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Review

China and Italy's Energy Development Trajectories: Current Landscapes and Future Cooperation Potential

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Abstract: In order to achieve the ambitious goal of "carbon neutrality", countries around the world are striving to develop clean energy. Against this background, this paper takes China and Italy as representatives of developing and developed countries to summarize the energy structure composition and development overview of the two countries. The paper analyzes the serious challenges facing the future energy development of both countries and investigates the possibilities of energy cooperation between the two countries, taking into account their respective advantages in energy development. By comparing the policies issued by the two governments to encourage clean energy development, this paper analyzes the severe challenges faced by the two countries' energy development in the future and combines their respective energy development advantages to look forward to the possibility of energy cooperation between the two countries in the future. This lays the foundation for China and Italy to build an "Energy Road" after the "Silk Road".

Keywords: fossil energy; renewable energy; hydrogen energy; power generation

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1. Introduction

Since COVID-19 broke out in 2019, the economic development of countries around the world has suffered a great deal [1]. To solve the problem of the economic downturn, countries are paying more attention to energy development. However, traditional fossil energy reserves are limited, and economic development requires large amounts of energy to support it, resulting in a series of complex problems such as an energy crisis and environmental pollution [2]. For this reason, all countries in the world take achieving "carbon neutrality" as the primary strategic goal in formulating energy development strategies, focusing on the efficient development of green, low-carbon, and clean energy. Taking the energy strategic development of developed and developing countries as a representative, not only can we summarize the current energy development status but also clarify the future energy development path.

Due to its rapid economic expansion, China, as a prominent representation of emerging nations, will undoubtedly substantially affect global energy development. China is one of the world's largest energy producers and consumers, accounting for over 24% of the global total energy consumption. Because of its special resource endowment, China's energy production has long been dominated by coal, which accounts for nearly 70% of the total energy consumption. As of 2020, coal accounts for 57% of primary power generation in China [3], with an installed capacity of thermal power units of up to 55.85% [4] and energy-related carbon emissions of 10 billion tons, or about 30% of the world's [5]. Among them, thermal power units above 0.3 GW account for 90% of the total installed capacity, meaning that the thermal power generation mode still occupies the dominant position in the power system [6]. However, China has limited coal resource reserves and more obvious geographical restrictions, with major production areas including Shanxi, Inner Mongolia, Shaanxi, Hebei, Shandong, and other provinces [7]. Long et al. [8] pointed out that the economic development of coal mining cities in China depends mainly on the coal resources in the region, and when the coal resources are not developed properly, the economic situation of the cities will be seriously affected.

In addition, with the development of thermal power generation technology in China, not only a large number of thermal power generating units have been built in China, but in December 2002, China started to build coal-fired generating units abroad [9], exporting thermal power generation technology to the world. However, with the operation of coal-fired units, more and more problems have emerged, the first of which is the problem of fossil energy reserves. Although China's coal reserves have reached 190.9 billion tons, including 136 billion tons of proven reserves [10], fossil energy is a non-renewable energy resource, and long-term dependence on fossil energy will cause a severe energy crisis. At the same time, burning coal will produce many pollutants, such as CO_2 and NO_X, which will seriously impact the atmosphere, water, soil, and other environments and hinder the goal of "carbon neutrality" [11]. Abbasi et al. [12] pointed out that China is the world's largest CO_2 emitter, accounting for approximately 29.4% of total emissions. In order to achieve the grand goal of "carbon neutrality" by 2060, China is also actively developing clean energy and striving to complete the transformation of their energy structure as soon as possible.

In order to reduce carbon emissions, improve energy efficiency, promote economic growth, and avoid increasing the country's energy security risks due to excessive reliance on coal-fired power development, China has vigorously promoted the development of renewable energy in recent years [13,14]. China has a vast territory and abundant natural resources [15]. In 2017, China already had more installed renewable energy capacities than any other country in the world, including wind, solar, and hydro [16]. China is rich in hydropower resources, accounting for nearly 70% of the total installed capacity of renewable energy in China. By the end of 2020, hydropower's installed capacity and power generation reached 16.8% and 17.1%, second only to the proportion of thermal power generation [17]. China leads the world in technology and construction experience in hydropower and has built a series of large-scale hydropower stations and water conservancy projects, such as the Three Gorges hydropower station, the Yangtze River's middle and lower reaches hydropower station group, and the Yellow River Basin water conservancy projects [18].

China is also very rich in wind power resources and is one of the ideal countries for wind power development and utilization. The installed capacity of wind power in China has been increasing yearly. As of the end of 2020, the installed capacity of wind power in China has reached 280 GW, accounting for nearly 40% of the global total installed capacity [19]. At present, China is still vigorously developing offshore wind power projects. As of 2023, China has formed an entire offshore wind power industry chain, with an installed capacity of over 30 GW, maintaining the world's first place. Although the development of wind power in various countries around the world has been affected by global climate change factors, with the continuous improvement of wind energy technology and the unique climate conditions in China, the installed capacity of wind power will continue to increase in the future. Therefore, many scholars, such as Liu et al. [20], have assessed the impact of land cover and airflow change on China's wind power development and proposed solutions based on the assessment results.

