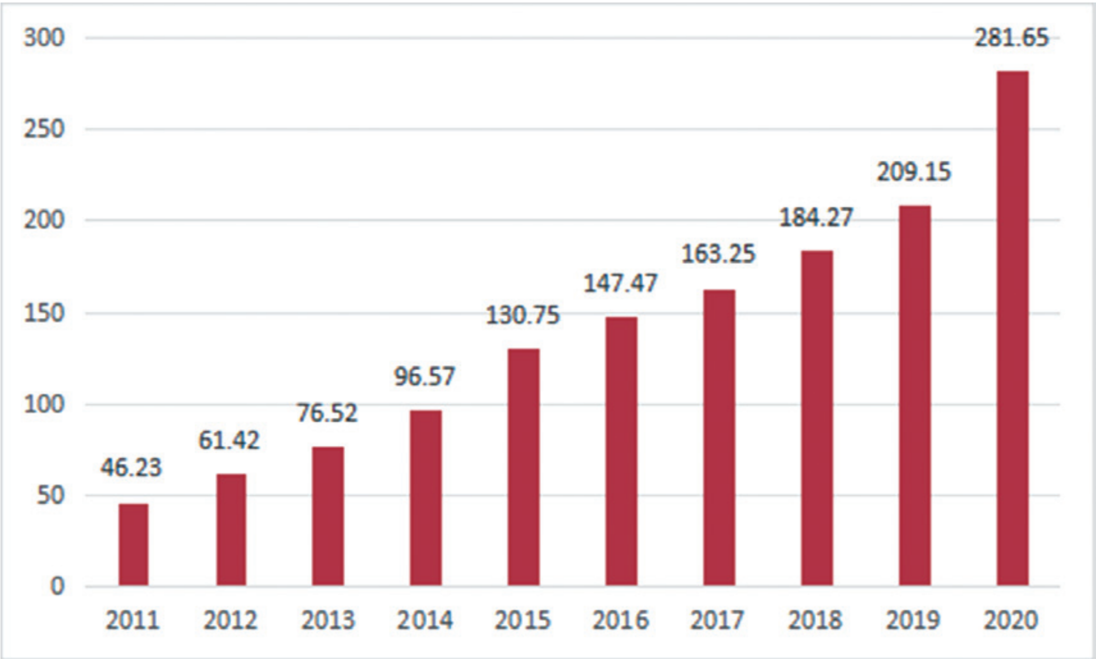

图 2.4 风力发电装机容量（2011–2020）（GW）

来源： 中国统计年鉴 2021、中国电力企业联合会

中国已成为世界上最大的风电设备制造基地，也是风力涡轮机和零件的主要出口国。中国风电产业技术创新能力也一直在增强，目前已有能力制造大型兆瓦级风电机组，开展关键和核心部件的自主研发和制造，风电产业体系在全球舞台上具极高竞争力。

2.1.2.3 龙头企业和重大项目

新疆金风科技有限公司（以下简称“金风科技”）生产大型风力发电机组、建设及运营中试型风电场，是中国风电设备研发制造行业的领导者和全球领先的风电整体解决方案提供商。金风科技是中国最大的风电设备制造商，到目前为止，金风科技逾 4.4 万台风电机组遍布世界，全球累计装机容量超 8600 万千瓦，运维服务量超 5000 万千瓦。

根据 2022 年发布的《“十四五”可再生能源发展规划》，中国将：

推动山东半岛、长三角、闽南、粤东、北部湾等千万千瓦级海上风电基地开发建设，推进一批百万千瓦级的重点项目集中连片开发，结合基地开发建设推进深远海海上风电平价示范和海上能源岛示范工程。

推进漂浮式风电机组基础、远海柔性直流输电技术创新和示范应用，力争“十四五”期间

开工建设中国首个漂浮式商业化海上风电项目。在广东、广西、福建、山东、江苏、浙江、上海等资源和建设条件好的区域，结合基地项目建设，推动一批百万千瓦级深远海海上风电示范工程开工建设，2025 年前力争建成一至两个平价海上风电场工程。

结合山东半岛、长三角、闽南、粤东和北部湾等重点风电基地开发，融合区域储能、海水淡化、海洋养殖等发展需求，在基地内或附近配套建设 1~2 个海上能源岛示范工程。

统筹海上风电与油气田开发，形成海上风电与油气田区域电力系统互补供电模式，逐步实现海上风电与海洋油气产业融合发展。

2.1.3 核电安全有序发展

2.1.3.1 核电资源分布

中国核电装机容量和发电量位居全球第二，经过多年发展，中国核工业已经领先世界，在核能系统方面具有先进优势。

从区域占比来看，核能发电主要集中在华东、华南和东北地区。2020 年华东地区核能发电量最高，占比 52.2%，华南地区紧随其后，核能发电量占比 38.9%。东北地区核能发电量占比 8.9%。

根据国家发改委和国家能源局发布的《“十四五”现代能源体系规划》（2021-2025 年），到 2025 年，中国核电运行装机容量将达到 7000 万千瓦左右，而 2020 年的运行装机容量为 5100 万千瓦。中国政府将积极推动沿海核电项目建设，保持平稳建设节奏，合理布局新增沿海核电项目。该规划还鼓励核能在清洁供暖、工业供热、海水淡化等领域的综合利用。目前，中国山东省海阳市和浙江省海盐市已在 2021-2022 年供暖季成功实现了商业核能供热。

该规划还支持开展核能综合利用示范，积极推动高温气冷堆、快堆、模块化小型堆、海上浮动堆等先进堆型示范工程。

2.1.3.2 核能发电

中国核能发电量自 2015 年以来迅速增长，已从 2015 年的 1708 亿千瓦时增至 2019 年的 3484 亿千瓦时，五年内增加了 103.98% 以上。

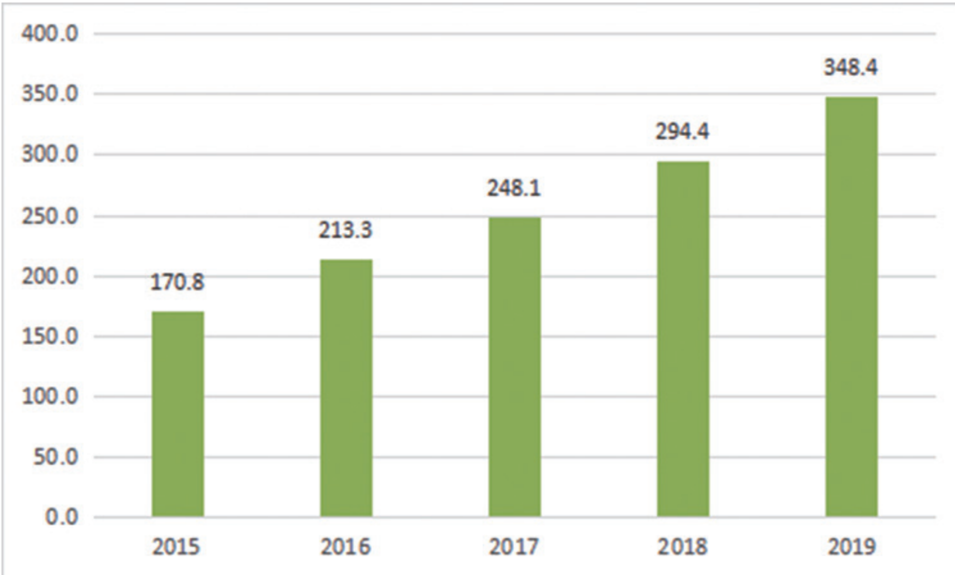

图 2.5 核能发电（2015–2019）（TWh）

来源：《中国统计年鉴 2021》

中国核能发电市场正在迈向黄金时代。2020 年，中国核电装机容量达到 4989 万千瓦，比 2011 年的 1257 万千瓦增长了近 3 倍。

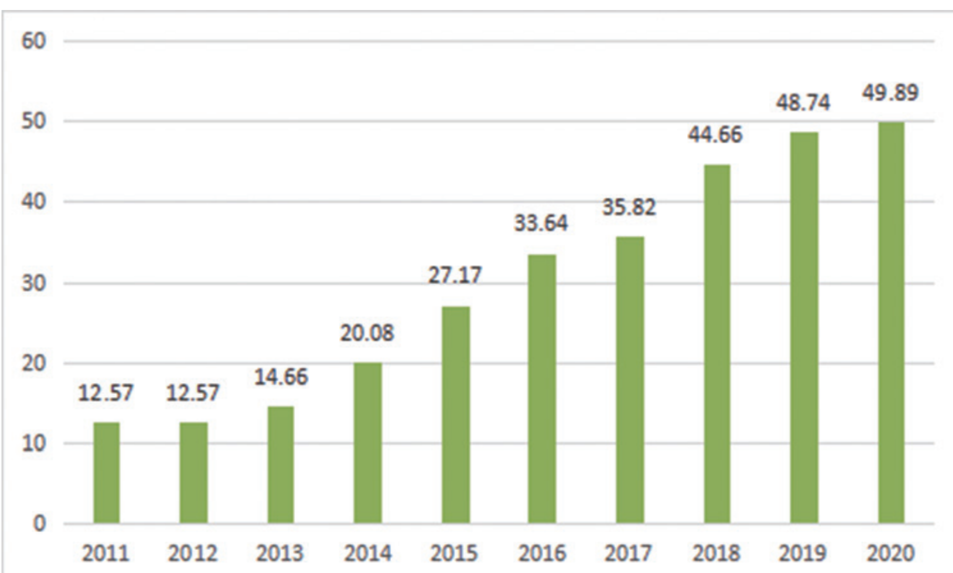

图 2.6 核电装机容量（2011–2020）（GW）

来源： 中国统计年鉴 2021、中国电力企业联合会

2.1.3.3 龙头企业和重大项目

中国核能电力股份有限公司投资控股秦山核电、江苏核电、三门核电、福清核电、海南核电、漳州能源、辽宁核电等七大核电在运、在建核电基地。2021 年，该公司核电机组累计商用发电量 1826.37 亿千瓦时，同比增长 18.61%，其中核电发电量 1731.23 亿千瓦时，同比增长 16.71%。

中国广核集团有限公司（以下简称“中广核”）成立于 1994 年，致力于发展核电、核燃料、风能和太阳能等清洁能源。截至 2019 年底，集团在运核电装机容量为 2714 万千瓦（占中国大陆地区在运核电装机容量的 55.7%），排名中国第一、全球前五。集团核准在建装机容量为 578 万千瓦（占中国大陆在建装机容量的 42.2%），是全球最大的核电建造商。

秦山核电基地是中国大陆核电的发源地，处于华东电网的负荷中心地区。目前秦山核电基地共有 9 台运行机组，总装机容量为 655 万千瓦，年发电量约 500 亿千瓦时，是目前中国核电机组数量最多、堆型最丰富、装机容量最大的核电基地。

三门核电有限公司规划建设 6 台 125 万千瓦的核电机组，总装机容量 750 万千瓦，分三期建设。一期工程于 2009 年 4 月 19 日正式开工，这是中国首个三代核电自主化依托项目，也是浙江省有史以来投资最大的单项工程。三门核电 1 号机组是全球首台 AP1000 核电机组，于 2018 年 9 月 21 日投入商业运行；2018 年 11 月 5 日，2 号机组具备商业运行条件。

“华龙一号”是中国拥有完全自主知识产权的第三代核电技术，是目前全球市场上最广泛接受的第三代核动力反应堆之一。

海阳核电站位于中国东部山东省海阳市，该市已成为中国首座采用零碳核能供暖的城市。海阳核电 1 号机组取代了 12 台燃煤锅炉，减排二氧化碳 18 万吨。

2.1.4 太阳能多元化应用

2.1.4.1 太阳能资源分布

根据中国气象局的数据，2021 年中国全国平均年水平面总辐照量约 1493.4 千瓦时 / 平方米。西部和高原地区的太阳能资源大于中部东部和平原地区。具体而言，新疆、西藏、西北中部和西部、西南西部、内蒙古中部和西部、华北西北部、华南东南部、华东南部部分地区年水平面总辐照量超过 1400kWh/m^2，其中，西藏大部、四川西部、内蒙古西部、青海西北部等地的局部地区年水平面总辐照量超过 1750kWh/m^2；新疆大部、内蒙古中部和西部、西北中部和西部、山西北部、河北北部、西藏东部、云南大部、福建南部、广东东部、海南大部等地年水

平面总辐照量为 1400kWh/m^2-1750kWh/m^2；西北东南部、内蒙古东北部、东北大部、华北东部南部、华东大部、广西、广东西部、华中大部、四川中部、云南东部及贵州西南部等地年水平面总辐照量为 1050kWh/m^2-1400kWh/m^2；四川东部、重庆、贵州中北部、湖南西北部及湖北西南部地区不足 1050kWh/m^2。

2.1.4.2 太阳能发电

近十年来中国光伏产业规模不断扩大，光伏发电装机容量呈快速上升趋势。2020 年中国光伏发电总装机容量为 253.56 吉瓦，同比增长 24.18%；相比 2011 年的 2.12 吉瓦，增长超过 100 倍。

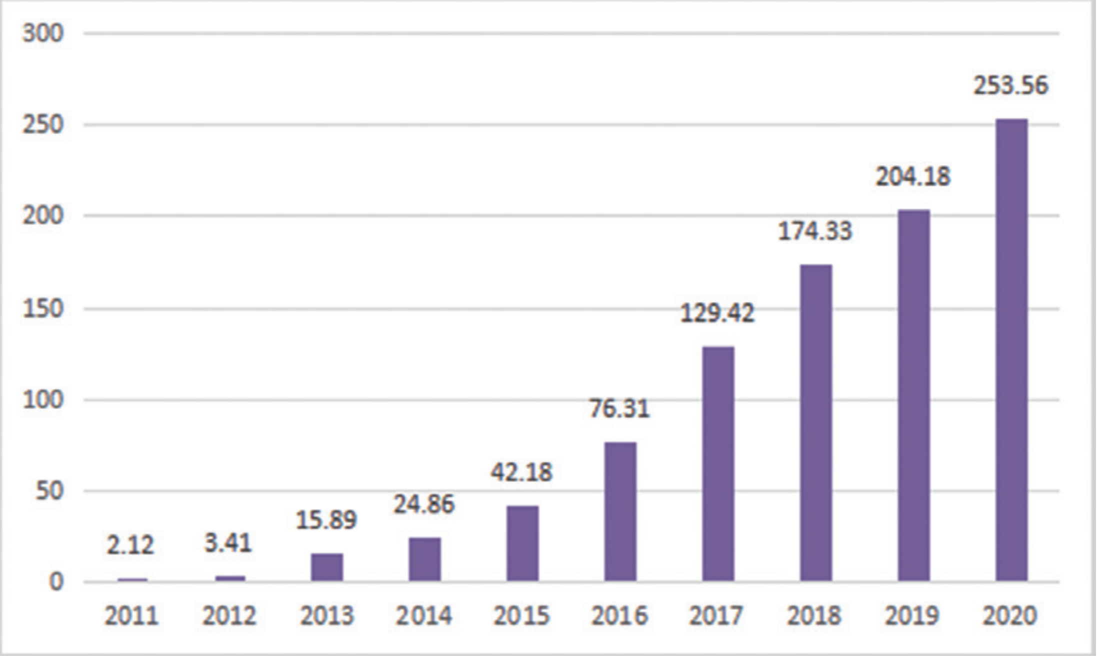

图 2.7 太阳能发电装机容量（2011–2020）（GW）

来源：《中国统计年鉴 2021》、中国电力企业联合会

2.1.4.3 龙头企业和重大项目

根据 2022 年发布的《“十四五” 可再生能源发展规划》，中国将：

在南疆以光伏为主建设千万千瓦级的新能源基地，探索光伏治沙等新发展方式；在东疆风电、光伏发电、光热发电相结合，建设千万千瓦级新能源基地。

发挥黄河上游水电调节优势，重点在青海海西州、海南州等地区统筹推进光伏发电和风电基地化开发。在甘肃庆阳、白银等地区建设千万千瓦级风电光伏基地。

重点在内蒙古西部的库布其、乌兰布和、巴丹吉林、腾格里沙漠地区，新疆南部塔里木盆地，青海西部柴达木盆地，甘肃河西走廊北部，陕西北部等地区，统筹资源条件和消纳能力，建设一批光伏治沙新能源发电基地。带动沙漠治理、耐旱作物种植、观光旅游等相关产业发展。

