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An overview of the recent development and prospects of renewable energy in Italy

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Abstract: The study examines recent developments in Italy's renewable energy industry, focusing on advancements, challenges, and prospects. Using secondary data, the research analyzes Italy's progress in renewable energy adoption, particularly in wind, solar, and hydroelectric power, and its alignment with the European Union's climate targets. Italy has made significant strides in increasing its renewable energy capacity, driven by favorable government policies, financial incentives, and technological innovations. The analysis highlights key projects and investments that have contributed to Italy's renewable energy growth, as well as regulatory frameworks that have facilitated this transition. Despite these advancements, the industry faces challenges such as regulatory hurdles, grid integration issues, and public opposition to certain projects. Italy is on track to meet its renewable energy targets, yet further efforts are needed to enhance grid infrastructure, streamline permitting processes, and increase public acceptance. The study suggests that sustained government support and continued innovation are crucial for overcoming existing barriers and ensuring the long-term success of Italy's renewable energy sector. A proactive approach in addressing these challenges will be essential for Italy to fully realize its potential as a leader in renewable energy and contribute significantly to global sustainability goals.

Keywords: renewable energy; Italy; energy policy; energy storage system; emission reduction; sustainable development

1. Introduction

Due to the severe environmental problems brought on by human energy consumption in recent decades, moving to clean energy sources and lowering greenhouse gas (GHG) emissions have received a lot of attention recently from the public, politicians, and the scientific community [1–3]. The generation of heat and electricity, as well as energy systems generally, can reduce GHG emissions by utilizing renewable resources [4–6]. Even with renewables' rapid acceleration—they have increased by 16% annually on average since 2009—renewables only registered at 28.7% of total consumption in 2021, compared to fossil fuels' 82% share in 2022 [7,8]. The most developed nations have made defining plans to limit and control carbon emissions as a priority in their energy and environmental policies [9]. The UNFCCC, signed in 1992, served as the process's foundation. The Kyoto Protocol, signed in 1997, and the Paris Climate Agreement, signed in 2015, marked the process' conclusion and the first universally accepted and enforceable global agreement [10]. One hundred ninety-five countries had signed the pact by the end of 2019. The primary objective of the Agreement is to considerably minimize environmental risks and impacts by keeping the average temperature intensification below 2 ℃ relative to pre-industrial levels and by stepping up efforts to keep this upsurge below 1.5 ℃ [11–13].

The advancement of renewables, a dramatic overhaul of the world energy system, exponential growth in the output of power from renewable sources, and changes to the energy mix are all necessary to meet these targets [14–16]. In fact, it's predicted that by 2050, final energy consumption derived from 85% renewable energy and 40% electricity would significantly reduce emissions to roughly 70% [17]. To fulfill its obligations under the Paris Agreement, the EU unveiled the "Clean Energy Package", a set of regulations designed to pursue three new goals by 2030: a minimum 40% decrease in GHG emissions from 1990 levels; a minimum 32% share of renewable energy sources in final energy consumption; and a minimum 32.5% reduction in primary energy consumption [18]. Considering this, every Member State has created a plan for a National Integrated Energy and Climate Plan (NECP) for the years 2021–2030, which outlines the laws and regulations required to meet the objectives. Italy's National Energy Efficiency Action Plans (NEEAPs) were enacted in 2014 with the goal of achieving a 17% reduction in primary energy usage by 2020 [18].

Italy produces a wide range of green energy, mostly due to regional differences and the distribution of certain renewable resources. Where there are high inclines in the landscape, like the Alps and along the Apennines spine, hydroelectric power is more prevalent. The south has a higher prevalence of photovoltaic because of its latitude and more solar exposure. The main places where wind energy is used are the big islands of Sardinia and Sicily, as well as Paglia, Campania, and Basilicata in the southern Apennines. Lastly, due to its unique geological features and historical significance, the region of Tuscany is the epicenter of geothermal energy. The objectives outlined in the NECP for 2030 are being worked towards by all regions of Italy. In recent times, there has been a noteworthy surge in the distribution and penetration of renewable energy sources throughout Italy. In 2010, there were only 356 towns in Italy that had renewable energy-powered electric or heating facilities. Currently,

every municipality in Italy has at least one renewable plant; as of June 2020, there were over 7900 municipalities nationwide. Legambiente's “Comunità rinnovabili” (Renewable Communities) report states that there are 7776 municipalities with at least one installed photovoltaic plant, 7223 municipalities with a solar heating plant, 3616 municipalities with bioenergy systems, 1489 municipalities that utilize hydroelectric power (via large structures or mini plants), 1049 municipalities with wind turbines, and 594 municipalities that additionally utilize geothermal energy. Additionally, more than 3000 towns already produce more power from renewable sources than they need for their households, and 41 of those can meet their heating needs as well [19].