In addition, China has also closely followed the pace of energy development in various countries worldwide, vigorously developing solar energy and becoming one of the largest photovoltaic markets in the world. As of the end of 2021, China's installed capacity of photovoltaic power generation has reached 306 GW [21], and it is expected that by 2030, their solar power generation will reach at least 400 GW, accounting for nearly 70% of the global total installed capacity [22]. All things considered, China's solar energy industry has entered a phase of fast expansion, with leading and supporting businesses in various fields, from solar cells and components to system integration, operation, and maintenance, creating an all-encompassing industrial system [23]. There are also a large number of scholars, such as Jing et al. [24], who used global solar radiation distribution data to establish a calculation method for the optimal tilt angle of PV systems, thus obtaining the spatial distribution of the optimal tilt angle and greatly improving the development of solar energy utilization in China.

Although China has made some achievements in the field of renewable energy, it is still difficult to meet the rapid growth of future energy demand via renewable energy alone. Moreover, there is serious instability in renewable energy [25], and the geographical area will restrict the development of renewable energy which cannot be applied to the whole country. Therefore, the Chinese government is actively promoting hydrogen energy technology development and considers it one of the important directions for future energy development [26].

With the advantages of high energy density, clean and pollution-free qualities, and easy storage, hydrogen energy can be used as a vital energy alternative and provides a new solution to future energy security and environmental pollution problems [27]. However, China has not yet formed a complete hydrogen energy industry chain. In response to this issue, Gao et al. [28] constructed a system dynamics model for the development of the hydrogen energy industry chain, simulating the development of China's hydrogen energy industry chain from 2016 to 2030 in order to obtain the best way for the sustainable development of the hydrogen energy industry chain. Zhang et al. [29] also analyzed the future development direction of hydrogen energy based on resource reserves and economic policies in various provinces in China, providing new ideas for further optimizing the direction of hydrogen energy development.

Among the many developed countries in Europe, Italy has numerous ports in the Mediterranean region. This unique geographical location makes its trade with other countries very prosperous, making it one of the significant economies in Europe [30]. In economic exchanges with many countries, China and Italy have had trade since the ancient Silk Road period, so the energy development between China and Italy is also closely related. Understanding Italy's energy development can provide insight into energy policies and future cooperation between countries.

Coal power used to have a significant role in Italy's energy structure. However, in recent years, due to climate change and environmental protection pressures, the Italian government has gradually reduced its reliance on coal power [31,32]. According to data from Terna, the Italian TSO, coal-fired power plants in 2019 had a total capacity of 7.896 GW, accounting for 12.8% of all fossil-fired power plants. The installed capacity fueled with natural gas accounted for over 72% of all fossil-fired power plants. Those figures have not changed significantly in 2023, although in 2022, 2 GW more coal-fired plants had been phased out. The overall coal-fired capacity in 2022 was less than 5% of the overall fossil-fired and renewable capacity. Generated electricity from coal in 2022 was slightly higher than 6% of the total. Although this proportion is relatively low, the share of coal-fired power has decreased yearly due to the rapid growth of natural gas and renewable energy. In 2018, the Italian government announced plans to phase out coal power completely by 2025 [33]. To achieve this goal, the government has introduced a series of measures, including restrictive measures for coal-fired power plants and a focus on supporting renewable energy development [34]. In addition, the government encourages the promotion of energy efficiency technologies to reduce energy consumption and carbon emissions. Despite progress in phasing out coal-fired power, Italy still faces significant energy structural challenges, according to Bersano et al. [35]. Rising natural gas import prices mean that Italy needs to undergo an "energy transformation".

In recent years, Italy has experienced a significant shift towards renewable energy, mainly due to the decline in the use of coal. The country has abundant natural resources such as sunlight, hydropower, wind power, and biomass, which make it an ideal place for developing renewable energy [36]. Italy is among the countries in Europe with ample hydropower resources, and hydroelectric power has always been a crucial source of renewable energy in the country [37]. According to data from Terna, in 2021, Italy's total installed capacity of hydroelectric power reached 22.9 GW, accounting for approximately 19% of the country's total installed capacity [38]. The Alps region stands out as one of the most important hydroelectric power regions in Italy, with a large number of hydroelectric power stations and reservoirs, making a significant contribution to the country's electricity supply. Recent studies have also shown that glacier melting affects hydropower production in Italy, and reducing the amount of water wasted by glaciers can improve the efficiency of energy production [39].

With the continuous development of renewable energy technology, other types of renewable energy such as solar and wind energy have also received increasing attention [40]. Italy was one of the earliest countries in Europe to develop solar technology, and its solar power industry has made significant progress in the past few decades [41]. As of 2022, Italy's solar installed capacity has reached 25.1 GW, accounting for approximately 20% of the total installed capacity in the country. Ascione et al. [42] and Rosato et al. [43] respectively conducted energy modeling for a residential area in Naples, studied the impact of using photovoltaic power generation on energy consumption and power generation costs in the area, and optimized the results, proposing plans to promote photovoltaic power generation and reduce power generation costs. With the continuous development of solar technology and the continuous decrease in costs, solar power generation will play an increasingly important role in the energy structure of Italy and the world. Italy's wind power scale is relatively small compared to the rapid development of hydropower and solar power generation [44]. As of 2022, Italy's installed wind capacity is about 11.8 GW, and its proportion in the domestic energy structure still has room for improvement. Contestabile et al. [45] collected a large amount of meteorological data from Italy to identify the most suitable nearshore wind farm construction plan.