2.1.5 氢能开发科学有效

氢能已成为世界主要发达经济体加快能源转型升级的重要战略选择。中国目前是世界上最大的制氢国，年制氢产量约为 3300 万吨。

2022 年 3 月，中国政府发布了《氢能产业发展中长期规划（2021-2035 年）》，以助力实现碳达峰、碳中和目标[①]。

根据国家发改委和国家能源局联合印发的规划，到 2025 年，中国将形成较为完善的氢能产业发展制度政策环境，产业创新能力显著提高，基本掌握核心技术和制造工艺。

到 2025 年，可再生能源制氢量达到 10-20 万吨 / 年，成为新增氢能消费的重要组成部分，实现二氧化碳减排 100-200 万吨 / 年。

到 2030 年，氢能产业布局合理有序，可再生能源制氢广泛应用，有力支撑碳达峰目标实现。

到 2035 年，可再生能源制氢在终端能源消费中的比重明显提升，对能源绿色转型发展起到重要支撑作用。

2.2 巴西的绿色能源发展

2.2.1 水电

水电是拥有成熟技术的可再生能源，在全球能源结构中占有较大比重，在电力系统净零碳排和绿色发展方面起着重要作用。然而，全球范围内水电扩张潜力有限，在“2050 净零碳排”等长期减碳战略中，水电的贡献并不大（IEA，2021; IEA，2022a）。

此外，与前十年相比，2021 年至 2030 年全球新增水电净装机容量预计减少 23%。巴西是世界第二大水力发电国，大型水电站约占其国内发电量的 65%[②]。然而，近年来的干旱对巴西的水电发电量产生了负面影响（Hirons，2020）。

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① http://english.www.gov.cn/statecouncil/ministries/202203/23/content_WS623ac568c6d02e53353282a4.html
②过去 10 年（2012-2021 年）水电发电比重的平均值（EPE，2022 年）。

水电对巴西绿色能源发展具有重要意义，但也引发了水坝和水库建设方面的争议。水坝和水库对水力发电厂的运营至关重要，但也给社会和环境带来负面影响和破坏①。

目前，巴西剩余的水能潜力主要位于亚马逊等比较敏感的环境地区，因此水电扩张遭到民众的强烈反对。在这些地区开发水电可能威胁河流生态系统和当地生物多样性，同时还会淹没部分陆地（Murray，2022）。

此外，由于电力需求最旺盛的是巴西东南海岸，利用新增水电不仅需要建设成本高昂的输电基础设施，还会给整个电力系统带来挑战（Murray，2022）。

基于以上情况，水电无法为巴西电力系统扩容做出太多贡献。根据《十年能源扩张计划（PDE）2030》，水电发电量将增加 8.5 吉瓦，仅占预期发电增量目标的 11%（EPE，2022a）。

2.2.2 核能

在国家科学技术发展委员会（CNPq）的领导下，巴西从 1951 年开始发展核技术，并在 1964-1985 年军政府统治期间加快了核技术的发展（WNA，2021）。1985 年，安格拉 1 号（Angra 1）成为巴西首座开始商运的核电站。此核电机组是与西屋电气公司签约的交钥匙项目，该项目初期运营表现不佳（TOLMASQUIM，2016）。

第二座核电站安格拉 2 号于 1976 年开工建设，但由于财政资源不足，加上需求增长低于预期，2001 年 2 月才开始商业运营。

后来又计划在同一地点建造安格拉 3 号，使其成为具有 1405 兆瓦发电量的第三座核电站。根据设计意图，这座电站将与 2 号机组成为双子核电站，但技术上更为先进，装有数字仪器和控制系统。该项目于 1984 年开工，后来暂停。核电业主 Electronuclear 公司受到腐败调查和融资困难的双重打击，项目被迫中断，完工日期推迟到 2026 年以后。目前已有 16 亿美元投资于安格拉 3 号，据估算，完工需要追加 30 亿美元的投资。预计安格拉 3 号于 2027 年开始运营。

巴西核电站选择的是压水反应堆（PWR）技术，这是全世界最常采用的技术，约 60% 以上的电厂设备已经到位。2030 年，根据十年能源扩张计划（EPE，2021），2030 年之后的新项目可能采用压水堆技术、模块化或中小型反应堆以及第四代反应堆，只要这些新技术足够成熟且具有竞争力。

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①巴西水力发电厂建设造成了水质变化、温室气体排放、人员搬迁以及文化遗产损失。

根据十年能源计划，除了安格拉 3 号之外，还将于 2031 年新建一座 1000 兆瓦的新核电站。2050 年国家能源计划（EPE，2020）[①]强调更加强劲的发展，该计划设定的目标是，在 30 年内将核电装机容量从从 8 吉瓦增加到 10 吉瓦（最多 8 座新核电站）。

在第 26 届联合国气候变化大会（COP26）上，巴西时任矿业和能源部长宣布了在短期内在能源拍卖会上签约建设新核电站的可能性，从 2023 年到 2025 年，私人资本可以参与建设。

2022 年 1 月，巴西矿业和能源部与电力研究中心（Cepel）签署了一项合作开展新核电站选址的协议。选择东南地区的意向较大，尤其是里约热内卢州。在以往的评估中，伯南布哥州是建设核电站的首选地区。

里约热内卢还将成为巴西跨国核能控股公司（ENBpar）的总部，该公司是 2021 年 9 月成立的新国有公司，目的是在巴西电力公司（Eletrobras）私有化后接管其核资产。ENBpar 是矿业和能源部的关联机构，其功能是确保联邦能控制核电站的运行。

巴西核部门正在进行重组，也在建立新的战略法律框架。为了实现这一目标，2021 年成立了具有简化结构的国家核安全局（ANSN），该机构由国家核能委员会（CNEN）分离而来，与矿业和能源部相关联。未来国家核安全局有望转为监管机构。

成立国家核安全局是为了将监管、监督和执行活动与核活动和核设施建设分开，以避免国内机构（联邦审计法院）与国际机构（国际原子能机构）之间的权限冲突。国家核安全局的职权范围不仅包括核能生产，还包括食品辐照等农业活动和核医学。

巴西拥有丰富的铀资源，而且很大一部分尚未勘探。已知的铀资源约为 244788 吨（U3O8），分布在巴伊亚州、塞阿拉州和其他州（INB，2021）。十年能源扩张计划（EPE，2021）指出，巴西的铀资源足够供应至少 14 个 1300 兆瓦的核电站，平均容量系数为 85%。巴西已经掌握了从采矿到组装燃料元件的所有核燃料循环技术。

巴西的铀矿开采由巴西国家核工业公司（INB）通过其位于巴伊亚州卡埃蒂特市的铀浓缩部门（URA）开展。该部门负责采矿和矿物加工操作，生产被称为铀浓缩物或黄饼（U3O8）的产品。已勘探的矿床枯竭之后，卡埃蒂特的铀矿停工了五年（2015—2019 年），直至 2020 年才开始重启生产。

为了实现规模效应，国外已经进入燃料循环阶段（转换与浓缩），由荷兰、德国和英国组成的欧洲财团 URENCO 是铀浓缩服务的主要供应商。因此，巴西所生产的铀的浓缩过程在国

①巴西能源规分两个时间段制定。未来十年的规划载于《十年能源扩张计划》（PDE）。《国家能源计划》（PNE）提出了未来 30 年的长期规划。最新版本为 PDE 2031 和 PNE 2050。

外进行，之后再送往核燃料工厂转换。不过巴西已经在雷森德（Resende）建设了浓缩设施，该设施可将铀浓缩至不到 5% 的 U-235（TOALMASQUIM，2016）。

实现 2050 年国家能源计划目标面临很多挑战，尤其是在实施经济可行的核项目方面。只有在安格拉 3 号开始运行后，才能启动新设施的建设，然而该项目的施工已经几度推迟。

若干环境和监管因素决定了核能在巴西电力供应结构中占比的提升。为了防止这些因素施加技术之外的限制，有必要对目前的商业模式加以界定，同时完善法律框架和监管框架，允许私人投资者与国家合作，共同促进核能发展。

模块化或中小型反应堆正日益引起人们的关注，特别是在偏远地区或电网规模较小的国家。小型反应堆具有满足当地社区需求的优点，不需要高额投资，也不需要昂贵的电力传输系统。

目前巴西正在开发固定床核反应堆 (FBNR)，主要开发机构是南里奥格兰德州联邦大学。FBNR 采用压水堆技术，但燃料元件由三元结构各向同性（TRISO）燃料颗粒制成。固定床核反应堆项目旨在开发一种创新型核反应堆（FBNR），这种反应堆具有设计简单、体积小、经济、安全、坚固且可持续的特点。固定床核反应堆属于地面核电站类型，设计用于城市或偏远地区，可自行发电或作为热电联产发电厂运行，也可用于工业目的的水和蒸汽脱盐。

固定床核反应堆是小型反应堆（70 兆瓦电力），由于燃料循环时间长，无需停堆换料。各模块在工厂补充燃料，然后运输到现场。无需现场添加燃料，因为燃料元件包含在密封的燃料室中，在受控条件下运往工厂进行补充。国际原子能机构“核反应堆和燃料循环革新型国际项目”（INPRO）对固定床核反应堆进行了评估，认为该项目具备达到总体安全水平的潜力。

目前正努力对接潜在投资者与工业合作伙伴，以生产 FBNR 原型。

与传统设计相比，小型模块化反应堆的特别之处在于其大小仅为传统核电厂的大约三分之一，具有建造时间短、成本较低的特点。这种反应堆可以降低项目成本，减少业务风险。

先进的反应堆设计有望推动核电发挥更大作用。新一代反应堆可以应用于各种非电力场景，具体创新包括重工业热能生产和热电联产、氢气和合成燃料生产、脱盐和离网应用。

综上所述，得益于可长期运行的现有核技术、小型模块化反应堆、混合核电和氢能系统，大规模发展核能已成为可能，核电和核创新有望在更广阔的领域发挥作用。

如果能实现核能发电量 1160 吉瓦的大胆目标，2020 年至 2050 年将累计减少二氧化碳排放 87 吉瓦。到 2050 年，核能每年可以减少 5 吉瓦的碳排放，比现今美国全年的排放量还多（NEA，2021a）。

2.2.3 生物质能

生物质能在巴西能源结构中占有非常重要的地位。生物质能产品占巴西一次能源消费的31%（EPE，2022）。巴西生物质能的主要用途是生物燃料、乙醇和生物柴油以及发电。

乙醇

1975 年，巴西推出国家乙醇计划，推广乙醇使用。最初，乙醇仅以无水乙醇的形式与汽油混合使用；1977 年，巴西立法要求汽油中必须含 4.5% 的乙醇。巴西第一批完全以含水乙醇为燃料的汽车出现在 1978 年。

乙醇汽车在 20 世纪 80 年代初迅速发展，占据了 1985 年轻型汽车销售量的 96%。然而，随着激励措施的取消和油价的下跌，乙醇燃料供应受阻。20 世纪 80 年代后半期，由于乙醇短缺，乙醇汽车销量直线下降。即便如此，因为以含水乙醇为燃料的车辆已经在市场上流通，无水乙醇与汽油混合已成惯例，乙醇消费量仍然很可观。

2003 年灵活燃料汽车出现，巴西乙醇市场开始进入新时代，这种汽车可以使用任何比例的乙醇或汽油。灵活燃料汽车的推广带动了巴西的含水乙醇销量。目前，灵活燃料汽车在巴西车辆中的占比高达 73%（Sindipeças，2022）。

根据现行法律，乙醇与汽油混合比例从 18% 到 27.5% 不等，目前在加油站出售的汽油的混合比例为 27%（E27）。官方术语“普通汽油”是指混合了无水乙醇的汽油。

“国家生物燃料政策计划”依据第 13.576/2017 号法律制定，是一项旨在促进生物燃料使用的政府政策。该计划提出了降低碳强度的年度目标，即以 gCO_2/MJ（克二氧化碳当量比兆焦耳）为单位的运输能量矩阵，最短期限为十年。为了实现这些目标，化石燃料分销商必须从生物燃料生产商那里获得生物燃料证书并购买脱碳信用额（CBIO）。该政策于 2020 年开始正式实施。巴西石油、天然气和生物燃料局（ANP）[①] 已授权 267 家乙醇工厂、30 家生物柴油工厂和 3 家生物甲烷工厂发放脱碳信用额（EPE/PDE 2031）。

国家能源政策委员会第 7/2021 号决议提出了“未来燃料计划”，其目的是提高可持续、低碳燃料的比重；整合各种公共政策，例如国家生物燃料政策计划、国家生物柴油生产和使用计划、国家车辆标签计划和 2030 路线图等。根据该计划，巴西还将研究在海事部门中使用航空生物黑烯和可持续替代品，在生物燃料生产中捕获碳的措施以及以氢能为燃料的方式。

①截至 2021 年 11 月。

目前，巴西政府的燃油税（CIDE）和收入税（PIS/COFINS）[①] 针对乙醇和汽油的税收政策并不相同。一些州政府对乙醇的政策也不尽相同，也就是说，乙醇和汽油所缴的流转税（ICMS）[②] 费率并不一样。此外，与仅以汽油为燃料的车辆相比，灵活燃料汽车所缴的工业税（IPI）[③]更低。

据估算，2021 年巴西乙醇产量为 304.3 亿升，比 2020 年修正后产量（350.8 亿升）下降了 13%，主要是因为甘蔗生产受到严重影响，更有利于制糖而非制醇。

截至 2020 年 12 月，共有 361 家乙醇和食糖生产单位在巴西农业、畜牧业和食品供应部注册，其有效装机压榨量为 7.45 亿吨甘蔗（产能系数为标称值的 90%）。

根据巴西石油、天然气和生物燃料局的数据，授权制醇单位的年无水和含水乙醇生产能力分别为 230 亿升和 430 亿升（基于 180 天的平均收获量）。

生产乙醇的其他原料包括甘蔗渣、秸秆和玉米。巴西拥有两家第二代商用乙醇工厂（Granbio 和 Raízen），标称生产能力分别为每年 6000 万升和 4200 万升。