Italy continued to rely mostly on fossil fuels for its energy mix even if its energy consumption in 2022 was 4.5% lower than in 2021 (149,175 kilotons of oil equivalent/toe). As per the Ministry of Environment and Energy Security's yearly report on the National Energy Outlook (MASE), natural gas accounted for 37.6% of the energy consumption in 2022, followed by oil and petroleum compounds at 35.7%, renewables at 18.5%, coal at 5%, imported power at 2.5%, and non-renewable trash at 0.8%. The industrial sector saw the steepest drop in consumption at 7.8%, while the transportation industry saw the largest increase. Although it was still lower than pre-pandemic levels, electricity demand declined by about 1%. The decrease in demand was characterized by high gas and electricity costs, mild climate conditions, and government attempts to cut consumption, according to the Italian Environment, Energy, and Networks Regulatory Authority (ARERA). Terna, the Italian power grid operator, reports that in 2022, the demand for energy was 317 TWh. Just as in 2021, domestic production covered 86.4% of this demand, with the remaining portion coming from imports. A total of 64.8% of the power generated was generated by non-renewable thermoelectric sources, with a 7.9% increase; 48.8% of this came from natural gas, 9.1% from solid fuels, and 6.9% from petroleum and other fuels. The percentage of electricity that came from renewable sources dropped from 35.3% to 30.6%, and they still made up roughly 19% of the total. For the first time, solar-generated electricity (about 28%) was on level with hydroelectric power (about 28%), partly because of less precipitation. Wind accounted for 20.7%, biomass for 17.4%, and geothermal for 5.5% of the remaining portion. A 1.8% rise occurred in power imports and a 16.4% increase occurred in power exports [20].

Compared to the same period in 2022, data for renewable energy consumption and production in the first half of 2023 shows an improvement. An additional 2.5 GW of renewable energy capacity was added, an increase of 120%. Hydropower generation increased by 17.6% over the same time periods, while photovoltaics and wind power had lower increases of 4.3% and decreases of 2.6%, respectively, while biomass and geothermal power stayed the same. A total of 35.4% of the power demand came from renewable sources, while the percentage of power generated by fossil fuels decreased by 16.6%. According to the European Climate Law, countries in the European Union are required to reduce their GHG emissions by a minimum of 55% by the year 2030. The ultimate objective is to attain climate neutrality by 2050. To achieve the goal set for 2030, governments were required to develop a comprehensive 10-year national energy and climate plan (NECP). Italy was among a small number of nations that submitted an updated version of its plan, called PNIEC, to

Brussels before the June 30, 2023, cutoff. The objective of the proposal is to raise the proportion of renewable energy in total energy usage to 40% by 2030. Additionally, the proposal targets renewables to make up 65% of electricity utilization, 37% of cooling and heating, 31% of transport, and 42% of hydrogen for industrial purposes by 2030. Italy set aside €59 billion to support the "green revolution and ecological transition" from 2021 to 2026 as part of the National Recovery and Resilience Plan (NRRP), which uses EU post-COVID recovery funding. Renewable energy, hydrogen, and sustainable transportation and networks are the specific targets of the €23.78 billion in incentives. Italy sought and got EU clearance to redirect NRRP funding to projects with a completion date of 2026 or later. These initiatives aim to make the economy greener, improve power and gas infrastructure, and address some of the difficulties in spending these funds [20].

Renewable energies are crucial in transitioning to a clean global economy by replacing fossil fuels, which are liable for global warming and climate change [21–23]. Understanding the linkage between sustainable development and energy is vital since there is a worldwide movement towards more cost-effective, eco-friendly, and sustainable energy systems [24–29]. Italy has achieved significant advancements in the implementation of renewable energy supplies in the current age. The expansion of solar photovoltaic (PV) and wind energy has been intensely remarkable, propelled by advantageous legislation and high-tech progress. The potential of bioenergy and geothermal energy has also expanded. However, their progress has been constrained by ecological considerations and technological obstacles. Italy's dedication to the National Energy Strategy and the European Union's objectives for renewable energy will persist in promoting the extensive implementation of renewable energy sources inside the nation. However, studies showcasing renewable energy's future promise in Italy are few and far between. When it comes to renewable energy technologies, there is a lack of studies that cover their present state, potential, and future growth in Italy. Accordingly, this research aims to examine the renewable energy industry in Italy from a critical perspective, taking stock of its present status, future potential, obstacles, and proposed innovations.

The novelty of the study is that this investigation uses the most current statistics on renewable energy sources' accessibility in Italy. This evaluation will be able to provide a picture of its potential development in the years to come. By compiling relevant information for use in future studies and expanding our knowledge of renewable energy technologies' potential—particularly in the circumstance of Italy—this article helps to close a knowledge gap in the current literature. To address future demands and aspirations, this study would offer significant insights for energy-related policy implementation, especially for the development of the renewable energy industry toward Italy's aim to reduce emissions by 33% by 2030, and to be carbon-neutral by 2050. This study has the potential to contribute towards the attainment of the sustainable development goals (SDGs) since all 17 SDGs are directly or indirectly connected to a more environmentally friendly energy system. This study may serve as a source of inspiration for developing countries worldwide to enhance their utilization of renewable energy, thereby promoting sustainable development.