Italy's hydrogen energy development is still in its early stages compared to China's current progress [46]. Although the Italian government has increased investment in hydrogen technology, its progress is still relatively lagging compared to other European countries [47]. Italy currently focuses on the research and application of hydrogen in heavy-duty vehicles and vessels and the hard-to-abate industry (steel and chemicals are among the most important). Hydrogen energy, as a renewable energy source that can achieve energy storage and transfer, has a broader application prospect in the context of energy transformation [48]. However, it should also be noted that hydrogen energy technology still has some challenges and limitations. Therefore, Italy still has much room for improvement in promoting the development of hydrogen energy. For example, Liponi et al. [49] conducted a study on the possibility of utilizing the Italian power grid to produce green hydrogen while considering the cost of production. In the future, Italy's hydrogen energy technology is expected to play a more significant role in contributing to domestic and global energy transformation.

This paper provides an overview of energy development in China and Italy from three perspectives: traditional thermal power generation development, renewable energy utilization, and hydrogen energy development. In the global response to the challenges of climate change and energy security, all countries strive to promote the development and application of clean energy technologies to reduce dependence on fossil fuels and carbon emissions. As representatives of both developing and developed countries, comparing the energy development status of China and Italy can provide a better understanding of the achievements of both countries in the energy transition and how they are addressing the challenges to achieve a cleaner, sustainable, and secure energy future. At the same time, it points out the direction for future energy cooperation between the two countries, promotes the development of energy cooperation between China and Italy, and lays out an energy road following the Silk Road.

2. Development of Traditional Fossil Energy

Coal is the most typical fossil energy and one of the earliest energy sources applied by humans in industrial development. Since the Industrial Revolution, coal has become one of the important sources of economic development for countries around the world.

2.1. Overview of Coal Power Development in China

The history of China's coal power development can be traced back to the 1950s, when China began a large-scale construction of coal power plants. In the 1970s, coal-fired power stations accounted for over 80% of the country's total electricity generation. However, in the late 1980s, China began to explore diversified energy development paths, including nuclear energy, hydropower, wind energy, etc. The proportion of coal-fired power in the total national electricity began to decline [50].

The annual growth rate of thermal power generation in China from 2001 to 2020 is shown in Figure 1. As shown in the figure, with the continuous growth of China's economy and the acceleration of urbanization, the position of coal-fired power in China's energy structure has once again risen [51]. In 2011, the proportion of coal-fired power in China's total electricity has rebounded to over 70%. As of the end of 2020, the installed capacity of China's thermal power generation units has reached 1060 GW [52]. From 2014 to 2015, due to economic development and other reasons, there was a negative growth in thermal power generation that year. Subsequently, the government introduced a series of policies, which led to a resurgence in thermal power generation. However, with the increasing development of coal-fired power, the first and foremost issues of environmental pollution and carbon emissions are becoming increasingly prominent. Although coal resources are relatively abundant in China, coal mining and use have caused many problems in terms of protecting and ensuring the sustainable utilization of coal resources [53]. The extraction and transportation of coal resources require a large amount of manpower, material resources, and financial investment, which has also brought many negative impacts on the environment and social stability [54]. At the same time, the release of SO_2, CO_2, and NO_X from coal combustion has also caused significant pollution to the environment [55]. Therefore, China has gradually reduced the proportion of coal-fired power, and the growth rate of thermal power generation has been decreasing year by year, while vigorously promoting the development of clean energy.

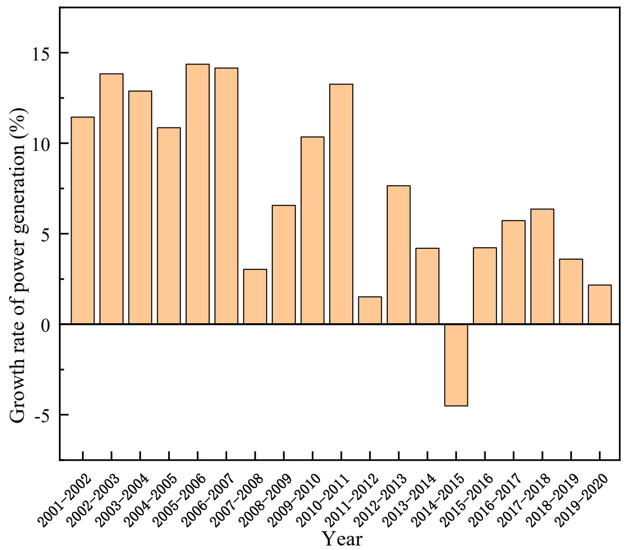

Figure 1. The annual growth rate of thermal power generation in China from 2001 to 2020.

China has made many efforts to diversify its energy structure. For example, the government has set the goal of increasing the proportion of non-fossil fuel sources in the national energy structure to 20% by 2030, reaching the peak of carbon emissions by 2030, and striving to achieve "carbon neutrality" by 2060 [56]. As of 2021, although China's coal-fired power generation still accounts for about 55% of the country's total electricity generation [57], the generation of clean energy is also constantly increasing, especially the scale of wind and photovoltaic power generation, which has surpassed many developed countries. The Chinese government has also taken a series of measures to strengthen the environmental governance of coal-fired power generation, including strengthening the technical equipment for desulfurization, denitrification, and dust removal in coal-fired power plants, as well as gradually phasing out old high energy consumption and high pollution thermal power generation units. A large number of scholars, such as Sammarchi et al. [58], have conducted emissions decarbonization research on thermal power units in Inner Mongolia, China, aiming to reduce CO_2 emissions by 90% during the lifecycle of the decarbonization system.

However, the "energy structure transformation" will take some time, and the development and use of coal still play an important role in China's growing energy demand [59]. In order to address this challenge, it is first necessary to design and reduce pollutant emissions, gradually phasing out outdated and inefficient power generation units, and secondly, to improve the power generation efficiency of thermal power generation units and design high-quality electricity consumption methods [60]. In addition, China has invested a lot of research in the technology of capturing and storing carbon emissions from coal-fired power plants. Effectively using carbon capture technology and designing reasonable carbon storage methods can not only significantly reduce CO_2 emissions but also improve energy utilization efficiency and avoid energy waste [61].