生物柴油

在生物柴油领域，巴西推出了刺激生物质能使用的新规划：国家生物柴油生产和使用计划（PNPB），其依据是第 11.097/2005 号法律。从该计划公布至 2021 年 9 月期间，巴西累计生产了 520 亿多升生物燃料。在全球三大生物柴油消费国中，巴西排名第三，仅次于印度尼西亚和美国。与欧洲和美国等生物柴油主要市场不同，巴西仅使用与化石柴油混合的生物柴油。巴西生物柴油出口量并不大， 2020 年只有 380 万升。截至 2021 年 8 月，巴西共有 50 家已注册生物柴油生产厂，集中在中西部和南部地区（USDA，2021）。

最初确定的比例是在化石柴油中添加 2% 的生物柴油，这一比例在 2008 年成为强制性要求。2010 年，生物柴油的比例达到 5%，此后一直在上升，2021 年 3 月达到了 13%，目前计划将 15% 的比例提前至 2023 年实现。第 11.097/2005 号法律确定了广义上的生物柴油定义，即用于柴油循环发动机的任何衍生自可再生生物质的燃料。

目前所生产的生物柴油约有 75% 来自大豆油，6.5% 来自动物脂肪。其他原料包括棕榈油（2%）、棉籽油（1.7%）和食用油（1.4%）。原材料约占生物柴油生产成本的 75% 至 80%，其他投入品（如甲醇和添加剂）占 10%。

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① CIDE 燃油税 PIS/COFINS 收入税是联邦税。
②流转税（ICMS）是州税。
③工业税（IPI）是联邦税。

在 2022 年 1 月之前，生物柴油商业化的新模式已经出现。这种模式鼓励生物柴油生产商和分销商开展自由谈判；要求 80% 的供应来自带有社会生物燃料标签（SBS）的植物；维持目前家庭农业优先参与的规则（EPE/PDE 2031）。

生物质能

生物质能总发电量为 16 吉瓦，约占巴西电力系统的 9%。甘蔗渣是使用最多的原料，甘蔗发电占全国生物质能总发电量的 73%（ANEEL/SIGA，2022）。

甘蔗提取汁液后会残留甘蔗渣，制醇和制糖会产生滤饼，生产生物燃料也会留下残渣，这些物质都可以用作生物质能原料。此外，收割甘蔗后留下的秸秆也富含生物质（EPE，2022）。

在巴西，糖和乙醇生产商开展热电联产早已成为传统。2004 年“替代电能激励计划”推出之后，生物质能热电联产再次掀起热潮。

除了自供电力之外，甘蔗生物质能电厂还可以在管制合同市场（ACR）和自由合同市场（ACL）出售电力。在管制合同市场中，电力购买和销售通过拍卖进行。拍卖模式是为了确保分销商在电力交易中获得更高的透明度，使竞争更为公平。在自由合同市场中，发电、商业运营和进出口代理商以及个人消费者可以就电力购买与销售合同展开自由谈判，分销商不得在自由市场购买电力。

为了提升生物质能生产商的竞争力，增加生物质能发电在巴西电力矩阵中的比例，联邦政府制定了监管机制和激励政策，专项拍卖会就是其中一种措施。首次专门针对生物质能存量电力的拍卖会于 2008 年举行（LER 2008），共有 590 兆瓦电力以最高价格签约，会上还确定于 2009 年和 2012 年再次举行此类活动。

2021 年有运营活动的 369 家甘蔗电站中，约有 220 家出售了电力，其中约 40% 是通过能源拍卖会出售的。截至 2021 年 8 月，已经举行了 60 场拍卖会，其中 30 场专门面向甘蔗电站的电力销售（CCEE，2021）。过去几年政府减少了生物质能发电在国家电力矩阵中的比重，但管制合同市场上生物质能发电的商业运营并未因此增加，反而有所减少。由此可见，即使未来生物质能发电在国家电力矩阵中的比重有所增加，最终趋势也是遵循市场配置，管制合同市场与现货市场的电能交割构成生物质能市场所售电力的大部分。因此，管制合同市场中售电单位所减少的总电力将在 2025 年底达到大约 1 吉瓦，剩余的 530 兆瓦可以在当年由管制合同市场或现货市场中的甘蔗生物质电站出售。在管制合同市场的合同金额中，包括了来自替代电能激励计划项目的电能，总计 278 兆瓦（ELETROBRAS，2021）。

甘蔗生物质发电具有季节性特点，收获季的发电量会明显增加。其他生物质能发电的燃料可以储存，因此更具可控性和确定性，这两点对电力行业十分重要，因为这有助于提高能源安全性和系统可靠性。

除甘蔗之外的其它生物质能的发电量占到电力矩阵的 2.51%。黑液生物质能所占的比例较为突出，这主要是因为纤维素、沼气和森林残留物增多，黑液产量也因此大增。象草、木炭、稻壳、自动烤箱煤气和柴火（ANEEL/SIGA）也对生物质能发电有所贡献，但参与度较低。

2.2.4 太阳能

光伏太阳能是利用太阳能发电的主要技术，其原理是将太阳能直接转换成电能，而半导体材料制成的光伏电池是这一转换过程的核心元件。

巴西大部分位于南北回归线之间，太阳光垂直照射，因此几乎全部领土都能接受高水平的太阳辐照，即使在冬天也是如此。这种地理条件使巴西在太阳能发电方面具有巨大潜力。巴西于 2010 年代出台了分布式电源并网新规，集中式光伏发电厂则通过拍卖会进行签约，这些政策大大促进了巴西光伏发电的发展。

集中式光伏发电

集中式光伏发电需要大型电站支撑，通过输配电线将电力送达最终用户。集中式光伏发电的电力交易不受管制合同市场和自由合同市场的限制。在管制合同市场，电能可通过公开拍卖出售给分销商；在自由合同市场，购买量较大的消费者可通过自由谈判达成购电合同。

光伏电能拍卖会于 2014 年启动。最初光伏发电项目仅可在再生能源专项拍卖上进行谈判。2017 年，光伏发电项目首次出现在通用（不限技术）电力拍卖会上，因为随着成本降低，光伏发电的吸引力也增加了。迄今为止，通过 10 场公开拍卖会签订了 4.7 吉瓦的太阳能装机容量（图 2.8）。

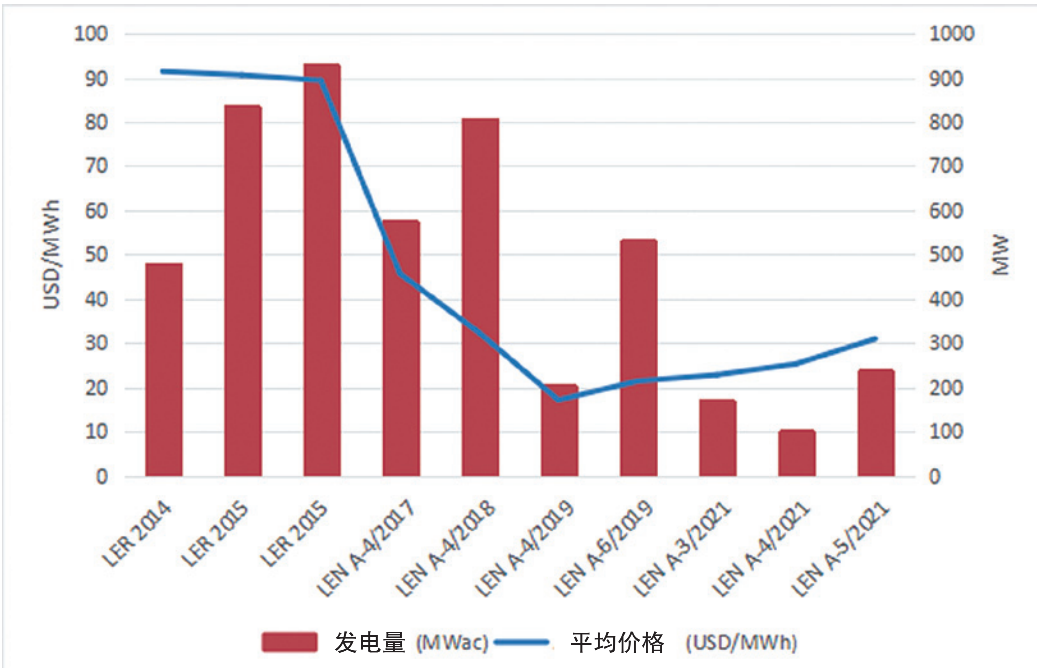

图 2.8 巴西管制合同市场拍卖会上出售的光伏电力（平均价格和发电量）

注：LER－可再生能源专项拍卖会；LEN － 通用（不限技术）电力拍卖会。A–X 表示电站运营必须在 X 年内开始。

来源： Greener（2022）

最近大量太阳能项目开始出现在自由合同市场。根据第 14.120/2021 号法律，可再生能源项目享受输配电价格的期限仅余三年，也就是说，三年后进入市场的可再生能源电站将全额支付税费。这条新规引发了一场太阳能项目许可证争夺赛。目前发放了共计 38 吉瓦面向自由市场的光伏发电许可证，但这些项目可能不会全部实施。

分布式光伏发电

2012 年，巴西国家电业局通过了第 482/2012 号决议，由此引入了可再生分布式发电净计量方案。这种分布式发电激励机制要求用双向流量计测量电力净流量。如果分布式发电量大于用电量，则多余的电能将提供给电网，消费者将获得“能源信用额”，当用电量大于发电量时，可以用“能源信用额”抵销。从这个意义上讲，配电网络承担着分布式发电系统 “电池”的功能 。

净计量方案刚出台时，很少有消费者选择可再生分布式发电。然而，2015 年以后电价上涨，加上规则逐步修订完善，分布式发电的吸引力开始增强。

由于目前的计量方法不能补偿电网成本（1 千瓦时用电量可以用 1 千瓦时发电量补偿），净计量方案已在修订中。根据第 14.300/2022 号法律，可以用新增分布式发电量来补偿的用电量将逐步减少。在新规则生效之前，巴西出现了安装光伏板的热潮。（图 2.9）。

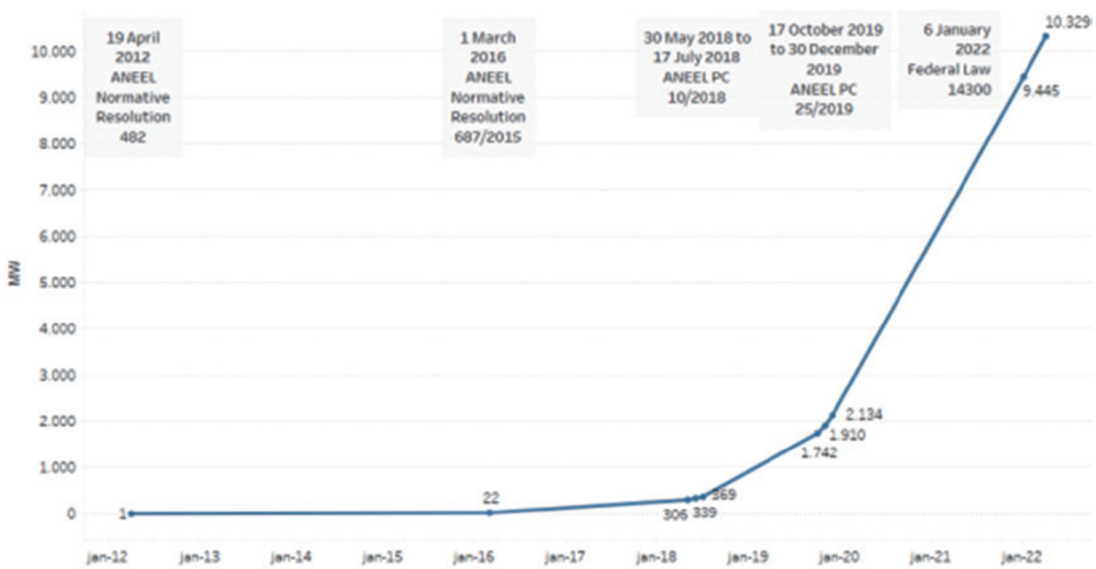

图 2.9：巴西光伏分布式发电累计装机容量（MW）变化趋势

来源：作者在巴西国家电业局（ANEEL）的数据基础上所做的阐释。

第 14.300/2022 号法律还推出了“社会可再生能源计划”（PERS），该计划将为低收入用电者安装光伏电池板提供资金。但是，其有效性将取决于分销商是否自愿加入。Losekann 和 Abuche（2022）指出，如果想要获得重大成果，就有必要继续完善该计划的制度设计，并补充更多财务资源。

2020 年分布式光伏发电装机容量接近 2.8 吉瓦，超过了包括集中式光伏发电在内的所有其他形式的装机容量，带动了巴西整体装机容量的增加。此后，分布式光伏发电继续快速发展，装机次数达到 96.6 万多次，2022 年第一季度装机容量突破 10 吉瓦大关（图 2.9）。

分布式光伏发电总装机容量为 10.3 吉瓦，其中住宅用电 4.7 吉瓦，商业用电 3.3 吉瓦，农村地区用电 1.4 吉瓦。但是，巴西仍然只有 1% 的家庭拥有分布式光伏发电。新冠感染期间，电价高企和远程办公促使更多家庭采用分布式光伏发电技术。光伏发电蓬勃发展，带动集成商和设备供应商激增（目前共有 2.12 万家活跃的光伏集成商）。

新冠感染严重影响了物流，干扰了全球光伏电池板的供应，这给国内供应商带来了机会，有助于让它们的产品替代某些重要进口产品。

光伏组件约占光伏系统最终成本的 38%。组件的主要投入是金属硅（即多晶硅的原材料，在投入成本结构中的占比为 60%），因此其价格直接影响到光伏组件的最终价格。2021 年多晶硅价格上涨了 200% 以上，因为受新冠感染影响，中国的多晶硅生产受到限制，进而导致组件供需失衡。单晶钝化发射极背面接触电池（PERC）模块的离岸价格平均上涨 26%。由于集装箱不足和港口拥堵，国际运费约占到岸价格的 3%，2021 年更是高达 16%。

半导体和电子元件占光伏逆变器总成本的大部分（分别为 48% 和 30%）。新冠感染加速了数字化进程，这些元件的需求随之大幅增加，导致全球供应不足，价格和运费上涨，进而影响到逆变器的成本。

光伏支架由铝或钢制成，可以确保材料的灵活性并延长其使用寿命。这些支架可以在巴西国内生产。

2.2.5 氢能

国际能源署（IEA，2019）将氢确定为助力脱碳的能源之一，尤其有助于无法进行电动化或电动化过于昂贵的行业（如空运和海运）实现脱碳。氢能够大量储存和运输能量，而且不会在燃烧过程中排放二氧化碳。氢（H2）是一种能量载体和媒介，可由其他燃料转化而来，能够使最终用户减少对特定能源的依赖，并提高能源供应的灵活性。但是，只有通过可再生能源（风能、太阳能或水电等）制氢时，氢才是绿色燃料。

巴西拥有风能、太阳能和水力发电的有利条件，因此成为绿氢的主要出口国。目前生产氢气的主要是二氧化碳排放量较高的炼油和化肥等行业。巴西顺应全球趋势，通过改良天然气来制氢（也称为灰氢）。巴西政府的过渡战略是先发展蓝氢，即采用电力系统中的全部减排技术，利用具有碳捕集利用与封存技术的化石燃料制氢。等生产成本降低之后再推广绿氢。