2. Solar

In Italy, solar photovoltaic (PV) energy has grown significantly in the last several years. 25,466 GWh of gross energy generated from solar PV was produced in 2021, up from 18,862 GWh in 2012. Positive policies supported by the Italian government in the 2019 National Integrated Plan for Climate and Energy have propelled the growth of solar. To encourage the installation of solar PV and other renewable energy sources, the actions contained feed-in tariffs, tax breaks, and regulatory changes [30]. Moreover, the decline in technical expenses has resulted in solar PV being more and more competitive with alternative energy sources, hence hastening its expansion. The Leveled Cost of Electricity (LCOE)3 for Solar PV in Italy has had a substantial decline over the last ten years, dropping from approximately €250/MWh in 2010 to around €50/MWh in 2020 [18].

However, the solar PV business in Italy still encounters obstacles despite favorable developments. An important concern is the integration of solar PV into the grid, as the rapid expansion of solar PV has placed pressure on the nation's power infrastructure. The diffusion of solar PV has been limited in southern Italy due to grid constraints and the scarcity of usable land for large-scale installations. This region has, nevertheless, seen the highest capacity of solar PV systems [31]. To address these difficulties, the Italian administration has enacted methods such as conducting auctions for novel renewable energy initiatives and providing inducements for energy storage to maintain system stability [30]. However, because of the advantageous political conditions and the declining costs of technology, solar photovoltaic (PV) systems will have a progressively important impact on Italy's endeavors to decrease reliance on fossil fuels [32]. Figure 1 presents the solar PV potential in Italy.

Figure 1. Photovoltaic power potential in Italy. Source: Solar resource map © 2021 Solargis [33].

In Italy, renewable energy communities (RECs) offer various benefits in terms of the environment, finances, and society, which help to promote the transition to sustainable energy sources. RECs add additional layers of sophistication to the management of the electric grid. This includes the integration of distributed energy sources (DERs), such as photovoltaic (PV) and wind, which are deployed at the distribution network level and within the properties of end-users. In the future, end-users will have the opportunity to actively participate in local energy markets by offering their services to distribution and transmission system operators. The administration in Rome aims to construct five gigawatts of photovoltaic power by 2027 through the establishment of energy communities. Italia Solare predicts that energy communities will add at least an additional twelve gigawatts of solar power capacity by 2030, based on their accumulated experience. Consequently, these areas would account for around 15% of the government's intended solar power increase over the following six years. Furthermore, the energy communities enhance the consciousness of photovoltaics and, hence, have the potential to further incentivize citizen participation. This potential would also enhance the use of photovoltaics.

3. Wind energy

In Italy, wind power has undergone substantial expansion, reaching a total installed capacity of 18,762 GWh in 2020 and 20,789 GW in 2021. This represents nearly 19% of the country's electricity supply in 2020 [34]. Figure 2 presents Italy's wind resource map [35]. Italy has witnessed a substantial surge in the installed capacity of wind energy in recent years. Based on data provided by the Italian Wind Energy Association (ANEV), Italy's installed wind energy capacity in 2021 experienced a 2% growth compared to the preceding year [36].

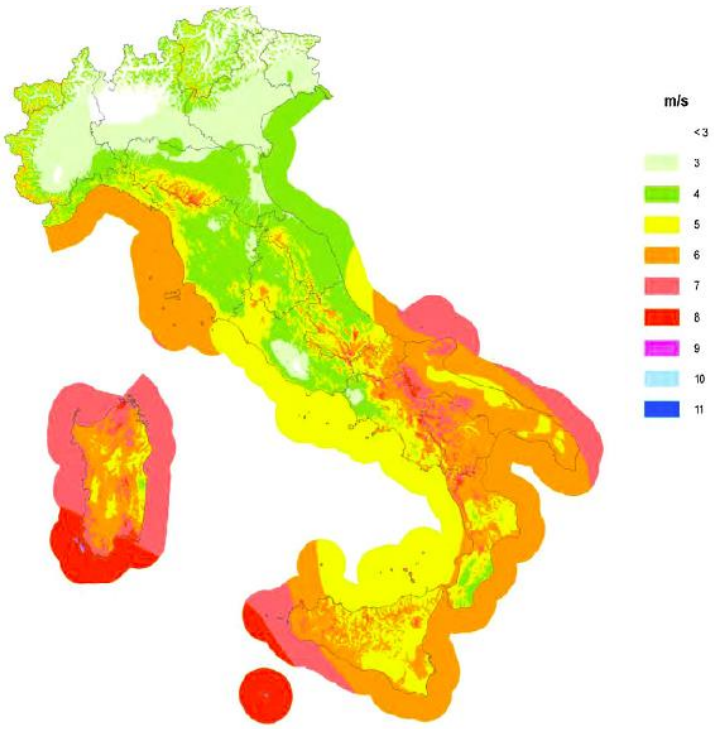

Figure 2. Italy's wind resource map (wind speed at 75 m altitude) [35]. Source: CESI.