Although China's dependence on coal will remain to be short term, with the implementation of various energy conservation and emission reduction measures, as well as the development of renewable energy in China, in the near future, China's coal-fired power generation will significantly decrease, being replaced by cleaner, more efficient, and sustainable energy supply methods.

2.2. Overview of Coal Power Development in Italy

Italy is a country that is not very rich in fossil energy resources, and most of its energy relies on imports, with long-term dependence on natural gas being the main source of its imported energy [31]. However, due to factors such as the Ukrainian war and the damage of the Nord Stream pipeline, the price of natural gas has experienced significant volatility since 2021 [32]. At the same time, with an unstable supply and cost of natural gas, Italy urgently needs to develop other energy sources to meet national demand and future development.

The composition of Italy's national installed capacity is shown in Figure 2. From the figure, it can be seen that although the installed capacity of fossil fuels is still large, with the development of various cleaner and more efficient power generation methods, Italy has gradually reduced its dependence on coal [62]. Cleaner power generation methods are actively and steadily developing, and power generated by renewable energy sources is between 35% and 40% depending on the use of hydropower [35]. Currently, Italy no longer builds coal-fired power generation units to generate electricity. Most natural gas-fired plants are high-efficiency combined cycles and industrial cogeneration systems. According to the statistics, the number of coal-fired power stations in Italy has decreased from 50 in 1992 to 11 in 2019, and it is planned that the last coal-fired power station will be shut down in 2025, ending Italy's centuries of coal-fired history. The reason for this trend is that, first, due to the environmental pressure imposed by the EU's policies, all countries need to accelerate the realization of the goal of "carbon neutrality"; second, compared with fossil energy with high prices and unstable sources, actively developing cleaner renewable energy is the long-term development goal in the future.

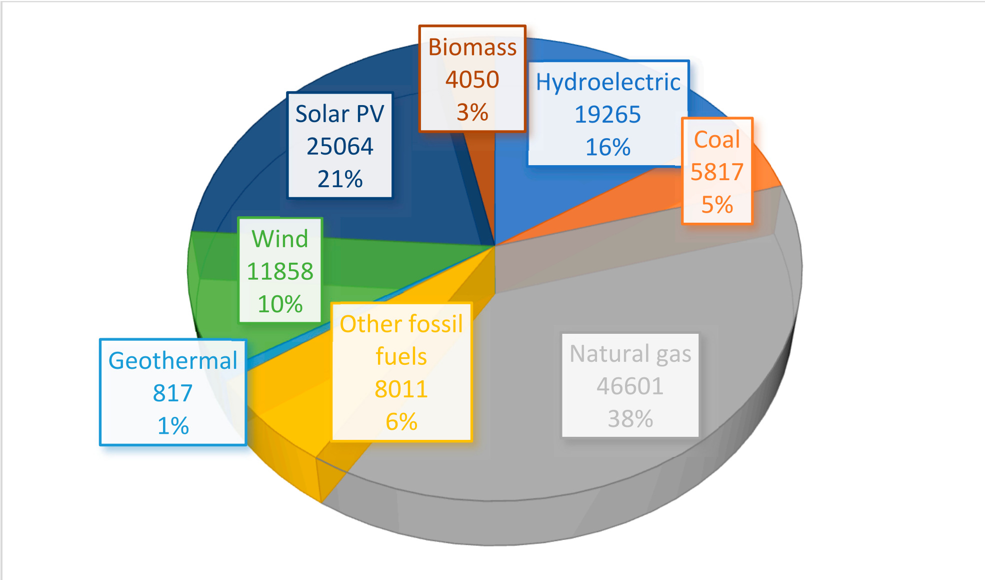

Figure 2. Sources of installed capacity in GW Italy.

Although the development of the coal-fired power industry has encountered severe challenges, Italy has taken measures to alleviate this situation to meet the energy supply needs of economic development. For example, they have promoted the use of renewable energy and have encouraged the renovation or replacement of existing coal-fired power units to meet new market demands. In addition, the government is also striving to promote the development of a low-carbon economy in the country in order to expand new opportunities during the transformation process [63,64].

Overall, Italy is gradually reducing its dependence on fossil fuels and increasing the use of renewable energy. Due to the requirements of the EU's energy policy, Italy also urgently needs to accelerate the completion of "energy structure transformation", vigorously develop clean energy on the premise of ensuring its economic development, and strive to achieve the emission reduction target of "carbon neutrality" by 2060 [65].

3. Development of Renewable Energy

Although China's energy development is already in a leading position in the world, Italy's development in the field of renewable energy cannot be underestimated, considering the share of the overall generated power. Both countries have recognized the importance of clean energy and increased investment in the corresponding fields.

3.1. Overview of Renewable Energy Development in China

The history of renewable energy power generation in China can be traced back to the early 1980s, when the Chinese government launched the first batch of renewable energy projects, mainly including hydropower, wind power, and solar power generation. With time, the scale of renewable energy generation in China continues to expand, and the technological level and economic benefits have also been significantly improved [66,67]. Currently, China accounts for 28.2% of its total energy consumption and is one of the largest countries in the world in terms of renewable energy generation [68], with its total renewable energy generation capacity exceeding 900 GW, of which hydropower, wind, and photovoltaic are the three primary sources.