已知巴西在绿氢生产设施建设方面的投资已逾 270 多亿美元，其中大部分集中在塞阿拉州的佩森（Pecém）、伯南布哥州的苏瓦沛（Suape）和里约热内卢州的阿苏（Açu）等港口。这些港口具有发展绿氢链的综合战略因素，例如因靠近工业中心而拥有发达的出口物流；有太阳能和风能等丰富的可再生能源。荷兰鹿特丹港计划到 2030 年时，向西北欧供应的氢达到 460 万吨 / 年，其中大部分来自其他大洲。观察鹿特丹港和潜在绿氢出口商之间的距离（表 2.1）表明，巴西港口运输绿氢方面具有战略性位置。

表 2.1 鹿特丹与潜在绿氢出口商之间的距离

港口	距离（km）
澳大利亚（纽卡斯尔）	16250
智利（瓦尔帕莱索）	12400
巴西（福塔莱萨）	7390

来源：作者搜集的材料。

塞阿拉州签署的绿氢项目意向备忘录已超过 22 项，包括与澳大利亚 Enegix 能源公司达成的协议，将在福塔莱萨都会区的佩森港口与工业综合体建造绿氢生产工厂，预估投资为 54 亿元。此外，还与葡萄牙电力集团（EDP）等公司签署了太阳能项目，将装机容量为 3 兆瓦的光伏发电厂用于制氢。伯南布哥州的苏瓦沛港与 Neoenergia、Qair 等公司签署了一项投资协议，合作内容除了利用改良天然气制氢外，还包括联合电解工艺、泵送和液化，目的是实现产品的长距离运输。

圣卡洛斯市与国际区域气候行动组织（R20）签署了一项谅解备忘录，推动建设制氢厂的可行性研究。Unigel 公司开始建造一座氮肥厂，用于生产氨和尿素，该公司还计划在巴伊亚州卡马萨里（Camaçari）建造第一座清洁氨工厂，该工厂有望在 2022 年底投产。2019 年巴西的化肥需求约为 3620 万吨，其中 81.5%（2950 万吨）来自进口。

澳大利亚绿色能源公司 Fortescue Future Industries 与巴西阿苏港签署了一项谅解备忘录，计划开发 300 兆瓦的氢电解槽绿色工业项目，从而在里约热内卢生产 25 万吨 / 年的清洁氨。北里奥格兰德州和皮奥伊州与私人投资者签署了生产绿氢的谅解备忘录；米纳斯吉拉斯州计划开展绿色钢铁生产项目。

当前各地区的制氢成本存在很大差异，未来的制氢经济取决于化石燃料、电力和碳的价格。目前天然气因为最具成本效益，成为世界大部分地区制氢的首选，例如，中东地区的天然气制氢仅为 1 美元 /kgH2。巴西是最具竞争力的绿色制氢国之一，计划到 2030 年时，该国生产绿氢的平均成本约为 1.50 美元 /H2kg（图 2.10）。其他国家和地区可能在成本方面更具竞争力，巴西的优势则在于其更加清洁的能源矩阵。

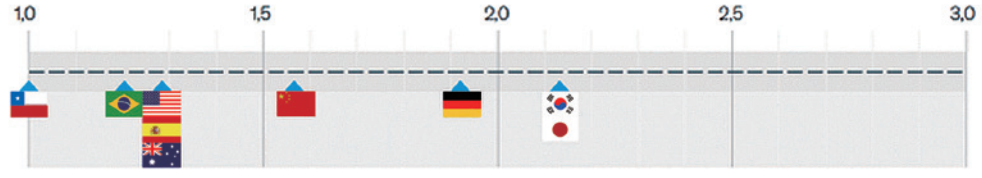

图 2.10 2030 年制氢平均价基准，USD/kgH2

来源：Gurlit 等，2021 年。

巴西并非最近才开展氢开发研究和制定氢能创新战略。早在 2002 年，科学、技术和创新部(MCTI)就启动了氢经济领域的科学、技术和创新计划,该计划旨在加强人力资源建设和培训，重点是确立不同燃料电池系统和制氢方面的技术示范，并开设研究生课程。

2005 年，矿业和能源部推出了巴西氢经济结构路线图，重点是评估巴西可能具有竞争优势的不同技术路线，例如水电解、乙醇和其他生物质能，另外还包括明确天然气在向绿氢过渡过程中的所起的作用、理解扩大分布式能源制氢市场的逻辑思路。

2010 年，科学、技术和创新部（MCTI①）与管理和战略研究中心（CGEE）指出了巴西制氢所面临的主要瓶颈，即投资额少、氢研发项目的持续性投资不足，以及对技术型公司的激励不够（CGEE，2010）。面对如此多的挑战，巴西科学、技术、创新与通信部（MCTIC）发布了《可再生能源和生物燃料科学、技术和创新计划》，旨在促进海洋、光热，海上风能和氢气潜力研究（MCTIC，2018）。

2020 年，矿业和能源部公布了 2050 年国家能源计划。到 2050 年，巴西的可再生能源潜力将是其需求的 17 倍以上，其中包括以氢为重点的颠覆性技术，主要挑战在于制定氢使用、运输和储存指南，以及对质量、安全、运输设施、储存和供应相关的监管提出改进建议（MME/EPE，2020）。

2021 年 2 月，国家能源政策委员会通过的 2 号决议确立了巴西能源部门的研究、开发和创新指南，研究资源将优先分配给以下主题（1）氢;（2）核能;（3）生物燃料;（4）储能;（5）可持续热电发电技术;（6）数字化转型;（7）能源行业战略矿物。

联合国于 2021 年 召开了“联合国能源高级别对话”，这是 1981 年以来联合国召开的首次全球能源会议，会上巴西政府发起了“巴西氢能公约”。矿业和能源部推出了《巴西国家氢能计划》（PNH2）发展指南（CNPE 第 6/2021 号决议）。巴西能源研究公司（EPE）为巩固巴西氢战略建立了技术基础，指出了面临的主要挑战和机遇，强调除了绿氢之外，蓝氢和碳捕集利用与封存技术对于可行性工艺成本也很重要（EPE，2021）。

2021 年 8 月，矿业和能源部推出了“国家氢能计划”，其原则是重视能源的国家潜力；要具有全面性；要与经济脱碳目标保持一致；重视并鼓励国家技术发展；致力于发展竞争性市场；寻求与其他国家的协同作用和联系；承认民族工业的贡献（MME，2021）。2022 年，巴西能源研究公司发布了一系列针对灰氢（天然气改良）、蓝氢（天然气改良与碳捕集利用与封存技术）和绿氢（天然气热解）的研究（EPE，2022，2022a，2022b）：

① 现已更名为“巴西科技创新和通信部”，通信亦属于其职能范围。

在可再生能源和低碳氢融资方面，拥有“研究开发和创新融资基金”以及巴西国有开发银行（BNDES）、巴西科学研究与发展项目资助署（FINEP）、私营部门和资本市场的融资渠道。在大学设立了多个研究小组和国际标准实验室，以开发适用于巴西的氢能技术，例如里约热内卢联邦大学工程研究院的氢能实验室致力于开发固体氧化物燃料电池和电动重型汽车等。在氢能实验室牵头及相关研发机构、政府机构和公司的合作下，巴西氢能研究开发和创新协会于 2017 年 4 月成立，该机构是一所致力于巴西氢能研究的非营利协会（GIZ，2021）。

坎皮纳斯州立大学氢能实验室的研究包括：（1）通过改良天然气、乙醇、水电解和氢气净化的过程生产氢能，（2）氢能在分布式发电项目中的应用（使用燃料电池），以及（3）氢能在运输领域的应用，例如南半球第一辆由氢和聚合物电解膜（PEM）燃料电池驱动的汽车（GIZ，2021）。

坎皮纳斯州立大学与日产汽车公司开展了一个合作项目，研究如何让电动汽车以生物乙醇为燃料，该项目开发了一种带有固体氧化物燃料电池（SOFC）的原型车，而该电池依靠的是乙醇能量。创立于 2003 年的 Hytron 公司从坎皮纳斯大学分离而来，2020 年被来自德国亚琛的诺曼艾索集团（NEA GROUP）收购，该公司致力于工程领域解决方案以及能源和天然气系统的系统集成，发展重点是氢能。

根据伊泰普水电站（Itaipu Binacional）和巴西电力公司签署的协议，设立了伊泰普技术园区（PTI）氢能研究中心（NUPHI）。该研究中心的实验性制氢厂可以分析氢获得与应用的全周期，包括生产、纯化、浓缩、储存以及随后在燃料或燃烧电池中与其他燃料（如生物甲烷）的混合使用。巴西公共交通公司（EMTU）和圣保罗大学（USP）于 2021 年开始研究氢能公交车；巴拉那联邦大学材料和可再生能源实验室（Labmater），科学、技术和创新部国家技术研究所以及塞阿拉联邦大学（UFC）技术园区都在开展氢能相关研究，其中塞阿拉联邦大学技术园区正在同时开展 20 多项研究，重点是绿氢中心（H2V）开发解决方案，包括在不使用电能的情况下利用污水制氢。

在目前的举措中，值得一提的是巴西 - 德国能源伙伴关系下的巴西绿氢行业路线研究、氢技术特别研究委员会的氢技术标准化（ABNT/CEE 067）以及可再生能源公共政策关于氢能研发项目的战略倡议。

2.2.6 巴西国家石油公司关于绿色能源的倡议

自 1975 年巴西推出国家乙醇计划以来，巴西发布了一系列公共政策，刺激生物燃料的使用。

生物柴油与化石柴油以及乙醇与汽油的强制性混合（前者比例为 10%，预计还会增加；后者比例为 27%）构成了巴西生物燃料消费和生产迅速扩大的基础。

巴西国家石油公司对可再生能源的投资

21 世纪头几年，全球都在关注可再生燃料，巴西国家石油公司也开始在生物燃料领域开展新项目。在生物柴油领域，在相关生产和销售法律框架获批后，该公司启动了投资。2004 年 12 月联邦政府推出了“生物柴油生产和使用国家计划”，其中包括新燃料征税模式以及将家庭农业纳入原材料生产的机制。次年，第 11.097/2005 号法律将生物柴油引入巴西能源矩阵。2008 年 1 月，在传统柴油中强制添加生物柴油的规定开始生效，生物柴油的初始比例为 2%。

为了实现生物柴油生产目标，2006 年，巴西国家石油公司对塞阿拉州、巴伊亚州和米纳斯吉拉斯州的三座生物柴油生产厂进行了投资。2008 年 7 月第一家炼油厂在坎代亚斯投产；2008 年 8 月第二家生物柴油厂在基沙达投产；2009 年 1 月蒙特斯克拉罗斯工厂投产。这三座炼油厂具有相同的设计产能，每年总共生产 1.7 亿升生物柴油。2008 年，巴西国家石油公司创建了 Petrobras Biocombustível 公司，以落实国家关于发展生物柴油和乙醇的所有举措，并与生物燃料制造商建立合作伙伴关系。在此背景下，巴西国家石油公司制定了开发地区农业市场的计划，目的是保证有足够的原料生产生物柴油，使用的主要原料为大豆油。该公司还与小农和工业生产者签订了植物油购买合同①。

2010 年，巴西国家石油公司的生物柴油日产量约为 1.1 万桶，占巴西生物柴油总用量的 10%。次年，该公司收购了生物柴油公司 BSBIOS Marialva Biodiesel Sul Brasil② 50% 的股权，生物柴油产能进一步提高。2012 年巴西国家石油公司成为巴西五大生物柴油生产商之一，其生物柴油工厂开始利用残留油脂生产生物柴油③。

巴西国家石油公司依托其在乙醇分销和出口方面的基础设施，于 2010 年开始对乙醇进行投资。第一笔投资与法国 Tereos Grupo 的巴西子公司 Tereos International 合作开展，双方共同出资 9.09 亿美元收购了巴西第四大甘蔗加工商 Açúcar Guarani 45.7% 的 股权。随后与 Grupo São Martinho 合作投资 2.44 亿美元，收购了 Nova Fronteira Bioenergia 公司 49%

① Petrobras. Relatórios anuais Form 20F, 2007 a 2018. Available in: < https://www.investidorpetrobras.com.br/apresentacoes-relatorios-e-eventos/relatorios-anuais/>. Accessed May 03 2022.

② Petrobras. Relatório anual Form 20F, 2009, p. 69. Acesso em: 03 maio 2022.

③ Petrobras. Fatos e Dados, 02.07.2014. < https://petrobras.com.br/fatos-e-dados/petrobras-biocombustivel-produzira-mais-biodiesel-a-partir-de-oleo-de-cozinha-usado.htm>. Accessed: May 02 2022.

的股权，以维持和扩大 Boa Vista 和 SMBJ Agroindustrial 工厂的生产。巴西国家石油公司还投资了 Bioóleo Industrial e Comercial 公司（生产蓖麻油、半精炼棉和大豆油）、Bambuí Bioenergia 公司和 Total Agroindústria Canavieira 公司[①]。

巴西国家石油公司还在北里约格朗德州投资了 5 个风电场（Mangue Seco 1、Mangue Seco 2、Mangue Seco 3、Mangue Seco 4 和 Macau），合计发电量达到 106 兆瓦；另外投资了两座小型水电站和光伏发电厂 UFVAR[②]。

退出可再生能源领域

2014-2018 年巴西国家石油公司的商业计划显示，扩大乙醇和生物柴油生产是公司主要目标之一。2014 年该公司生产了巴西生物柴油总用量的 17%。然而，由于陷入腐败丑闻和金融危机，公司于 2015 年被迫调整计划，将投资重点放在盐前石油项目上。

巴西国家石油公司还制定了一项内容广泛的资产出售计划，以减少债务并专注于石油和天然气的勘探与生产。2016 年公司决定退出生物燃料生产，自 2013 年以来，这方面的业务就一直处于亏损状态[③]。

2016 年 12 月，巴西国家石油公司以 2.02 亿美元的价格出售了其在 Guarani 乙醇厂的股份（46%）；2017 年又出售了 Nova Fronteira。2019 年，公司完成了四笔出售业务，将 Belém Bioenergia 出售给 Galp 生物能源公司；另外还出售了 BSBios Biodiesel Sul Brasil 公司、PBio 持股（6.07%）的 Bioóleo Industrial e Comercial 公司 和 Complexos Bioenergéticos 公司。2020 年出售了 Bambuí Bionergia。几次撤资之后，这家国有公司在巴西生物柴油生产中的参与度降至 6%。

2021 年 4 月，巴西国家石油公司出售了其所持的 Mangue Seco 风电场的股份。

巴西国家石油公司在可再生能源领域的前景

经历了 2014-2015 年的信誉危机之后，巴西国家石油公司需要调整债务指标，因此逐步退出了可再生能源生产。在投资组合调整和油价上涨的利好背景下，目前公司财务状况已明显转好。总债务从 2014 年的 1322 亿美元减少到 2021 年的 587 亿美元[④]。2021 年公司利润达到 212 亿美元。

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① Petrobras. Relatórios anuais Form 20-F, 2009/2010.
② Petrobras. Relatório anual Form 20F 2015, p.6-74. Accessed: May 06 2022.
③ Petrobras, Relatório Form 20-F, 2016, p. 113. Accessed: May 07 2022.
④ Petrobras. Relatórios Form 20F 2015/2021. . Accessed: May 06 2022

在新的财务条件下，公司能够审视可再生能源在其战略中的作用，从而在能源转型过程中重新定位公司。大多数（若非全部）国际石油公司都在转变为能源公司，巴西国家石油公司也应该遵循同样的轨迹。

最近的一些行动表明巴西国家石油公司恢复了可再生能源业务，重心放在可再生柴油、生物喷气燃料和氢气等新技术领域。可再生柴油是生物柴油的替代品，由植物油制成，可与传统柴油混合使用，甚至能用作柴油发动机的独立燃料[①]。生物喷气燃料被视为推动运输脱碳的重要途径，国际民用航空组织（ICAO）要求 2027 年开始使用生物喷气燃料[②]。公司的 2020~2024 年商业计划中提到了可再生柴油和生物喷气燃料，将其作为公司战略的组成部分。

在 2022~2026 年商业计划中，巴西国家石油公司计划对生物质炼油厂投资 6 亿美元，以生产可再生柴油和生物喷气燃料。公司还启动了船舶燃料（biobunker）和其他新的可再生能源技术研发项目。

巴西国家石油公司正在考虑投资氢能领域及核能、风能和太阳能发电行业，以完善其在能源转型期间的定位。

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① Petrobras. Fatos e Dados < https://petrobras.com.br/fatos-e-dados/petrobras-se-prepara-para-futuro-do-mercado-de-refino-e-gas-natural.htm#:~:text=O%20BioQAv%20ou%20bioquerosene%20de,brigat oriamente%20a%20partir%20de%202027>. Accessed: May 09 2022.