The growth in the wind energy sector has been propelled by the establishment of extensive wind farms, particularly in the southern zones of the state. This expansion has been facilitated by the implementation of favorable government policies outlined in the National Energy Strategy. The objective of this strategy is to elevate the proportion of renewable energies in the nation's energy combination to 28% by the year 2030 [18]. By use of feed-in-tariffs, priority shipment, and technical developments [36], Italy's wind energy sector has received significant support from the European Union through financing programs like Horizon 2020. This initiative has allocated funds for multiple wind energy research projects within the state. These initiatives encompass the enhancement of wind farm efficiency, the advancement of cutting-edge wind turbine technologies, and the evaluation of the ecological and socioeconomic consequences of wind power generation [37].

Undoubtedly, community interaction is crucial in influencing public perception of wind energy projects. The perceived advantages linked to these projects, such as economic profits, community ownership, and participation in decision-making procedures, have been recognized as crucial factors. Previous research conducted by Firestone *et al.* [38] and Solman *et al.* [39] demonstrates the positive impact of these factors on the public's perception and acceptance of wind energy projects. The aforementioned studies highlight the significance of promoting community engagement and guaranteeing that locals have a vested interest in the decision-making procedures related to these initiatives. According to Caporale *et al.* [40], the perceived dangers associated with wind energy have an impact on social acceptance, but they appear to be less significant compared to the risks associated with fossil fuels. In Italy, socio-economic benefits have a substantial impact on the decision-making process regarding wind energy, in comparison to the effects on the environment and aesthetics. Italian citizens may be perceived as adventurous when it comes to embracing wind energy advancements, which could contribute to the positive reception of wind energy in society.

Nevertheless, various obstacles remain that must be confronted to guarantee the enduring progress of wind energy in Italy. These challenges encompass the imperative of securing the social and ecological sustainability of wind farm growth, addressing prospective controversies with other land uses, and managing the intermittent nature of wind power generation [36]. Notwithstanding these challenges, the potential of wind energy is projected to grow in the future ages, especially in southern Italy [41].

4. Biomass and bioenergy

Within the renewable energy framework, biomass and bioenergy have gained significant scientific interest as a sustainable energy source [42,43]. In Italy, bioenergy has become a very promising alternative power source as part of the country's efforts to decrease its reliance on fossil fuels and address the impacts of climate change. Additionally, bioenergy plays a significant role in ensuring energy security [44]. Biomass, which refers to solid fuels derived from organic sources and waste, is the primary source of bioenergy in Italy. Approximately 50% of the power generated from solid biomass is derived from burning municipal solid

waste. This accounts for 70% of the overall bioenergy production. The total installed capacity for this type of electricity generation was 19,634 GWh in 2020 and 18,272 GWh in 2021 [18]. The primary biomass power plants are in Southern Italy [45]. Italy is one of the leading biofuel producers and consumers in the European Union. There are currently 21 active producers engaged in primary transformation, one of which is a second-generation biofuel firm operating the world's first commercial-scale cellulosic ethanol facility (Figure 3).

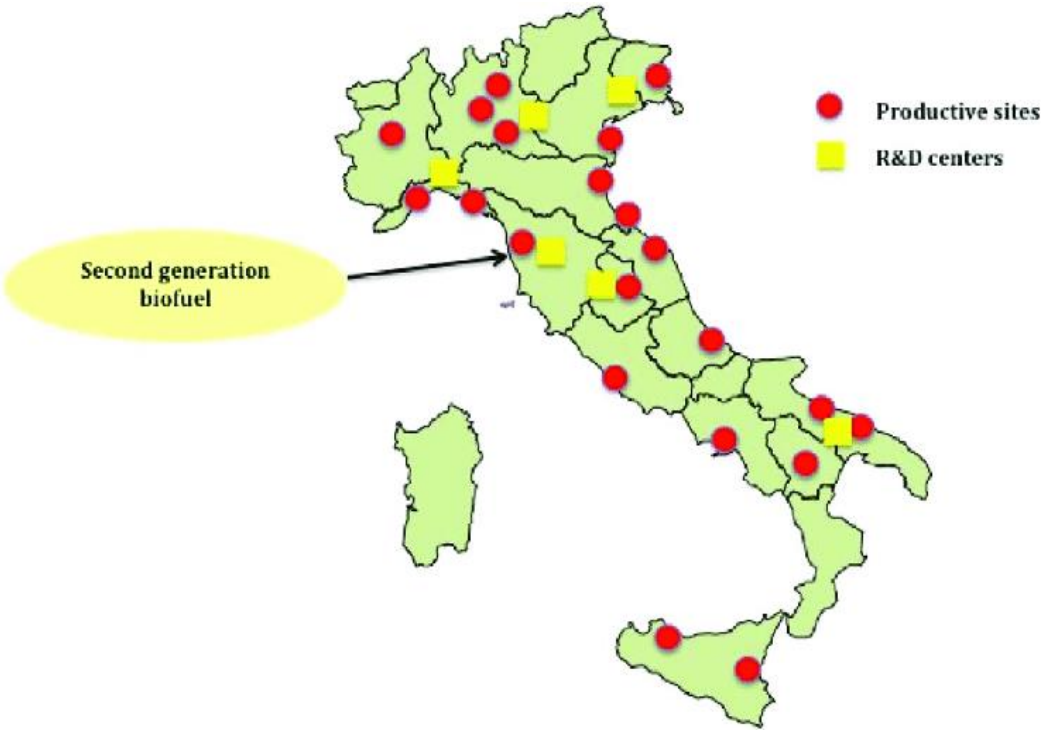

Figure 3. Location of the Italian biofuel plants [46].