Hydroelectric power has always been the main source of renewable energy in China [69], accounting for over 60% of the country's installed capacity of renewable energy [70]. China has abundant hydropower resources, which are widely distributed throughout the country. Many large hydropower stations have been built, such as the Three Gorges hydropower station and the Yangtze River hydropower station which was built during the Great Leap Forward [71]. According to data from the National Energy Administration, as of 2022, the installed capacity of hydroelectric power generation in China is 413.5 GW, an increase of 22.58 GW compared to the same period last year and a year-on-year increase of 5.8%. The development of hydropower in China has entered a peak period, and the construction scale of large-scale hydropower stations is expanding year by year. At the same time, the technological level of hydropower in China is constantly improving, and more and more new technologies are being applied to the construction and operation of hydropower stations, utilizing the flexibility of hydropower peak shaving to cooperate with wind and solar power grid connections [72]. While increasing the installed capacity of hydropower, the country is also actively addressing environmental damage and immigration issues caused by hydropower development [73]. Many scholars have begun to study the construction of small hydropower stations in water-rich areas in southwestern China, the rational use of natural resources, and the avoidance of new economic and environmental problems caused by excessive hydropower development [74]. With the continuous maturity of hydropower technology, China's hydropower installed capacity will inevitably reach new heights in the future, becoming an indispensable part of China's renewable energy generation technology.

In addition, benefiting from China's unique geographical location, the development of wind power is also becoming increasingly mature. As early as the late 1980s and early 1990s, the Chinese government began implementing new energy policies and listed wind power as one of the key development projects. With the advancement of technology and policy support, China's wind power industry is gradually developing and growing.

In the early 1990s, China introduced wind power generation technology and built some small-scale experimental wind farms. The scale and installed capacity of these wind farms are relatively small, but they have laid the foundation for the development of wind power in China. At the beginning of the 21st century, the Chinese government began to strongly support the development of wind power, and the installed capacity of wind power has been increasing day by day [75]. As of 2022, the installed capacity of wind power is about 370 GW, an increase of 11.2% year on year. The technological level and equipment manufacturing capacity of China's wind power industry are still continuously improving. In recent years, in order to better fully utilize energy, China has also vigorously developed offshore wind power projects, and a large amount of research has provided favorable theoretical support for wind power site selection in China's coastal waters [76]. With the further advancement of China's energy restructuring and new energy policies, China's wind power industry has entered a phase of transformation and upgrading. Government policies to encourage the development of renewable energy have been introduced [77], including measures such as increasing the feed-in tariff for wind power and coupling wind power generation with other renewable energy generation, thereby reducing the impact of wind power fluctuations on the power grid [78], driving China's wind power industry toward gradual maturity. In the future, China's wind power will continue to move toward scale and intelligence, becoming an important component of China's energy structure adjustment and sustainable development [79].

With the increasing attention to environmental protection and carbon emissions in recent years, China is also accelerating the development of solar power generation [80]. The development history of solar power generation can be traced back to the 1970s, when China began to develop solar cell technology and built some small solar power plants. With the advancement of technology and policy support, China's solar energy industry is gradually developing and growing. Currently, China's solar photovoltaic installed capacity exceeds one-third of the global total solar photovoltaic installed capacity, becoming a global leader in solar photovoltaic power generation [81]. At the beginning of the 21st century, the Chinese government began to strongly support the development of solar power generation. In 2005, China's installed solar power capacity was only 0.07 GW, but it has grown rapidly since then. According to data from the National Energy Administration, as of the end of 2022, the installed capacity of solar power generation is approximately 0.39 GW, a year-on-year increase of 28.1%. With the development of solar power generation technology, the power generation capacity of China's solar thermal power station cannot be underestimated. As of

July 2022, Qinghai Zhongkong Delingha 0.05 GW solar thermal power station announced that the power generation capacity of the station reached 0.7552 GW, exceeding the annual design power generation one month ahead of schedule, becoming the first tower-type molten salt energy storage solar thermal power station in the world whose annual actual power generation fully reached and exceeded the design power generation. This shows that the development level of China's solar thermal power plants has taken the lead in the world.

In addition, renewable energy sources such as biomass energy and geothermal energy are also receiving more attention and application [82] to further promote the development of renewable energy in China. To sum up, China is actively transforming its energy structure from "thermal power generation" to "clean energy power generation". Its renewable energy power generation technology is gradually maturing. In the future, the installed capacity of renewable energy power generation will also be steadily increased, striving to achieve the great goal of "carbon neutrality" by 2060 [83].

3.2. Overview of Renewable Energy Development in Italy

Italy is a country that relies heavily on renewable energy resources. Italy's renewable energy resources include various forms such as solar energy, wind energy, geothermal energy, hydropower, and bioenergy [84]. In the past few decades, the Italian government has taken a series of measures to encourage the use of renewable energy [85]. In 2008, the Italian government introduced a law called "Conto Energia", which further promoted the development of renewable energy. The law stipulates that the government will provide subsidies to households and businesses using renewable energy to encourage more people to use renewable energy and reduce their dependence on fossil fuels [86]. This measure is no longer effective, but solar and wind energy have reached grid parity due to the reduction in the costs of solar panels and inverters, and for small power plants installed in households, it is possible to benefit from a tax deduction on the capital cost.