② PPetrobras. Fatos e Dados. “Petrobras se prepara para futuro do mercado de refino e gás natural”. 23.09.2020.< https://petrobras.com.br/fatos-e-dados/petrobras-se-prepara-para-futuro-do-mercado-de-refino-e-gas-natural.htm#:~:text=O%20BioQAv%20ou%20bioquerosene%20de,obrigatoriamente% 20a%20partir%20de%202027>. Accessed: May 04 2022.

三、绿色能源发展：优势与劣势

3.1 中国视角

3.1.1 良好的政策环境保障绿色能源发展

20 世纪 90 年代，中国政府不仅制定了可再生能源发展纲要，也开始通过法律手段和经济激励政策推广可再生能源发展，但彼时中国仍处于探索的初级阶段。直至“十一五”期间（2006-2010 年），随着全球能源形势的深刻演变，中国能源政策调整为“坚持节约优先、立足国内、多元发展、依靠科技、保护环境、加强国际互利合作，努力构筑稳定、经济、清洁、安全的能源供应体系，以能源的可持续发展支持经济社会的可持续发展”。①

为了规范和促进中国可再生能源的发展，政府进一步完善能源政策体系，将可再生能源列为“十一五”期间能源建设的重点之一。“十一五”期间，中国单位国内生产总值（GDP）能耗下降 19.1%，非化石能源利用率提高到 8.3%。与此同时，全国化学需氧量（COD）排放量下降 12.5%，二氧化硫排放量下降 14.5%。此后，中国中央政府“十二五”规划明确提出“绿色发展，建设资源节约型、环境友好型社会”的目标，指出“面对日趋强化的资源环境约束，必须增强危机意识，树立绿色、低碳发展理念，以节能减排为重点，健全激励与约束机制，加快构建资源节约、环境友好的生产方式和消费模式，增强可持续发展能力，提高生态文明水平②”。随着中国进入重工业化加速阶段，能源可持续利用成为维护国家发展利益的关键。十八大以来，中国各地区、各有关部门出台了一系列绿色能源和低碳发展政策措施，推动太阳能、风能、水能、生物质能、地热能等清洁能源开发利用取得了明显成效③。

国家指出了未来能源产业发展的主要目标和方向，为相关机构和企业制定发展政策提供了重要参考。2019 年，中国国家发展改革委员会发布了《产业结构调整指导目录 2019 年本》④，其中明确提出鼓励利用太阳能、风能、海洋能和地热能。突出技术开发和装备制造，鼓励相关机械设备领域的生产发展。⑤

2020 年 5 月，中国国家能源局印发《关于建立健全清洁能源消纳长效机制的指导意见》，

① 《中国能源形势与政策》，http://www.nea.gov.cn/2011-08/22/c_131065968.htm
② http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm
③ http://www.gov.cn/zhengce/2020-12/21/content_5571916.htm
④ https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=18453，2020 年生效， 2022 年修订。
⑤ http://www.gov.cn/xinwen/2019-11/06/content_5449193.htm

着力解决可再生能源开发利用过程中产生的水电、风电、光伏发电的送出和消纳问题，提出建立健全可再生能源电力消纳保障机制；2021 年，国家能源局发布《关于加快发展新型储能的指导意见》[①]，提出构建清洁低碳、安全高效的能源体系，实现碳达峰和碳中和目标的必要性和重要性；到 2025 年，中国力争实现新能源储能由初级商业化向规模化发展的转变。

2022 年，为深入贯彻落实《中共中央、国务院关于完整准确全面贯彻新发展理念做好碳达峰碳中和工作的意见》和《2030 年前碳达峰行动方案》有关要求，国家能源局研究发布了《关于完善能源绿色低碳转型体制机制和政策措施》[②]，提出要完善国家能源战略和规划实施的协同推进机制、完善引导绿色能源消费的制度和政策体系、建立绿色低碳为导向的能源开发利用新机制，特别是要完善新型电力系统建设和运行机制、完善化石能源清洁高效开发利用机制、健全能源绿色低碳转型安全保供体系、建立支撑能源绿色低碳转型的科技创新体系、建立支撑能源绿色低碳转型的财政金融政策保障机制以及促进能源绿色低碳转型国际合作。中国国家发展改革委员会及国家能源发展局等有关部门联合发布的《能源技术革命创新行动计划（2016-2030）》中提到，推动能源智能生产技术创新，重点研究可再生能源传输、消费、监管三大板块。

在能源产业规划领域，中国政府制定了多项具体规划，提出了对绿色能源所涉及的各领域的发展要求。2014 年 6 月，国家发布《能源发展战略行动计划（2014-2020 年）》，明确提出，到 2020 年，核电装机容量达到 5800 万千瓦，在建容量达到 3000 万千瓦以上；力争常规水电装机达到 3.5 亿千瓦左右；风电装机达到 2 亿千瓦，风电与煤电上网电价相当；光伏装机达到 1 亿千瓦左右，光伏发电与电网销售电价相当；地热能利用规模达到 5000 万吨标准煤。《电力发展“十三五规划”》则规划从供应能力、电源结构、电网发展、综合调节能力、节能减排、民生用电保障等六方面提出了具体的发展目标，如，太阳能光伏发电装机达 1 亿千万瓦以上、生物发电装机 1500 万千瓦左右、核电装机达 5800 万千瓦。除综合性政策，针对风能、核能、太阳能、生物质能等，政府也出台了一系列实施方案和指导意见，对能源产业特别是绿色能源产业发展政策基本做到了全面覆盖。

在促进能源绿色低碳转型国际合作领域，中国政府提出将积极推动全球能源治理中绿色低碳转型发展合作。建设和运营好“一带一路”能源合作伙伴关系和国际能源变革论坛等，力争在全球绿色低碳转型进程中发挥更好作用。依托中国—阿盟、中国—非盟、中国—东盟、中国—中东欧、亚太经合组织（APEC）可持续能源中心等合作平台，持续支持可再生能源、电力、核电、

① http://zfxxgk.nea.gov.cn/2021-07/15/c_1310079331.htm
② http://zfxxgk.nea.gov.cn/2022-01/30/c_1310464313.htm

氢能等清洁低碳能源相关技术人才合作培养，开展能力建设、政策、规划、标准对接和人才交流。提升与国际能源署、国际可再生能源署等国际组织的合作水平，积极参与并引导在联合国、二十国集团、APEC、金砖国家、上合组织等多边框架下的能源绿色低碳转型合作。将充分利用国际要素助力国内能源绿色低碳发展。落实鼓励外商投资产业目录，完善相关支持政策，吸引和引导外资投入清洁低碳能源产业领域。完善鼓励外资融入中国清洁低碳能源产业创新体系的激励机制，严格知识产权保护，推动建立清洁低碳能源技术创新国际合作平台，支持跨国企业在华设立清洁低碳能源技术联合研发中心，促进清洁低碳、脱碳无碳领域联合攻关创新与示范应用。

中国政府一贯重视和支持与世界各国协同发展，共谋福利，探索建立多双边绿色能源经济发展合作机制，在“共商、共建、共享”基础上实现绿色能源项目上的合作，实现能源优势互补。

3.1.2 产业技术革新带来绿色发展新动力

近年来，中国积极发展以太阳能、风能为代表的新能源，已具有一定的规模成效。中国单个能源产业链完整链条正在形成，随着新一代信息技术的发展，与新能源的融合应用进一步推动中国新能源产业发展，为绿色能源的推广、应用带来更强大的技术支撑。中国能源产业链完善，特别是清洁能源核能、氢能已形成较完整的产业链条，有助于稳定产业发展的基础上向纵深推广精耕。目前中国已形成完善的核电产业链，逐步建立起了与压水堆核电站相匹配的核电工业体系，拥有了一批大型、专业的核电设备制造生产企业以及众多规模不一的核电站辅助设备制造大中型生产企业。氢能领域，全国 25 个省市及自治区累计发布氢能及燃料电池产业专项政策 190 余项。氢能制备储运、燃料电池系统集成、加氢设施等主要技术和生产工艺不断进步，氢能由示范应用逐步走向规模化推广，产业链条不断完善。长三角、珠三角、环渤海三大区域氢能产业初具规模，苏州、佛山、武汉、成都等地汇集多家氢能企业及研发机构，全产业链发展态势良好。总的来说，目前中国已基本构建了较为完善的涵盖制氢、储运、加注和应用的氢能产业链。

2020 年以来，中国各地加快布局 5G 网络，三大运营商相继发布 5G 建设计划，合计建设 50 万个 5G 基站，覆盖全国所有地市级（含）以上城市[①]。在 5G 通信技术下，电力领域可以实现更多智能化的升级、改造，在应用方面也将呈现新业态；而大数据应用可以采集、存储、分析处理大量的信息数据，更高效的处理电力传输、配电等过程中需求及问题；中国云计算市场处于快速发展阶段，容器、微服务等技术的不断成熟，推动着云计算的变革。随着云计算的

①根据中国行政区划，省级行政区直接管辖的城市与地区同级。

应用场景的不断拓展，云计算的应用已深入达到新能源、政府、金融、工业、交通、物流等传统行业；物联网技术是支撑国家战略的重要基础，在推动国家产业结构升级和优化过程中发挥重要作用。物联网是新一代信息技术的高度集成和综合运用，对新一轮产业变革和经济社会绿色、智能、可持续发展具有重要意义；智慧新能源平台将新一代信息技术与能源生产、传输、存储、消费以及能源市场深度融合发展。

2015 年 4 月中共中央、国务院印发《中共中央国务院关于加快推进生态文明建设的意见》，提出建立节能、碳排放权交易等制度。9 月印发的《生态文明体制改革总体方案》明确提出，建立绿色金融体系，推广绿色信贷。2016 年 3 月，“十三五”规划纲要明确提出，建立绿色金融体系，发展绿色信贷、绿色债券，设立绿色发展基金。中国绿色基金、绿色股票指数、绿色债券指数、绿债认证和披露、绿色评级方法、环境压力测试、碳金融产品、国际合作等方面都有新的进展，绿色金融市场规模日益发展壮大，市场的参与主体越来越多元化，各类绿色金融产品及其衍生工具不断发展创新。2016 年 8 月，人民银行等七部委发布的《关于构建绿色金融体系的指导意见》指出，绿色金融可以是对环保、节能、清洁能源、绿色交通、绿色建筑等领域的项目投融资、项目运营、风险管理等所提供的金融服务。因此 2016 年也被成为中国绿色金融元年。具体来讲，绿色金融主要包括投资贷款和贷款担保、低息贷款、产业金融复制、产业发展基金、绿色基金等。相关主体也不仅仅局限于银行、基金公司等大型实体机构，一些机构已经尝试通过各种新途径对于绿色项目进行精准识别和认定，提供无抵押的信用贷款给小微企业。通过精准和科学识别产业的上下游核心企业是否绿色，来鼓励小微企业与绿色企业进行经济活动，引导产业链的下游将自己的经营重心放到绿色商品的流通或者制造环节。

3.1.3 特色经济提升绿色能源需求

2018 年，中国与 17 个国家共同发布《关于构建“一带一路”能源伙伴关系的部长级联合宣言》[①]，为构建更加紧密的能源命运共同体、推动国际能源绿色可持续发展提供了新途径。此后，成功举办了两届“一带一路”能源伙伴关系论坛和多场高官磋商，为成员国搭建了双边、多边项目合作和技术交流的优质平台。2019 年，成员国共同发布了“一带一路”能源伙伴合作原则和实践行动。同时，该伙伴关系也正式写入第二届“一带一路”国际合作高峰论坛圆桌峰会联合公报[②]。上述公报重点关注绿色能源项目投资，加强绿色能源领域能力建设和技术力量建设。

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①巴西尚未正式加入“一带一路”能源伙伴关系。

② https://bremc.obor.nea.gov.cn/

2022 年 2 月，中国成功举办第 24 届冬季奥运会。北京冬奥会依托于绿色能源的综合治理和大胆应用，展现出绿色、包容、开放、整洁的新风貌。绿色冬奥的成功经验与中国大力发展新能源和循环经济、推动低碳技术研发和推广应用密不可分。北京冬奥会所有比赛场馆 100% 使用清洁能源供电，全球首次大批量使用氢燃料电池客车服务体育赛事。“微火”成为冬奥主火炬、“绿电”点亮冬奥场馆、新型制冰技术打造“最快的冰”、临时设施拆除后仍能重复利用；绿色金融贯穿冬奥会筹办举办的全过程。北京冬奥会对清洁能源的追求和努力，彰显了中国政府大力发展清洁能源产业、积极履行碳减排大国责任的信心和态度，以冬奥会为契机，中国集中力量技术攻关，探索新能源大规模输送、并网及消纳的一体化新路径，充分展示新能源应用潜力，也有利于推动新能源产业化推进，为能源低碳转型积累宝贵经验。

3.1.4 能源产业发展仍不平衡

中国资源禀赋、区域分布和能源结构都不够平衡。中国石油、天然气等优质能源短缺，煤炭资源丰富，探明储量排名低，供给不足；可再生能源储量充沛，但目前中国能源结构仍旧严重失衡开发程度不高。《中国统计年鉴》数据显示，2020 年，煤炭在一次能源消费中占比高达 68%，石油占比 7%，天然气占比 6%。与世界平均水平相比，该结果显示中国对于煤炭的过度依赖情况仍未减轻，核能等其他清洁能源发展利用处于起步阶段。

尽管近年来油气产量不断增加，但相对于中国庞大的需求量仍有较大缺口。2019 年，中国原油和天然气对外依存度分别超过 70% 和 45%，高度依赖进口的油气成为中国保障能源安全的短板。2020 年，受新冠感染影响，中国油气产量未达预期。目前，中国储气量约为年消费量的 5.7%，远低于世界 12% ～ 15% 的水平。储气设施仍存在 LNG 接收站规模普遍偏小、布局分散、土地和岸线资源利用率低、配套设施和运营成本增加等问题。

中国是全球能源第一消费大国。而随着经济持续发展，中国能源需求还在持续增长，2010 年至 2020 年，中国能源消费增长 54.6%。2017 年能源消费量为 31.32 亿吨油当量，占全球能源消费总量的 23.2%。①

迄今为止，中国能源消费记录上还未出现过负增长，并且一次性能源消费保持连续正增长。根据英国石油公司 BP《2022 年世界能源统计年鉴》，2021 年全年中国一次能源消费总量为 157.65 艾焦，居世界首位，全球占比为 26.5%，其次是美国的 92.97 艾焦，印度和俄罗斯分别以 35.43 艾焦和 31.3 艾焦分列第三和第四位国家，整个欧洲消费为 82.38 艾焦。中国原油

① BP，世界能源统计 2019 年，2020 年。

消费保持 7.2% 的较快增长，天然气消费增长 12.8%，而同期用电量增长 10%，消费能力略高于产能，能源依存度较高。①

能源供需不匹配②。根据中国国家统计局公布的数据，2019 年中国能源生产结构中，原煤占 68.8%，原油占 6.9%，天然气占 5.9%，水电、核电、风电电力占 18.4%③。 2019 年中国进口原油 50572 万吨，同比增长 9.5%，进口天然气 9656 万吨（约 1333 亿立方米），同比增长 6.9 % .