By 2030, the Italian government seeks to protect the existing production of solid biomass. Italy has implemented technology and projects in the heating sector to effectively decrease pollutants and GHG emissions. Furthermore, in the transportation industry, the untapped value of bio-methane will be further harnessed. The National Recovery and Resilience Plan has allocated around 2 billion euros to support the production of bio-methane. This funding will be used for initiatives that aim to convert and increase the efficiency of present biogas plants, as well as for the construction of additional plants in the agricultural segment. Moreover, the utilization of bio-methane in the transportation and electrical industries has the potential to yield economic advantages and several favorable environmental side effects.

In Italy, although there is a rising interest in bioenergy, there are still numerous obstacles that must be tackled to guarantee its sustained advancement. These factors encompass the necessity to guarantee the long-term viability of biomass generation and supply chains, the requirement to mitigate the probable adverse effects of bio-energy generation on biodiversity and ecosystem services, and the necessity to tackle social and economic concerns associated with the advancement of bioenergy in rural regions, with its possible influence on food security besides the environment [47].

5. Hydropower

The most efficient green power source in Italy is hydropower which provides 41% of the total energy, or 46 TWh annually, or 16.5% of all electricity produced in Italy. In Italy, there are 4300 hydroelectric plants that employ more than 1500 people. Since most of the current hydroelectric plants were constructed more than 70 years ago, they are generally rather ancient. Two factors are threatening their ability to produce energy: aging and the effects of climate change. Together, these two elements limit many of these plants' potential. Experts in the field declared that renovating these hydropower plants is crucial. Italy's current hydropower sector may grow by 6000 MW by 2030 with proper renewal and maintenance interventions. It might produce an additional 4.4 TWh of ecologically friendly electricity from renewable sources in just ten years, as well as eliminate more than 2 million tonnes of CO_2 [48]. Figure 4 presents Italy's map displaying the highest amount of hydroelectric power generated annually.

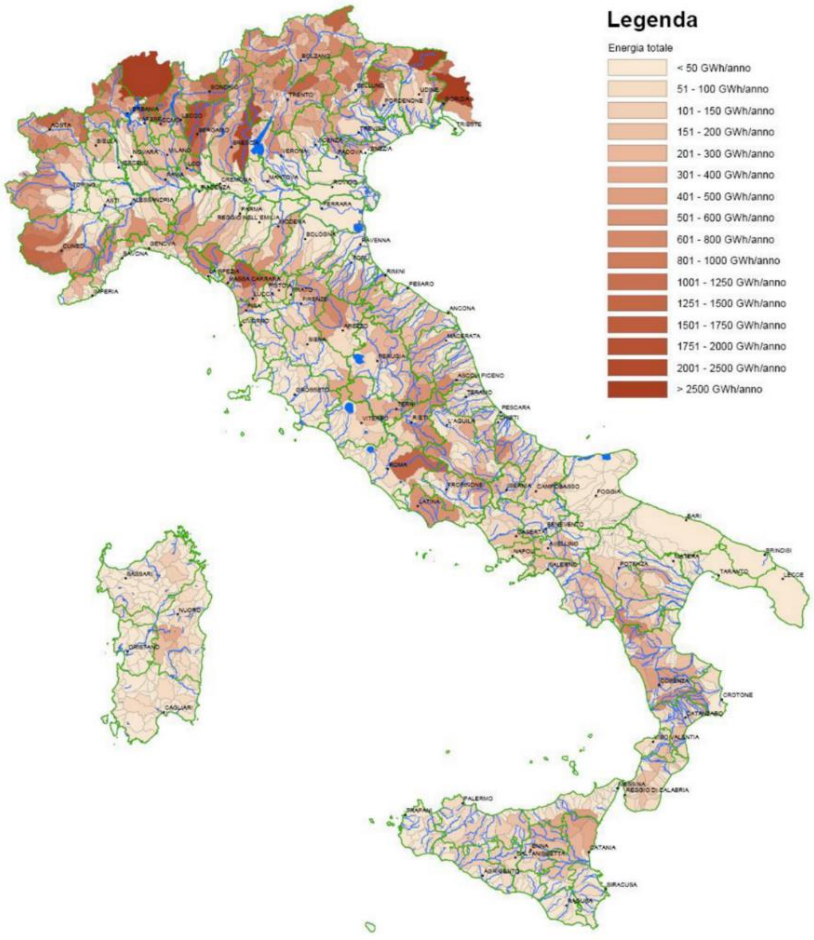

Figure 4. Italy's maximum yearly hydropower production map. Source: Ecological Research and Services for the Environment [49].