Solar energy is one of the most important renewable energy sources in Italy. The country is rich in solar energy resources, and the installed capacity of solar photovoltaic power generation has now exceeded hydropower with 25 GW, accounting for 20% of the total power generation capacity [86]. In 2022, Italy's solar power generation exceeded 28, 000 GW, accounting for 10% of the total electricity generation. In order to further promote the development of solar energy, many scholars in Italy are also actively studying the efficient operation of solar power plants, striving to obtain the high-quality development of solar power generation technology. Abd Alla et al. [87] conducted a study on the climate conditions in southern Italy to identify the most suitable areas for using solar power generation technology and maximize the utilization of solar energy to avoid energy waste. D'Adamo et al. [88] found that based on the current government subsidies for installing photovoltaic systems in residential areas, the economic benefits gained by the country far outweigh expenditures, demonstrating the benefits of vigorously promoting solar energy development.

Italy has abundant wind energy resources, although less than Spain and Northern EU countries, and wind energy has become the third largest renewable energy source in the country. Italy's installed wind energy capacity has exceeded 11 GW, accounting for almost 10% of the total power generation capacity. In 2022, Italy's wind power generation exceeded 20,000 GW, accounting for 7% of the total electricity generation. The Italian government has also introduced a series of policies to encourage wind power generation, and many scholars, such as Clò et al. [89], have found that the economic benefits of using wind power can reduce electricity price fluctuations. At present, Italy is also actively developing offshore wind power projects [90]. Although the development of this technology is still in the ascendant stage, the installed capacity of offshore wind power in Italy is not expected to account for a large proportion of renewable energy generation in the future, since the depth of the seas surrounding Italy is quite high and wind generators have to be floating and anchored at the bottom of the sea with higher costs than fixed ones.

Italy is located in the center of the Mediterranean Sea, with numerous ports throughout the country, making it very rich in hydraulic resources. Hydraulic energy is now the second largest renewable energy source by capacity in the country [91]. At present, Italy's installed capacity of hydraulic energy is around 20 GW, accounting for 15% of the total capacity [92]. In 2022, Italy's hydroelectric power generation exceeded 30,000 GW, accounting for almost 11% of the total electricity generation. The Italian government also encourages the construction of more hydroelectric power plants and has taken some measures to reduce the impact of hydroelectric power on the environment. However, large power plants cannot be built due to the scarcity of valleys and areas that are not inhabited, and the installed hydropower capacity has been the same for decades. Instead, There is some possibility for small power systems and refurbishing decommissioned systems with new hydro turbines. Many scholars, such as Galletti et al. [93], have accurately modeled hydroelectric production around the regional scope of Italy, combined with factors such as climate change, and accurately and efficiently simulated the location and installed capacity of hydroelectric power plants to avoid environmental damage and the waste of renewable energy.

Italy has abundant bioenergy resources and has become one of Europe's largest biomass power generation countries. The Italian government has also introduced a series of policies to encourage biomass power generation, such as implementing fixed subsidies and encouraging the use of biomass power generation. In 2022, Italy's biomass power generation exceeded 17,000 GW, accounting for 6% of the total power generation.

Although Italy is currently experiencing a gradual increase in renewable energy generation, a combination of the country's unique geographical conditions and a comparison of its renewable energy development with that of other European countries shows that there is still a large upside to Italy's renewable energy development and that its natural renewable resources could be used more efficiently [94].

In summary, China has rich experience in developing renewable energy, and its renewable energy generation is also in a leading position globally. Italy has abundant natural resources, and its abundant solar, wind, and hydro energy can be utilized with higher quality. Therefore, in the future, the two countries can strengthen technical cooperation, jointly improve their respective renewable energy development, and work together to achieve the goal of "carbon neutrality" by 2060.

4. Development of Hydrogen Energy

4.1. Overview of Hydrogen Energy Development in China

As a clean energy source, hydrogen energy is gaining more and more attention and importance [95] and is being used in some application fields, such as aerospace and national defense. As the country increases its support for new energy, the development of hydrogen power generation is also gradually advancing. The development history of hydrogen power generation in China can be traced back to the early 1980s, when China's hydrogen technology had already begun to develop. The Chinese government issued the "Guiding Opinions on Promoting the Development of the Fuel Cell Vehicle Industry" in 2017, which set the development goal of reaching a scale of over 10,000 vehicles in the fuel cell vehicle industry by 2020 and an output value of over CNY 150 billion by 2025, vigorously promoting the popularization of fuel cell vehicles [96]. Meanwhile, with the improvement of various links in the hydrogen energy industry chain, China's hydrogen energy industry is undergoing a qualitative leap.

After 2000, China began to strengthen research on and the development of hydrogen power generation technology, gradually forming a hydrogen power generation technology system with fuel cells as the core. In 2003, China successfully developed its first fuel cell unit, achieving a leap from research to industrialization in China. Subsequently, China has launched multiple application fields such as fuel cell vehicles, buses, and heating. In terms of hydrogen vehicles, China has become the world's largest producer and seller, with the production and sales of fuel cell vehicles exceeding 20,000 in 2019. In addition, with the gradual promotion of hydrogen energy applications in industries, electricity, energy storage, and other fields, the scale of China's hydrogen energy market is also expanding year by year [97]. Although China is actively conducting research on hydrogen fuel cell vehicles, there is still significant room for improvement in performance compared to fuel cell vehicles already developed in the United States and Japan [98].