中国能源资源向优势资源区高度集中，能源供需错配格局进一步显现。在能源资源分布上，煤炭产能高度集中在山西、新疆、内蒙古和陕西等省份，占全国总产能的 70% 以上；油气、煤电、水电资源集中在西部地区；风电、光伏等新能源集中在北方地区。从需求来看，东部地区能源需求量大，而经济最发达的沿海地区，包括湖南等 GDP 大省，对动力煤的工业需求量非常大。但这些地区能源资源匮乏，需要通过北煤南运、西电东送、西气东输等跨区域能源资源配置来满足负荷需求。在能源“双控”和煤炭消费总量控制下，受限于交通运输能力，这些能源稀缺、负荷需求大的地区，在用能高峰时段容易出现“断电”现象。另一方面，各种能源之间存在明显的协调问题，不利于构建有效的现代能源体系，协调优化煤炭、油气、电力和新能源等发展存在体制机制和政策支撑问题。

3.1.5 绿色能源发展水平不高

作为世界第二大能源生产国和消费国，中国能源消费结构有所调整，但仍存在不少问题。长期以来煤炭还是主要的能源消费主体，原油、天然气等消费总量所占比例较少，在实际发展的过程中，煤炭向石油过渡的过程中，出现了利用率不高等相关问题。

立法支持有待进一步完善。为实现能源高质量发展，中国必须建立与辅助服务市场相结合的综合能源市场体系。而当前现行能源体制仍存在质量不高、监管体系尚不健全等问题；此外，能源价格形成机制和财税政策有待完善，资源消费税设置不全面。

中国环境贸易逆差较大，对欧美市场依存度高。以中国光伏组件生产为例，95% 的生产订单仍来自国外厂商。此外，金融危机后，德国、西班牙、日本等重要市场需求大幅下降，贸易保护主义开始显现。 一定程度上，新能源财政补贴减少，多方面设置绿色贸易壁垒，影响国内新能源产业发展。

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① BP，2019 年、2022 年世界能源统计
②能源发展趋势与挑战，中国能源。2021 年 7 月，Y. Jing Zhu。
③ http://www.cinic.org.cn/sj/sdxz/shengchanny/817661.html

科技创新能力不足。能源研究特别是基础研究水平仍然薄弱，对氢能、燃料电池等前沿技术的投入和研究有限，不足以实现绿色转型的跨越式发展。

3.1.6 国际规则对接仍有障碍

中国虽然制定了《中华人民共和国可再生能源法》和《可再生能源发电上网电价和费用分配管理暂行办法》，但法律体系仍不完善，法律设计相对粗糙。中国应在未来更加注重提高能源绿色发展的战略性、前瞻性和可操作性，为能源转型提供坚实的法制保障。

政府应该主导制定新能源战略、新能源发展总体规划、新能源立法、新能源发展支持体系，特别是在新能源发展初期，要发挥政府的带动性功能。美国和日本政府启动了国家主导的新能源技术和技术推广项目。欧盟也为成员国制定了相对统一的新能源发展目标，努力建立欧盟统一的新能源市场。中国应加强向新能源转型过程中政府的作用，统筹各地区新能源的发展，提高中国在向绿色能源转型过程中的综合竞争力。

新能源产业很可能引领世界经济发展方向，并带动人类社会新变革。大多数 G20 国家都设定了绿色能源占电力消费比重的目标。中国应积极整合企业、科研机构和政府资源，制定和实施绿色能源技术中长期研发规划，启动国家级大型科研项目，广泛开展国际合作，力争让新能源技术与国际接轨。另一个关键问题是可再生能源如何适应能源数字化、智能化的发展趋势。从能源的角度看，全球有从资源依赖到技术依赖的趋势；技术进步赋予了可再生能源竞争优势。目前，我国绿色能源产业技术发展不足，限制了可再生能源的应用和应用场景的丰富性。尽管中国在数字化发展方面取得了很多成就，但在国际化运营尤其是本土化领域还缺乏经验。可以考虑推动能源产业科学高效发展，同时满足国际市场需求。

3.1.7 行业优势与劣势

2011 年，中国和巴西签署了涵盖多个领域特别是能源领域合作的联合公报，表示愿进一步深化在石油贸易融资、油气勘探开发、电力、能源装备、和平利用核能、生物燃料等新能源，进一步拓展能源合作新领域。2012 年 2 月，双方签署共同行动计划，正式启动十年合作计划。同时，在金砖国家能源合作机制加持下，中国和巴西能源合作成果显着。中国企业对巴西的投资大多集中在可再生能源领域，这得益于巴西的投资机会多和市场潜力大，以及与中国强大的供应链和雄厚的融资实力有关。

太阳能

中国太阳能资源丰富，全国三分之二以上的地区年辐射量在 502 万千焦耳 / 平方米以上。中国太阳能光伏企业虽然大部分为中小企业，但技术水平高，综合实力强，培养了一大批化工和能源专业人才，为新能源的发展储备了充足的人力资源。目前发展的主要难点是技术水平上的瓶颈，在国际光伏产业中仍处于低端。光伏发电原材料大部分仍依赖进口，多晶硅生产技术水平不高，尚未实现技术突破。

尽管起步较晚，但巴西在该领域具有独特的优势。巴西国土大部分位于热带，日照时间长，太阳能发电潜力巨大。此外，巴西非常重视环境保护，相关法规非常严格。光伏发电作为一种清洁能源，对环境影响小，易于推广。另一方面，随着近年来全球光伏发电的快速发展，更多新技术、新材料的应用，成本逐渐下降，也为巴西发展光伏发电创造了条件。由于生产效率高、成本低、物流便利等优势，中国企业目前在太阳能制造领域处于领先地位。中国企业可为巴西光伏项目提供高性价比的全方位服务。

氢能

水力发电在中国电力结构中占有重要地位，优势明显。主要特点是清洁环保、优先接入电网、电价低、相对稳定、成本低、竞争力强、易调峰节能。世界最大的水电站——三峡水电站位于中国，除拥有不同规模的各类水电站外，在国际水电领域也是独树一帜，拥有高水平的管理运营团队和丰富的资源熟练的施工经验，全国共有水电站相关企业 1.89 万家，多集中在南方沿海省市。

中国正在建设装机容量超过 2000 万千瓦、投资规模超过 1000 亿元的抽水蓄能电站。 抽水蓄能是目前最为成熟的大规模储能方式，具有调峰、调频、调相、储能、多功能、超大容量、系统简单、经济可靠、生态保护等优点．可有效保障电力系统安全稳定运行，提高新能源利用水平。

核能

核电与太阳能、风电一样，在运行过程中不会产生大量的温室气体排放，核电的碳排放量甚至低于其他清洁能源发电。太阳能和风力发电受季节和天气因素的影响，具有间歇发电的特点，供电的稳定性相对较差，相比之下，核电几乎可以完美避开季节和天气等因素，具有明显的全天候发电优势。此外，核电作为低碳高效的大规模基荷电源，利用小时数高，用电成本低，不排放二氧化硫、氮氧化物和烟尘颗粒等大气污染物。由于核电具有上述清洁低碳的特点，核电必将成为世界能源从高排放、高污染向清洁低碳能源转型的重要选择之一。

核电安全是行业发展的重中之重，因此核电行业具有较高的行政准入壁垒、技术壁垒和资金壁垒。历史上发生过多次重大核事故，但主要原因基本上是人为操作不当和核电站设计存在缺陷造成的。2021 年，吸取日本福岛核事故 30 年的经验和教训，中核集团联合中广核研制“华龙一号”。与美国（AP1000）和法国（EPR2）一样，中国也掌握了第三代核电技术。由于核电行业的特殊性，2020 年前经国务院正式批准的中国核电项目（示范项目和研究堆除外）全部由中国核电、中国广核和国家电投运营。其中，中国核电装机容量市场份额达到 42.3%，中广核装机容量市场份额达到 42.5%（不包括合资企业），上述两家公司是中国领先的核电运营商。

生物质

中国生物质能源虽然资源丰富，发展潜力巨大，但在能源消费结构中所占比例很低，难以成为大规模使用能源。目前，中国生物质能源利用方式主要有生物质发电、生物液体燃料、生物质成型燃料、生物质气体和生物制氢技术等。中国生物质能源资源占能源消费总量的比重也较低。从装机容量看，截至 2021 年底，我国生物质发电累计装机容量达到 3798 万千瓦，占发电总装机容量的 1.6%。 2021 年我国生物质发电结构中，垃圾焚烧约占 61.2%，农林生物质发电约占 35.5%，沼气约占 3.3%。

生物质能源在中国除了不能得到广泛应用外，还有成本不可控的弊端，对于农林生物质发电企业来说，燃料成本占其运营成本的 60% 以上，生产经营条件确实难以维持。简而言之，在中国，生物发电的生态环境价值尚未得到充分体现，产业结构尚未达到基本平衡。巴西是全球推动生物燃料产业发展的先行者，解决了燃料乙醇等生物液体燃料开发利用的一系列关键技术和产业化难题。未来中国可加大与巴西在生物质液体燃料领域的合作，如在第二代和第三代燃料技术方面取得突破，与巴西实现优势互补，互利共赢。

3.2 巴西视角

本部分主要梳理和介绍巴西绿色能源发展的优势和劣势。巴西推广绿色能源的主要优势是资源的可用性。巴西自然条件优渥，风量稳定且丰富利于风力发电应用；日照充足利于太阳能能源获取；生物质来源丰富而多样。巴西绿色能源的主要劣势在于巴西在这方面属于后起国家，落后于已经拥有完整产业的先行国家，巴西已通过多种方式寻求发展先进的生产链和开发技术。

3.2.1 太阳能

优势

太阳能在巴西具有一定些优势，这主要是因为巴西的天气特征和工业能力，具体优势如下：

1. 广泛的集成商和设备供应商网络；
2. 几乎全部领土都能受到高水平太阳辐照，即使在冬季也是如此；
3. 光伏面板易于操作，且操作和维护需求低。

不足

1. 太阳能的一个常见弱点是间歇性和需要特定的基础设施。因此，建议与现有项目混合发电（例如：将光伏发电项目设在水力发电水库或风力发电场），尽量减少对新工程的需求，降低相关的社会环境影响；

2. 巴西的设备供应行业无法提供比较精密的零部件，这意味着产业较多依赖进口。应当刺激本地供应商提高光伏组件组装、微型逆变器以及逆变器和电池的生产能力；

3. 分布式光伏发电需要更强的融资能力，因此多由高收入阶层开展。为低收入消费者创造更优渥的融资条件，使其拥有更加充足的现金流，是一项重大挑战；

4. 环保部门和政府机构应该协调好光伏系统组件的回收工作，鼓励发展专注于此类组件处置和回收的产业链；

5. 应该规范自由市场上余量分布式发电机的销售、每小时电价的门槛、可能出现的电力零售竞争和配套服务市场的参与。

3.2.2 氢能

优势

就目前来看，巴西绿色制氢具有以下主要竞争优势：

1. 具有生产加工的有利气候和地理条件，能够以较低的成本提供用于制氢的自然资源（天然气、乙醇和水）；

2. 在巴西，可用于开发绿氢和促进该国分布式发电的光伏和风能产量呈增长趋势，以绿氢作为可再生能源储能载体仍具有潜力；

3. 考虑到鹿特丹港和其他潜在绿氢出口国之间的距离，巴西拥有生产运输的便利性（海岸线较长）和优越的地理位置；

4. 拥有行业代表性组织（巴西氢能研究开发和创新协会）；

5. 巴西天然气市场的发展变化有利于氢能发展，由于天然气管道网络较长，具备了注入氢气或将氢气与天然气混合的条件；

6. 利用可再生能源发电的成本不断降低，预计 2030 年巴西绿氢的平准成本将约为 1.50 美元 / 千克氢。

不足

1. 缺乏保障运输的管道和供应基础设施。目前巴西拥有的相关基础设施仅适用于天然气，并且集中在沿海地区；

2. 监管障碍和官僚主义仍然存在。需要进一步确定哪些公共机构承担与绿氢监管和使用相关的职能，还需制定科学的技术标准，例如，氢气与天然气在管道中的混合技术标准；

3. 需要进一步规范碳市场，鼓励私营部门投资可持续能源项目。天然气市场尚未制定将氢注入天然气管道网络方面的相关监管规定。

4. 经济低增长和财政高度失衡，对氢能的公共和私人投资量也产生了一定影响。

3.2.3 核能

优势

1. 核能有助于补充巴西的间歇性能源。巴西拥有用于水电的大型水库，可在在其负荷曲线底部（频率高且运行成本低）生产核能，有助于保持水库充盈，度过降雨量较小的时期。

不足

1. 巴西资本成本相对较高且投资水平低，而核电项目资金密集度高，因此发展核电面临挑战。平均而言，新启动核能项目的固定成本大约能占到总成本的 73% 至 85%。Barkatullah 和 Ahmad（2017）指出，核能项目规模可高达 90 亿美元；

2. 巴西的大型发电项目常有延误，不利于聚集资本密集型资源。Angra 3 号项目就是一个典型案例；

3. 尽管巴西在核能方面有一定经验，但巴西并未被视作该领域的技术领先者。需要拓展更多的国际伙伴关系克服这一障碍。

3.2.4 生物质能

优势

1. 生物燃料有助于燃料供应安全，这也是当今面临的一个关键问题；

2. 生物燃料使用在巴西有着悠久的历史，其生产供应链已经基本组织完善并且具有较高的生产能力；

3. 生物质能提供了废物二次利用的机会，有助于解决城市资源紧张问题（如废物处理）；

4. 甘蔗生物质热电联产可以作为水力发电的补充，因为生物发电量的增加发生在收获期间，与河流枯水期可以做到相互配合补充。

不足

1. 巴西在生物燃料方面的实力主要集中在传统技术上，从传统技术向先进技术转移和发展是一项巨大挑战；

2. 生物燃料的供应随季节变化和价格波动而变化；

3. 甘蔗生产过程中存在劳动条件不稳定的缺点。

四、中国—巴西绿色能源合作潜力领域

4.1 水电

中国和巴西是世界水电装机容量第一和第二大国，在水电利用方面表现突出。 世界前十大水电站中，只有两座不在中国或巴西，中国三峡水电站和巴西伊泰普水电站更是高居榜首。

巴西曾对水电领域进行整合，并与中国在大型水电站和长距离输电技术方面开展了合作。对于远离消费中心的工厂而言，长距离输电技术对保证其用电至关重要。

20 世纪 80 和 90 年代，在水坝建设方面已有长期经验的巴西公司参与了中国水电站的建设。在三峡水电站建设中，巴西相关服务公司就曾与中国的项目牵头公司开展过合作（BIATO Júnior，2010）。