With its many mountain ranges, Italy's terrain provides the ideal setting for its numerous hydroelectric projects. Lorenzo Vanossi constructed the first water-powered electric generator in Italy shortly afterward in Chiavenna, Lombardy; in 1895, Paderno d'Adda saw

the opening of the country's first hydropower station, which was quickly followed by Vizzola sul Ticino. These plants are now widely distributed, but in the past, they might have been very uncommon. It is quite difficult to pinpoint their precise position because they are so numerous. The largest hydroelectric facility in Italy is at Entracque, in Piedmont, in the Province of Cuneo. During the busiest time of year, this tiny village of just over 800 residents welcomes over 5000 visitors, most of whom are tourists. Their attraction stems from the town's strategic location at the center of the Maritime Alps. Besides, the Luigi Einaudi hydropower facility was constructed in the 1970s in the Alps. Although construction really started in 1969, the plant didn't begin to run until 1982 because of delays brought on by the region's harsh weather, which only permitted work to be done for six months out of the year [48].

Two distinct water levels are needed for the Entracque plant to function: the Rovina-Piastra and the Chiotas-Piastra passage one. The Piastra dam, on the other hand, is situated 1000 meters below the Chiotas dam and has a 9 million m^3 water reservoir. The Chiotas Dam is situated nearly 2000 meters above sea level. At 1500 meters, Rovina Lake is situated about halfway between these two dams. The three reservoirs are connected by a lengthy underground piping system that continues to the center of the hydropower station, which is completely subterranean. It was not at all easy to get all the water to the turbines. Because the dam is situated at a very high altitude, construction of the power plant, the reinforced pipelines, the diversion tunnels, and the dam was frequently disrupted by heavy, regular snowfalls. After construction was finished, Italy's largest hydropower plant was created. The Province of Turin's total power needs may be satisfied by its 1065 MW of generated power. The public can visit the hydroelectric plant, Luigi Einaudi. During engaging guided tours, guests are shown a three-story scale model that illustrates the operation of the facility.

The hydropower facility in Edolo, in the Province of Brescia, is another sizable hydropower facility in Italy. Like the Einaudi plant, Enel is the owner of this as well. It uses the energy produced by a 1265-meter water drop to produce 1000 MW. Another of Italy's sizable hydroelectric facilities is located farther south, in the Province of Caserta, in Presenzano. It is called Domenico Cimarosa. It uses two water drops, each 500 meters tall, and generates power similarly to the Edolo plant. Most hydroelectric facilities in Italy are rather small. Less than 1000 plants produce between 1 and 10 MW, but about 3000 plants produce 1 MW [48].

6. Ocean energy

Wave energy is a possibility in Italy because of its 7600 kilometers of coastline and 60% coastal population. The theoretical yearly potential of 166 TWh, or half of its current electricity needs, is achieved despite the moderate average wave density. Despite the obstacles, Italy is aggressively looking into wave energy alternatives to prepare for a sea energy-powered future [50]. The National Recovery and Resilience Plan (NRRP) allots 680 million euros to Mission 2C2, an investment that focuses on the promotion of innovative

plants, such as marine energy converters. The reasoning behind this is that meeting the renewable energy targets for 2030 and 2050 will need significant investment in the search for novel approaches to energy generation, including plant layouts and technology. The project's goal is to assist in the development of offshore renewable energy systems that combine several technologies, including those with high development potential and systems that utilize wave motion, in creative designs while also incorporating storage. As a result, the intervention plans to construct 200 MW of renewable energy plants over the course of the next few years. Considering the various technologies employed, putting these interventions into practice would enable the production of about 490 GWh annually, resulting in an estimated decrease of 286,000 tons of emissions [51].

The western shores of Sardinia and Corsica, as well as the Strait of Sicily and the coastal areas of Algeria and Tunisia, have the greatest potential for wave energy in the Mediterranean. In these regions, the average energy flow ranges from 10 to 13 kW/m. The primary location for extracting tidal energy in Italy is the Strait of Messina. This area, along with the Strait of Gibraltar, holds the distinction of being the most favorable location in the Mediterranean. The strong currents in this area, which can reach speeds exceeding 2 meters per second, make it possible to generate up to 125 GWh of energy annually. This amount is enough to meet the energy demands of cities like Messina [51]. There are many initiatives happening in wave energy generation, but the most important ones at the public level are focused on researching the electricity system and the establishment of the Blue Italian Growth National Technology Cluster (BIG). The BIG aims to use the development of marine renewable energies as a catalyst for economic growth and to revive the shipbuilding industry in the country [51]. Figure 5 displays the regional distribution of offshore wave power across the whole Mediterranean Sea, including the Italian coast.