At present, China's hydrogen power generation is in a steady development stage. The government has increased investment in the field of hydrogen energy and actively promoted the application of hydrogen power generation technology. Compared with the application of proton exchange membrane fuel cells in the automotive field, high-temperature fuel cells such as the solid oxide fuel cell and molten carbonate fuel cell are more suitable for large-scale power generation technology, and the high-temperature exhaust gas discharged from them is also more suitable for secondary utilization [99]. A large number of scholars have conducted research on the large-scale power generation technology of high-temperature fuel cells, using fuel cells as the prime mover in distributed energy systems, fully utilizing the exhaust heat of fuel cells, and improving the system's power capacity based on the principle of "energy cascade utilization" [100–102]. China has now formed a hydrogen power generation technology system with fuel cells as the core and hydrogen transmission, distribution, storage, and other supporting facilities as the basis while increasing research and development efforts on hydrogen production, storage, transportation, and use.

In the future, the development of hydrogen power generation in China will focus on industrialization, marketization, and scaling up, accelerating the promotion and application. The government will continue to increase investment in hydrogen power generation, guide and support enterprises to increase research and development efforts, promote hydrogen energy to replace traditional fuels in the energy field, promote China's energy structure adjustment, and promote an industrial transformation and upgrading.

4.2. Overview of Hydrogen Energy Development in Italy

Since the early 1990s, Italy has started researching and developing hydrogen power generation technology. Subsequently, the Italian government released the "Hydrogen Technology Development Plan" in 2003, aiming to encourage the application of hydrogen energy in the fields of transportation, electricity, and industry. In recent years, relevant policy measures have been continuously taken to reduce dependence on fossil fuels, and domestic enterprises are also accelerating the research and development of hydrogen energy technology [103].

The Italian government has launched a series of plans and projects to promote the development and application of hydrogen energy technology. The government released the National Hydrogen Energy Strategy in 2020, aiming to promote the application of hydrogen energy in areas such as transportation, energy consumption, and industry. Among the strategies, the government will invest EUR 200 million in the research and deployment of hydrogen technology, facilities, and infrastructure and plans to build 1000 hydrogen charging stations by 2030 [104].

Some essential industries in Italy, such as transportation, steel, and petrochemicals, have also begun to adopt hydrogen energy technology. For example, Italian Airlines has started testing hydrogen fuel cell technology to reduce carbon emissions in the aviation industry. Meanwhile, the steel producer TerniEnergia also uses hydrogen energy technology to reduce carbon dioxide emissions. In addition, Italian companies are actively promoting research into and the development of hydrogen energy technology. Iveco (previously part of the Fiat Group and now an independent company) launched its first hydrogen-powered electric truck in 2020 and plans to launch more hydrogen-powered vehicle products in the coming years. Saipem focuses on developing offshore hydrogen production facilities [105].

Regarding power generation, the Italian government has made some progress in researching and deploying large-scale hydrogen power generation projects. Since 2009, Italy has been promoting a plan called "Blue Energy", which aims to build a giant ocean wind turbine on the Mediterranean coast in southern Italy to generate hydrogen gas for power plants. These initiatives will help Italy achieve its carbon neutrality goal and promote the global energy transition. Meanwhile, Italy is also actively pursuing the application of high-temperature fuel cells for power generation, with scholars Baccioli et al. [106] applying molten carbonate fuel cell designs to the power systems of large ships, and used MCFC to cooperate with internal combustion engines to provide power support for ships. In the future, Italy will continue to vigorously develop the application of hydrogen-powered ships, gradually replacing internal combustion engines with fuel cells as the primary power source, developing green energy for amphibious use on land and sea, and reducing carbon emissions [107].

Overall, although Italy has made some progress in the field of hydrogen power generation, its practical scale is still limited and requires greater investment and policy support to promote its development and practical application in the field of sustainable energy. Although there are some differences in the development of hydrogen energy between Italy and China, with the increasing global demand for clean energy, both countries will continue to increase the research on and application of hydrogen technology.

5. Challenges and Future Perspectives

China and Italy, representing developing and developed countries, have made remarkable progress in the field of energy development. However, they both face various challenges while transitioning toward clean energy and undergoing an "energy structure transformation". This section provides a detailed overview of the challenges that both countries must address.

The foremost challenge is energy security. As they shift from traditional fossil fuel-based energy generation to clean energy generation, both countries need to improve their energy technology level and maximize their renewable energy generation. However, renewable energy sources have significant volatility and are influenced by many factors. Due to significant changes in the global climate in recent years, uncertainties in renewable energy generation have increased.

China is a vast country with abundant resources, while Italy is rich in natural resources. However, both countries still face the challenge of an unstable supply of renewable energy. The construction of wind and solar power generation facilities requires careful consideration of the local economic and meteorological conditions. There is a mismatch between energy supply and demand in regions with high wind and solar irradiation. This results in units facing fluctuating start–stop flexibility and frequent changes in unit loads. Such changes can significantly impact the safety of power generation equipment and the power grid. Therefore, it is crucial to strengthen the construction and upgrading of the power grid. In particular, Italy's renewable energy development has been slow due to unstable policies and confusing management, resulting in a relatively low installed renewable energy capacity. Currently, Italy's renewable energy accounts for about 22% of its total primary energy consumption and almost 40% of its total electricity consumption.