为了更好地了解近期中巴在水电领域的合作，有必要探讨中国在巴西电力领域的存在，这包括三个重要方面：贷款、投资和建设项目。中国公司参与了巴西能源传输、本地发电和配电等相关活动。

Barbosa 指出：“巴西丰富的资源禀赋、扩大装机容量和电网的必要性以及有利的市场、法律和政策条件，与中国的财力和技术能力恰相匹配，这为中国企业的到来创造了理想条件”(2020，p.3）。值得一提的是，中国企业常投资于巴西资源丰富、具有自然优势的领域，这就为水力发电能够占到巴西发电总投资的 81% 提供了有力解释。

多家中国公司涉足巴西能源行业，其中有两家脱颖而出，分别是中国三峡（CTG）和国家电网。两者都在以发展巴西水电行业为目标的双边合作中发挥着至关重要的作用。国家电网更是在贝洛蒙特水电站的建设中表现突出。该水电站是巴西最重要的水电设施之一，装机容量超过 11 吉瓦。

由于能源供需端之间存在很长的地理距离，长距离输电线路对水电项目至关重要。中巴两国都加强了该领域生产和技术能力。近期，国家电网签署了巴西贝洛蒙特水电 ±800kV 特高压直流输电项目二期运营许可证。该项目全长 2539 公里，横跨巴西 5 个州 81 个城市，是世界最长的 ±800kV 特高压直流输电项目，也是水电领域的一项重要创新工程。

国家电网向巴西水电领域的技术转让是两国合作的表现之一，同时也揭示了未来双方进一步深化合作的方向。安装超高压 (UHV) 输电线路和智能计量系统可以加强巴西的输电行业（Cote，2014 年）。

此外，考虑到水力发电厂建设对环境和社会的负面影响，例如水质变化、温室气体排放、

人口搬迁和遗产丧失等，中巴两国可以共同制定新的水电站建设方法以减轻这些负面效应。双方可以在分享水电项目环境解决方案方面进行合作。

4.2 太阳能

太阳能发电具有发电过程简单、地区适应性强、资源取之不尽用之不竭等优势，是目前世界范围内发展迅速的新能源发电领域。中国和巴西均具备进一步发展太阳能发电的潜力。

从资源量来看，巴西太阳能资源丰富。其国土的 80% 位于热带地区，超过 50% 以上的国土海拔超过 500 米。巴西年平均日照时间超过 3000 小时，全国各地水平面太阳能总辐照量在 1534kWh/m^2 至 2264kWh/m^2 之间，平均约 1700kWh/m^2，具有极高的开发价值。巴西东北部和中部光照最为丰富，陆上集中式光伏可开发装机约 28519Gwp[①]。

从国内需求来看，随着巴西能源结构的调整，太阳能具有广阔的发展前景。巴西可再生能源矩阵中的一个问题是严重依赖水电，而水力发电又严重依赖 11 月至次年 3 月的雨季降水。气候变化正在改变全球温度和降水的分布，在此背景下，该国的可再生能源供应面临更多的不确定性和极端天气事件带来的风险。2021 年巴西经历了历史上最严重的干旱，长期无雨的极端天气重创该国电力生产系统。巴西当局被迫将电力供给系统转向成本更高的火电，同时还从阿根廷、乌拉圭等邻国进口电力。此外，由于世界范围内环保呼声越来越高，在热带雨林区域新建水电站越来越难，而与此同时巴西城市化进程和工业发展却需要更多电力供应。巴西迫切需要调整可再生能源结构调以满足不断增长的电力需求。考虑到该国太阳能资源丰富、可得性高且目前在可再生能源矩阵中占比很小，太阳能可能具有很大的发展潜力。

从建设效率和成本来看，根据巴西光伏太阳能协会 (Absolar) 的研究报告，太阳能发电厂在巴西被公认为是建设速度冠军。由于太阳能技术的多功能性和敏捷性，仅需安装一天即可将家庭或企业转变为生产清洁、可再生和可获取电力的小型工厂。即使是大型的太阳能发电站，从拍卖到开始发电也只需要不到 18 个月的时间。至于发电成本，大型太阳能发电厂的发电价格比应急化石热电厂或从邻国进口的电力低十倍，后者是导致巴西消费者电价上涨的两个主要因素[②]。

在政策方面，根据巴西矿业和能源部与巴西能源研究公司发布的《十年能源扩张计划（PDE）

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① http://com.gd.gov.cn/go/article.php?typeid=38&contentId=21450.

② https://www.invt.com/news/brazil-top-15-pv-power-113

2030》，巴西计划到2030年，实现发电装机容量2.36亿千瓦，大幅增加分布式发电、风电、天然气、太阳能装机容量，削减包括燃煤、柴油和燃料油在内的化石能源发电装机容量[①]。另外，为鼓励光伏产业发展，巴西政府也为相关组件的进口和生产提供了资金支持。2020年巴西取消了包括多种光伏组件、逆变器和太阳能跟踪器在内的商品进口关税。在此之前，巴西进口的大部分光伏设备需缴纳12%的关税。该决议还规定，如果光伏发电厂使用“巴西制造”的组件，则可以从国家开发银行BNDES和其他政府机构获得资金支持[②]。此外，为了支持本土分布式光伏市场发展，巴西政府还取消了对小型太阳能发电系统的征税，装机容量在1兆瓦以下的光伏电站也可免缴流转税[③]。

从中国方面来看，如上文所述，中国也是太阳能资源非常丰富的国家。经过几十年的探索，中国在太阳能发电领域积累了大量经验和成熟技术。中国在2000年开始规划布局太阳能产业的发展。随后启动了送电到乡、光明工程等一系列扶持项目，通过光伏和小型风力发电解决西部七省区（西藏、新疆、青海、甘肃、内蒙古、陕西和四川）700多个无电乡的用电问题。这几个省份是中国太阳能资源极为丰富的地区，同时也是中国发展最为落后的地区。在这些地区推广太阳能发电，不仅解决了当地农村用电问题，还充分利用了资源优势，通过太阳能产业带动了整个地区的经济发展。这些政策的成功也使中国太阳能光伏年装机容量实现了从KW级到MW级的转变（王捷等，2022）。

目前，中国是世界光伏产业发展增速最快的国家，拥有全球最大的太阳能光伏产业规模。中国在部分太阳能发电关键核心技术领域实现了全球领先。因此中国太阳能利用的发展经验可供巴西借鉴，两国在太阳能发电关键技术领域有交流和合作空间。

从国内需求和政策导向来看，中国拥有14亿人口的巨大市场，且正处于国家推动清洁能源代替传统化石能源的转型阶段，因此未来几十年中国市场对太阳能等清洁能源的需求是巨大的。中国在2020年提出了“双碳目标”，即二氧化碳排放力争于2030年前达到峰值，努力争取2060年前实现碳中和。电力行业是中国碳排放最多的领域（2020年约排放二氧化碳40亿吨），因此控制电力行业碳排放是推动中国尽早实现碳达峰、碳中和的关键（邓玥，2021）。2021年中央财经委员会第九次会议上提出构建以新能源为主体的新型电力系统的要求。

① https://portal.apexbrasil.com.br/regulatory_report/the-ministry-of-mines-and-energy-mme-and-the-brazilian-energy-research-company-epe-launched-the-2030-ten-year-energy-expansion-plan-pde-2030

② https://www.pv-magazine.com/2020/07/22/brazil-eliminates-import-duties-for-cells-modules-inverters-and-trackers/

③ https://www.imsilkroad.com/news/p/460447.html

此外，根据中国国家发改委、国家能源局等 9 部门联合印发的《“十四五”可再生能源发展规划》，2021 至 2025 年，中国将加快能源绿色低碳转型、落实应对气候变化国家自主贡献目标。可再生能源发电量增量在全社会用电量增量中的占比超过 50%，太阳能发电量将实现翻倍①。

基于上述分析，中国与巴西可在以下两个重点领域开展深入合作：

一是进行关键技术研发，提高太阳能发电的稳定性和发电效率。太阳能发电优点突出，例如太阳能资源无穷无尽，分布广泛，只要在有光照的地方都可以使用太阳能发电；太阳能电池组件结构简单，体积小、重量轻，便于运输和安装；光伏发电系统建设周期短，而且可根据用电负荷容量调整大小。但是，太阳能发电的缺点也很突出。首先，太阳能发电受气候环境因素影响大，其能量直接来自阳光。雨雪天、阴天、雾天甚至云层的长期变化都会严重影响电力系统的状态。 空气污染也会影响其效率。如果空气中的颗粒物（如灰尘）沉降在太阳能电池组件表面，遮挡部分光线照射，则会降低电池组件的转换效率，导致发电量下降，甚至损坏电池板。其次，太阳能的能量密度和发电的转换效率低。虽然太阳投向地球的总能量巨大，但由于地球表面大部分被海洋覆盖，真正能到达陆地表面的太阳能只有到达地球范围太阳辐照能量的 10％左右。光伏发电的转换效率指光能转换为电能的比率。目前晶体硅光伏电池转换效率为 13％～ 17％，非晶硅光伏电池只有 5％～ 8％②。太阳能电池转换效率低是阻碍光伏发电大规模推广的瓶颈。最后，光伏组件的原材料晶体硅的生产过程并不环保。晶硅电池的主要原料是高纯硅。硅砂在转化为晶硅的过程中，要经过多次化学和物理过程，不仅消耗大量能源，还会造成环境污染。因此，中巴两国科学家在提高太阳能发电的稳定性和效率、降低零部件生产过程中的能耗和污染等关键技术问题上有着广阔的合作空间。

二是光伏相关产品贸易和产能投资。在利好政策环境的推动下，巴西光伏产业装机容量实现快速增长，这为两国光伏相关产品贸易提供了机遇。中国是全球贸易市场上光伏产品的重要供应国。据中国光伏行业协会统计数据，2021 年，中国多晶硅、硅片、电池片、组件产量分别达到 50.5 万吨、227 吉瓦、198 吉瓦、182 吉瓦，这四个环节产值突破 7500 亿元；中国光伏产品出口额为 284.3 亿美元，同比增长 43.9％③。2022 年一季度，中国光伏组件出口额约 106 亿美元，同比增长 122.9%。其中对巴西出口 13.3 亿美元，占比 12.6%，仅次于印度、荷兰，位列第三④。巴西对中国而言是关键的出口市场，未来随着巴西国内新能源扩张计划的持续推进，

① http://www.gov.cn/zhengce/2022-06/08/content_5694539.htm
② https://solar.in-en.com/html/solar-2326665.shtml
③ http://www.gov.cn/xinwen/2022-02/24/content_5675307.htm
④ http://www.xinhuanet.com/energy/20220510/6abd571f3b5740a784af22ad41bb1585/c.html

两国在光伏领域的贸易量或将继续扩大。

此外，由于光伏产业属于资金和技术密集型产业，中国和巴西两国依托各自优势进行投资合作更加有利于提高两国绿色能源利用效率。当前，全球范围内能源及产业发展低碳化的趋势已经形成，两国也出台了相关政策支持光伏产业发展，因此中国和巴西在太阳能发电领域开展投资合作面临着有利机遇。中国政府在《智能光伏产业创新发展行动计划（2021-2025 年）》中提出，将积极鼓励企业与先进国际机构和企业开展智能光伏领域技术、人才、资本、标准等合作，支持企业在海外建设智能光伏工厂、开发智能光伏电站项目，为全球光伏治沙、光伏扶贫等先进智能光伏模式推广应用做出贡献[①]。巴西是中国在拉美进行光伏投资的重要目的地。中国公司比亚迪已经在巴西设立了光伏发电厂。两国应继续开展包括电站投资、建设和运营在内的全产业链一体化投资合作。这样不仅有利于弥补巴西当地电力供应缺口、降低电价，还有利于创造新增就业机会，促进巴西后疫情时期经济的绿色复苏。

4.3 风能

受到气候变化、温室气体和其他污染气体减排的强烈推动，风能一直是世界上增长最快的可再生能源之一。巴西和中国都将风能视为本国充满发展前景的清洁能源。根据巴西矿业和能源部所属能源研究公司发布的《十年能源扩张规划》，巴西政府计划在 2020 年至 2030 年间吸引超过 3000 亿雷亚尔的投资用于电站建设，其中风电和光伏发电新增投资占比超过 50%[②]。巴西的目标是到 2029 年有三分之一的新增电力来自风能。截至 2019 年，巴西风电装机容量达到 15.4 吉瓦。而最近的一项评估预测，当地的风力发电潜力高达 880 吉瓦[③]。根据中国政府发布的《“十四五”可再生能源发展规划》，中国承诺二氧化碳排放力争于 2030 年前达到峰值、努力争取 2060 年前实现碳中和，明确 2030 年风电和太阳能发电总装机容量达到 12 亿千瓦以上。风电和光伏发电具有资源储量大、建设地点灵活、经济高效等优势，有望成为中国未来电力市场的新支柱[④]。中巴两国都有加快发展风电的强烈意愿，这为两国提供了重要的合作机遇。

首先是海上风电开发合作。海上风电已成为全球清洁能源发展的新趋势。根据全球风能委员会（GWEC）的数据，2021 年海上风能投资首次超过海上石油和天然气。据世界风电权威媒

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① http://www.gov.cn/zhengce/zhengceku/2022-01/05/content_5666484.htm
② http://com.gd.gov.cn/go/article.php?typeid=38&contentId=21450
③ https://www.investgo.cn/article/yw/tzyj/202104/538945.html
④ http://www.gov.cn/zhengce/2022-06/08/content_5694539.htm

体《风能月刊》的报告，2021 年至 2025 年全球海上风电装机容量预计将超过 70 吉瓦，占风电比重将从目前的 6.5% 飙升至 21%[①]。巴西拥有近 8000 公里的海岸线，海上风电作为最现代化的可再生能源之一，在巴西具有巨大的发展潜力。但是，受制于资金、技术、基础设施瓶颈等因素，巴西海上风电站建设迟缓。目前巴西的风电扩张主要是陆上项目。与陆上风电场相比，建设海上风电场在技术上更复杂、成本更高且建设速度更慢。一般来说，建设一座陆上风电场从开始到实施需要两到三年的时间，成本在 100 万到 200 万美元之间，而建设一座海上风电场需要 5 到 10 年的时间，成本在 1000 万到 5000 万美元之间。中国的投资和技术将有助于巴西发展海上风电项目。近二十年来，随着中国风电技术的快速发展，现已形成完整的海上风电技术产业链，中国的风电建设正逐步从陆上转向海上。截至 2020 年底，中国海上风电累计装机容量位居世界第三，占全球装机容量的 21.6%（徐彬等，2022）。2021 年全球新增海上风电装机容量约 13.4 吉瓦，最大的贡献来自中国，占四分之三，约 10.8 吉瓦[②]。中国海上风电场的设计、研发、制造、安装和运营经验可供巴西借鉴。两国在提高海上风电建设技术、降低成本方面交流合作前景广阔。