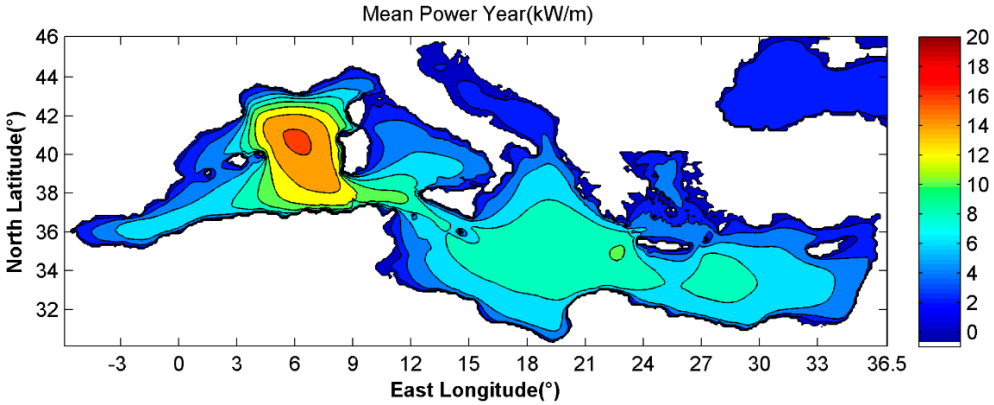

Figure 5. Average yearly wave energy supply beside the Italian coast [52].

7. Geothermal

Italy possesses significant reserves of geothermal energy, which are believed to range from 500 million to 10 billion tonnes of oil equivalent and can be extracted and utilized. This indicates a range of energy between 5800 and 116,000 terawatt hours, in comparison to an annual energy demand slightly exceeding 300 terawatt hours [53]. To summarize, extracting

a small portion of the energy mentioned would be sufficient to completely meet all domestic energy needs. It is vital to note that this data specifically refers to the surface layer, which is less than five kilometers deep. The energy derived from terrestrial heat, which is renewable, clean, and unlimited, now has a relatively minor impact on the composition of Italian energy, providing only a small amount. However, Italy remains a prominent producer of geothermal energy in both Europe and the world. The primary catalyst for this phenomenon is the nation's abundant reserves of geothermal resources. The peninsula boasts a multitude of natural hot springs scattered throughout different regions, which are poised to be harnessed as a pivotal factor in the country's swing to renewable energy sources [53]. Figure 6 presents the accessibility of geothermal resources in Italy. The colorful layers represent regions delineated by their potential for high-temperature geothermal energy (shown in red), medium-temperature geothermal energy (indicated in yellow), and low-temperature geothermal energy (indicated in blue).

Figure 6. Accessibility of geothermal resources in Italy [54].

Tuscany is the region that epitomizes Italian geothermal energy the most due to its significant historical and geological factors. Starting with Larderello, which currently houses the largest geothermal plant in Europe, the quantity of regional geothermal plants has increased over the years, and there are now over thirty. The majority of Tuscany's geothermal power is sourced from the heat produced by the intrusion of a magmatic pluton beneath the volcanic system of Mount Amiata. Specifically, the primary regions where geothermal resources are utilized to generate electric energy are Pisa, Siena, and Grosseto. Italy possesses numerous regions that boast extensive geothermal resources, including the Veneto region, particularly in the vicinity of the Euganei hills near Padua, and the Friuli-Venezia Giulia

region near the town of Grado, where drilling has been conducted to facilitate direct heating for buildings. Additionally, Campania, particularly in the region surrounding Naples between Campi Flegrei and the island of Ischia, Sicily in Alcamo, Sciacca, the Aeolian Islands, and Pantelleria, and Emilia Romagna, specifically Casaglia in the province of Ferrara, are also notable for their presence of aquifers. Notably, Emilia Romagna boasts an intricate network of aquifers referred to as the Ferrara Ridge [53].

Despite having a comparable capacity to Tuscany, Sicily, and Campania, together with some marine areas, have a minimal impact on the Italian energy balance in absolute terms. The other regions mentioned also have insignificant contributions. In addition, there are additional prospects in Basilicata, Veneto, and Sardinia, as well as in Emilia Romagna, Puglia, and Abruzzo for pressurized systems. Approximately 6 terawatt hours of energy is produced annually in Italy, with an installed capacity of around 1.1 gigawatts. The total capacity of the plants that convert heat into electric energy, known as geothermoelectric plants, is slightly more than 900 megawatts. Additionally, there is a capacity of just under 200 megawatts that is derived from direct uses such as urban heating, thermal springs, medicinal uses, and greenhouse agriculture. It is well acknowledged, as documented by the Italian Geothermal Union, that in Italy, approximately one-seventh of geothermal energy is used for thermal purposes, and six-sevenths are used for generating electricity [53].