The second issue is the environment. Vigorously developing renewable energy entails reducing dependence on fossil fuels and thus reducing carbon emissions, but unreasonable renewable energy development also poses a certain threat to the environment. Due to hydropower development in renewable energy, China's hydropower stations are built along the Yangtze River, and the most famous Three Gorges hydropower station is built in the Yangtze River Basin. In the process of constructing hydropower stations, it is necessary to plan land reasonably to avoid wasting land resources. The hydroelectric power stations in Italy are built based on mountains, and the main hydroelectric power stations are built on the mountains. During the construction process, it is necessary to consider the amount of snow melting in the mountains, otherwise it will damage the original natural resources of the mountains. In addition to developing renewable energy, China and Italy have also invested significant efforts in developing hydrogen energy. Hydrogen fuel cells have the characteristics of a clean and efficient operation, whether they are used as prime movers for regional power grid power supply or as power devices for automobiles. Fuel cells have demonstrated outstanding working characteristics. However, the source of hydrogen is an important issue that cannot be ignored. Taking China as an example, Figure 3 shows the distribution of hydrogen sources in China. The figure shows that most hydrogen production currently comes from fossil fuels. In the process of producing hydrogen, attention should be paid to the impact of fossil energy decomposition on the environment. At the same time, due to its low density and flammable and explosive characteristics, hydrogen has high requirements for transportation safety, which also increases the cost of using hydrogen.

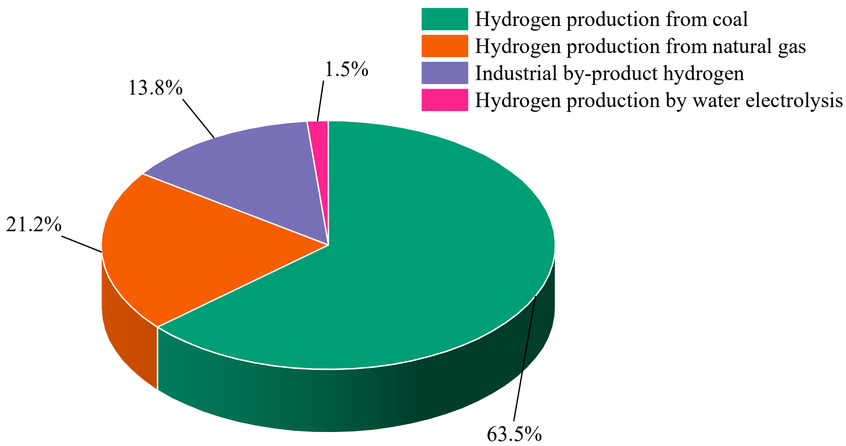

Figure 3. Distribution of hydrogen product sources in China.

Finally, there is the issue of implementing an extensive energy structure in a reasonable manner. Fossil energy accounts for a large proportion of the energy structure of China and Italy. Although both countries strive to achieve the great goal of "carbon neutrality" by 2060, they should also ensure that the energy transformation meets the requirements of people's livelihood in the process of transformation. Abandoning fossil energy without sufficient preparation not only leads to insufficient national electricity demand and supply, thereby slowing down national economic development, but also affects the normal operation of existing fossil energy power generation units. Therefore, the issue of energy transformation cannot be rushed, and mature renewable energy technology support and comprehensive policy coordination are needed to gradually promote the development of clean energy on the historical stage.

Although China and Italy face various challenges on the path of energy transformation, they each have their own advantages in energy development. In the future, the two countries can solve these challenges through technological cooperation and build a bridge for energy development.

Firstly, in terms of renewable energy, China's offshore wind power technology has taken the lead in the world, and its installed capacity has surpassed that of developed countries. Although Italy has vigorously promoted the development of offshore wind power projects in recent years, there is still significant room for improvement in offshore wind power technology. Therefore, the two countries can vigorously carry out technological exchanges and cooperation to jointly promote the development of wind power technology. In terms of the development of solar power generation technology, Italy has abundant solar resources, and its solar photovoltaic power generation technology is also relatively mature. Therefore, China and Italy also have a significant cooperation space in solar power generation projects.

Secondly, hydrogen energy cannot be ignored in clean energy. In recent years, countries around the world have been vigorously developing technologies such as hydrogen-powered vehicles and hydrogen fuel cells. China is currently the world's largest hydrogen producer and has the conditions for a large-scale and cost-effective hydrogen energy development. However, Italy has not formed a mature hydrogen energy industry chain, so China has performed even better in hydrogen energy development. Although there is a slight gap in the development of hydrogen energy between the two countries, China has signed some cooperation projects with the European Union on hydrogen energy development, aiming to jointly improve the production, transportation, and terminal use of hydrogen.

Finally, China and Italy have established trade cooperation talks on the "Silk Road" since ancient times, and the two countries have rich experience in cooperation and exchange. With the strong support of the two governments' policies and the continuous emphasis on "energy structure transformation", future energy cooperation between the two countries will inevitably be the trend, achieving a win–win situation through continuous technological cooperation.

6. Conclusions

All countries worldwide are focusing on economic development following the decline of COVID-19. However, they must also actively engage in an "energy structure transformation" to meet the requirements of the "carbon neutrality" goal. This paper has taken China and Italy as examples of developed and developing countries and outlined their energy development history and structure composition.

China has relied primarily on coal-fired power generation, while Italy has depended on imported fossil fuels for its energy supply. However, due to factors such as energy conservation and emission reduction requirements and the instability of fossil energy sources caused by the Ukrainian war, both countries are promoting clean energy development. China and Italy have complementary mature technologies in renewable energy development, enabling the two countries to collaborate in energy development.

Both China and Italy are actively promoting the development of the hydrogen energy industry chain. After analyzing the energy development situation of the two countries, this paper has highlighted the challenges they will face in the future transformation of their energy structures. It looks forward to the possibility of energy cooperation between the two countries. With the help of government policies and the continuous maturity of clean energy technology, there is significant potential for future development in energy cooperation between China and Italy. The two countries can work together to achieve a win–win situation in the field of energy where both the economy and technology can improve together.

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