二是围绕风电设备的贸易与投资合作。中国是全球最大的风机制造国。中国风电机组产量约占据全球三分之二以上市场份额[③]。据中国可再生能源学会风能专业委员会统计，截至 2020 年底，中国风电机组累计整机出口到美国、英国、法国、澳大利亚等 38 个国家和地区，遍布全球六大洲，出口台数共计 2728 台，累计容量达到 637.4 万千瓦。此外，作为全球最大的风电装备制造基地，中国发电机、轮毂、机架、叶片、齿轮箱、轴承等零部件产量占全球产量的 60%—70%[④]。作为巴西风电设备的主要进口来源国，中国一直是巴西风电供应链中重要的贸易伙伴。随着巴西经济在新冠感染后迎来绿色复苏，预计其国内风电规模将加速扩张，这为两国在风电领域深化绿色贸易提供了良好机遇。此外，对于中巴两国来说，围绕风电供应链开展的投资合作也将是双赢的选择。巴西国内政策鼓励在本地生产风电设备。2013 年起，巴西要求风力涡轮机的本地生产化率达到 80%[⑤]。当前中国的风电发电技术装备（长叶片、高塔架应用）、产业链均达到国际先进水平，中巴在风电领域的投资合作既有利于加快巴西风电建设步伐、促进当地制造业发展和就业，对中国企业来说，在巴西建设供应链也有助于提升风机产品的本土竞争力。

① https://ocean.cctv.com/2022/03/23/ARTIAi2y5lbzjYlF8fClwtdE220323.shtml
② http://www.nea.gov.cn/2022-01/21/c_1310437803.htm
③ https://news.bjx.com.cn/html/20220104/1197316.shtml
④ http://tradeinservices.mofcom.gov.cn/article/yanjiu/hangyezk/202204/133031.html
⑤ http://br.mofcom.gov.cn/article/jmxw/202205/20220503315415.shtml

三是陆海交通物流合作。根据《巴西国家能源计划 2050》，目前巴西发展风电建设的一大障碍是运输问题。风电设备主要有风力发电塔、风力发电机舱、风电桨叶等大型设备，都属于超长、超重、超宽、超高的组件。当前巴西国内大部分地区（包括风能资源丰富的东北地区）交通基础设施依然不能为风电设备提供稳定的运输。未来随着巴西风电场规模升级，风电设备尺寸和重量还将持续增加，风力发电设备运输的瓶颈问题成为制造商和企业家关注的重点。不仅陆路运输困难，即使是海运也无法彻底解决该问题。在巴西，项目工作进度可能因船舶无法进行沿海航行而延误。对于陆上风电项目，巴西现有的港口基础设施与风电组件的规模相比不足或规模过小。而对于物理尺寸更大的海上风电项目，将零部件从制造现场运输到风力涡轮机组装区的过程则更为复杂和困难。中国和巴西在海陆交通方面的合作有助于解决巴西风电建设中的物流问题。两国既能以提高运输承载力为目标加强道路和港口基础设施建设合作，也能在大型风电装备运输方式方法方面加强交流，例如，中国目前已解决大型风电叶片在山区和狭窄道路运输的难题。创新的运输方式将有利于巴西破解风电物流难题。

4.4 核能

核能是国际能源合作的重要组成部分，在人类应对气候变化挑战的情景下，发展核电作为清洁技术对减少碳排放尤其具有重要作用。

核能可以从核裂变、核衰变和核聚变反应中获得。目前，绝大多数核电电力是由核电站中铀和钚的核裂变产生的。关于核能的争论一直都存在。支持者认为，核能是清洁又高效的能源。像美国这样的核技术先进国家，核能已成为最大的清洁能源来源。核电站每年可发电近 8000 亿千瓦时，生产了该国一半以上的零排放电力。这使美国每年可以避免 4.7 亿多公吨的碳排放，相当于减少了 1 亿辆上路汽车。来自核反应堆的热能也可以用作当今电网中最可靠的能源。此外，核能的发展可以创造更多的就业机会。核电厂工人普遍享有远高于当地平均水平的薪酬待遇，他们纳税并为当地经济发展做出贡献。此外，核能的和平开发利用事关国家安全。强大的民用核能有利于国家的和平与稳定。

然而，反对核能发展的声音从未止息。核能的安全利用是最具争议的问题。2011 年 3 月，日本东北部太平洋发生里氏 9 级地震，引发福岛第一核电站核泄漏事故。此后十年里，核废水处理一直是困扰日本的一大难题。当日本政府宣布将福岛第一核电站储存的核废水排入海洋时，引起了包括日本民众在内的全世界的争议。在白俄罗斯和乌克兰，今天仍在处理核事故的后果，持续监测辐射水平、清理土壤污染物以及为受辐射的人提供康复服务。此外，作为电力商品，核电的成本是影响其竞争力和长远发展的重要因素。核电站的建设和运营成本很高。

核电初期投资大，建设成本可占总成本的 50% ~ 70%。相比之下，火电的建设成本占比仅为 20% ~ 30%。核电的建设周期也更长。核级设备对设计、材料和制造工艺的要求比常规设备更高，因此核电站从前期规划到投产通常需要 5 至 7 年的时间[①]。高资本成本、严格的许可和监管批准，加上交货时间长和施工延误，对核电在电力市场上的竞争力造成了不利影响。

基于以上讨论，中巴在核能领域的合作应重点围绕两个问题：一是如何提高核能利用的安全性？ 二是如何降低核电建设和运行成本？

从技术角度看，中巴应积极开展第三、四代核电技术交流。核电站技术主要可分为四代。第一代技术是实验性核电站，其主要目的是通过试验示范形式来验证核电在工程实施上的可行性。该实验装置如今已基本退役；第二代核电技术的安全性优于第一代，但严重事故处理措施仍然薄弱；第三代核电技术是当前主流，安全性更高、工期缩短、寿命延长；以防止核扩散为目的的第四代核电技术是核废料最少、安全性和经济性最高的技术。

当前，中国通过关键原材料、设备的自主研发，已经掌握了具备完全自主知识产权的第三代核电技术并实现了核电出口。“华龙一号”（HPR 1000）在国内外共有 4 个机组实现并网发电，得到了用户的认可。中核集团同包括拉美的巴西和阿根廷在内的 20 多个国家和地区建立了核电项目合作意向。中国第四代核电技术也取得了突破。随着世界首座球床模块式高温气冷堆项目的成功实施，中国研制出具有自主知识产权的第四代核电机组。

巴西也是世界核能技术开发利用的重要国家。2000 年，在美国能源部的倡议下，巴西、美国、英国、瑞士、南非、日本、法国、加拿大、韩国和阿根廷等十个有意发展核能的国家，共同组建第四代国际核能论坛（GIF），同意合作研发第四代核能系统。巴西在与世界传统核技术领先国家的合作中积累了丰富的经验。中巴加强核利用交流合作，有助于相互借鉴经验，共同为应对全球气候变化挑战、促进世界低碳发展作出贡献。

从经济角度进行分析，中国和巴西在核电站建设运营及核燃料开采和贸易方面具有潜在的合作机遇。中国企业虽然不是巴西传统的核电站建设者和运营商，但凭借发电效率更高、成本更低的第三代和第四代核能技术，未来可能在巴西市场占有一席之地。

新冠感染导致巴西安格拉 3 号机组建设推迟至 2027 年完成。根据巴西 Eletronuclear 电力公司的消息，巴西将在 2023 年前为该机组找到合适的建设者和运营商，潜在合作伙伴包括中国企业[②]。

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① https://news.bjx.com.cn/html/20180619/906674.shtml

② https://www.cnnpn.cn/article/19686.html

此外，中国和巴西在铀矿开采和贸易方面具有巨大的合作潜力。巴西铀矿资源非常丰富，探明储量约 30.9 万吨，但仅有少量被开采利用。中国铀资源对外依存度高，主要从哈萨克斯坦、乌兹别克斯坦、加拿大、纳米比亚、尼日尔和澳大利亚等国家进口。

随着中国核电产业的扩张，对高品质铀的应用需求将持续增加，拓展同巴西的铀贸易有利于中国能源进口多元化。此外，中国开发的以“CO_2+O_2”地浸采铀工艺为标志的第三代绿色铀矿开采技术，具有低成本、高效率、环境友好的领先优势。资源和技术的互补为中巴深化铀资源开发利用提供了可能。

4.5 生物质能

巴西是世界上仅次于美国的第二大乙醇生产国，也是全球拥有乙醇燃料汽车最多的国家。中国是世界上最大的汽车燃料市场。

如前所述，巴西在推广生物燃料方面已有很长历史。甘蔗乙醇和生物柴油行业得到整合，国家生物燃料政策计划为生物质能发展提供了新的动力。巴西目前已推出重要的先进生物燃料计划。

尽管中国交通脱碳的主要选择是电动汽车，但生物燃料也与脱碳具有一定相关性。2017 年，中国政府曾要求在汽油中添加乙醇并且其含量预计在 2022 年达到 10%。但是，出于对玉米价格上涨的担忧，该命令实施起来困难较多。如今乙醇混合物在中国汽油中占比约为 2%。

潜在的生物质能合作伙伴关系有利于加强国际贸易。由于甘蔗乙醇产生的二氧化碳排放量低于玉米乙醇，因此巴西乙醇具有环境友好的优势。此外，甘蔗乙醇对食品供应的影响较小。当前中国主要进口来自美国的玉米乙醇（Pratt，2021）。

巴西和中国在生物燃料技术领域合作前景广阔。先进的生物燃料很可能提高生产力，克服目前使用生物燃料所面临的障碍（尤其是生物燃料与粮食生产的竞争）。巴西在生物燃料开发方面处于领先地位，而中国的技术能力可以为巴西提供更多助力。两国共同参与的生物期货平台可以成为双方合作的起点。

4.6 氢能

中国是世界上最大的氢生产国，拥有大规模的绿氢能项目。中巴在发展绿氢能产业方面可开展包含电网集成、电力市场发展、电力系统灵活性、促进行业能源效率在内的可再生能源系统集成项目。通过签署生物能源合作谅解备忘录，双方可在可再生能源研发方面进行合作。巴西和中国均已加入金砖国家能源研究合作平台，两国负责开发氢能领域适用技术的研究小组可开展相关合作。

五、建议

绿色能源对中国和巴西来说都至关重要。如果能深化双边合作，不仅两国人民可以从中获益，而且可以产生溢出效应，加速双方向绿色经济过渡。

在绿色能源双边合作中建立相应实体。中巴两国应努力建立这样的授权实体，借助中国 - 巴西高层协调与合作委员会(COSBAN)，建立绿色能源的基础框架，整合资源并实现信息共享。该实体的职责是规划两国绿色能源的发展路线，并传递绿色能源转型的信号。该实体将成为完善法律法规的推动者或倡导者，营造良好的法制环境，更好地反映企业和消费者的需求，更准确地解释特权和义务，这将成为帮助国内外投资者进行决策参考的因素之一。

作为国际舞台举足轻重的参与者，中巴两国的举动值得被关注，国际社会也应该听到中巴两国在绿色能源方面的声音。尽管供应链环节的电力设备部署是各国的内部事务，加强国际合作，也可以让各国发挥各自优势，从原有的模式中降低成本，提高效率。

发展论坛，汇聚可再生能源和清洁能源的研究和技术开发机构。两国都有在绿色能源领域拥有丰富经验的机构（如大学和研究中心），因此，通过国际论坛分享双方的经验将有助于解决共同的技术挑战，扩充双方的知识库。

弥合绿色能源不同利益相关者之间的差距，促进决策。绿色能源涉及范围比较广泛，发展迅速，因此充分了解进展情况，判断其未来发展趋势，将对社会大有裨益。由于政府干预与市场调节存在时滞现象，及时交换不同利益相关者的意向和意见对于相关措施的协调和校准非常重要，减少相关政策的摩擦和成本的政策法规有助于缩短此类时滞。事实上，政府与市场之间存在双向互动，做好政府工作必须充分倾听市场的声音，建立收集市场期望和需求的机制，特别是在中国和巴西企业的绿色能源双边合作方面。绿色能源全链条还应包括教育、金融、基础研究甚至法律和咨询。调动和整合利益相关者，需要认识到合作的重要性和有效性，首先要做到信息交流，从而以更有效的方式做出决策。

协调发展绿色能源和传统能源，增强供应链韧性。传统能源向绿色能源转型需要更多助力，提高社会对转型重要性的认识将有助于向绿色能源转型。当能源供应超过需求时，企业之间的竞争不可避免。在新冠感染的影响下，全球供应链受到重创，目前油气价格居高不下，绿色能源蓬勃发展获得重要推动力，为新生的绿色能源发展创造了空间。中国和巴西都是世界较大经济体，这意味着在不同领域存在较多差异。因此有必要建立一些试验区，对这些试验区的电网等基础设施进行改造和改进，以降低实施能源转型的成本。随着越来越多的企业涉足绿色能源，试验区的优势将更加突出，不仅可以通过更多低成本的应用来降低传统能源

的转型成本，也可以为其他企业树立良好的榜样。依托试验区，绿色能源转型的推进将更加顺利。

引导消费者选择绿色能源家用设备和设施。总体而言，中国消费者乐于接受新的生活方式，巴西消费者则享受不同文化的互动。但是，消费者需要理由来改变其消费习惯，为了引导消费者替换传统能源设备，需要开展系统性部署工作。首先，中国和巴西都可以倡导绿色能源的意义，并提供转型设备挑选指南。发布的绿色能源标准和准则可以基于一个规则体系，使消费者在选择绿色能源产品和服务时更有信心。同时，擅用明星效应，对于引领转型新风向也很重要。通常在转型初期，消费者可能会为使用新产品支付更多费用，因此，可以通过提供完善的售后服务体系，加快产品更新换代进程，降低消费者使用绿色能源产品的成本和门槛。也可以利用社交媒体等平台，为中巴消费者提供更多的沟通渠道，帮助其分享购物体验甚至发起投诉，让绿色能源设备制造商及时调整设计和功能，吸引更多消费者。

鼓励研究更先进、适应性更强的技术，有效利用绿色能源。推动绿色能源的重点包括技术开发和商业化，这两个过程可以从两个方面来加强。商业化不仅是技术的试验场，也为技术升级提供导向、指出需求。虽然企业会主动开展技术研究，但基础研究大多是非营利性的，需要政府的支持。中国和巴西都具备开发某些绿色能源的能力，因此合作研究也可以成为推动两国绿色能源发展的重要推动力。合作形式可以多样化，例如，巴西的研究机构可以与中国的投资者或公司合作，或以两国研究机构合作的方式，确定重要课题，共同寻找解决问题的方法。中国拥有相对完善的制造体系，这有助于将产品从实验室转移到真正的市场。随着新理念、新材料和新技术融入产品的生命周期，可以通过更大的市场和更多的消费者来提高绿色能源的应用效率，中巴企业的合作优势也由此得以体现。