The study conducted by Pellizzone *et al.* [55] in Viterbo, Italy, found that the perception of renewable energies, including geothermal energy, is generally positive and optimistic. However, similar to the findings of Carr-Cornish and Romanach [56], the study also revealed that when a geothermal project is proposed in the immediate vicinity, the favorable perception of the affected population decreases. This phenomenon is commonly referred to as “Not in my backyard”. Acceptance of a geothermal power plant is a complex matter that depends on how close the plant is to the surrounding populations. This element should be taken into account from the beginning of the project. Acceptance is a crucial factor in the successful adoption of emerging technologies like geothermal energy. Geothermal resources in EU nations, like as Italy, have not been fully utilized due to limited public acceptance and other factors [57]. The geothermal sector in Italy relies heavily on public awareness and perception. Furthermore, the significance of social acceptance is widely acknowledged as crucial for the effective execution of renewable energy policy. Therefore, it is imperative to provide further information and educational initiatives to enhance public knowledge and understanding of geothermal energy, so alleviating any uncertainties and addressing public concerns.

8. Renewable energy policy

Italy is committed to achieving carbon-neutral status by 2050 and is making good progress towards its 2030 goals for reducing emissions and improving energy efficiency. The country is seeking to have renewables account for 30% of its total energy use and 55% of its power generation. Nevertheless, in 2023, the Ministry of Energy drafted a paper outlining more aggressive objectives, aiming for a 40% proportion of renewable energy in overall energy

consumption by 2030. The Italian Government passed Law Decree No. 181/2023 (referred to as the “Energy Decree”) on December 9, 2023. This decree was then transformed into Law No. 11 on February 2, 2024, with some changes made. The Energy Decree aims to enhance Italy's energy security, foster the utilization of renewable energy sources, and provide assistance to energy-intensive enterprises. This decree implements a range of measures designed to advance environmental sustainability, energy efficiency, and innovation in the sector. It demonstrates the country's dedication to a pressing and essential energy transition. Italy has witnessed significant expansion in the field of clean energy and has effectively incorporated substantial amounts of fluctuating renewable power generation. The nation has enhanced the safety of its energy by diversifying its natural gas supply, and utilizing the pipeline and LNG infrastructure it has developed in the past decade. This is significant as natural gas plays a crucial role in generating electricity and providing heating. By expediting the transition to alternative energy sources and prioritizing energy efficiency, particularly in buildings, the country may effectively decrease its reliance on natural gas and enhance energy security. Additionally, this approach will contribute to the achievement of the country's climate ambitions [58].

The early years (1990s–2000s) saw a focus on promoting renewable energy through feed-in tariffs (FITs) and green certificates. FITs guaranteed fixed prices for renewable energy producers, while green certificates provided tradable certificates for each unit of renewable energy generated. These policies spurred initial growth in the sector, particularly for hydropower and wind energy [59]. As the FITs system faced criticism for its high costs in the 2010s, Italy transitioned to a market-based approach with auctions and tenders for renewable energy projects. This aimed to promote cost-competitiveness and attract private investment [59].

Moreover, the National Integrated Energy and Climate Plan (PNIEC) adopted in 2020, outlines Italy's strategy to achieve carbon neutrality by 2050. It sets ambitious targets for renewable energy development. The target is to achieve a 30% share of all energy used and a 55% share of power output from renewable resources by 2030 [58]. The current system incentivizes renewable energy production through tradable green certificates, which producers receive for each unit of renewable energy generated. This market-based approach aims to promote efficiency and cost-effectiveness [59]. Besides, additional tax breaks and deductions are offered to encourage investments in renewable energy technologies and energy efficiency measures [58].

Italy aims to diversify its renewable energy mix beyond traditional sources like hydropower. Solar, wind, and geothermal power are projected to play a significant role in forthcoming growth [58]. Investments in grid infrastructure and storage solutions are crucial to facilitate the incorporation of renewable energies like solar and wind into the grid [58]. The building sector is a key target for energy efficiency improvements, with policies promoting the retrofitting of existing buildings to reduce energy consumption [58].

9. Energy storage system

To achieve the energy and emission reduction goals set by the European Union (EU) for 2030, EU member nations must develop a comprehensive national energy and climate plan for the period between 2021 and 2030. Italy has implemented a plan named PNIEC. The goal of PNIEC is to expand the contribution of renewables to 40% of gross final energy utilization by 2030, which is now less than 20%. Additionally, the aim is for renewables to make up 65% of electricity consumption by 2030, compared to the current level of roughly 35%. The number of newly installed renewable energy plants in Italy had an almost twofold increase from 2022 to 2023, rising from 3 to around 6 GW, with most growth occurring in the photovoltaic sector. Given the growing reliance on variable renewable energy sources in Italy's energy mix, the inclusion of electricity storage is necessary to effectively incorporate power generated by renewables into the national grid and ensure its availability during periods when sun and wind energy are not accessible. Furthermore, the presence of electricity storage is crucial to prevent congestion in the power system, as most renewable energy output is generated in Southern Italy but predominantly consumed in the northern regions. Hence, the PNIEC includes provisions for the establishment of additional energy storage infrastructure to accomplish a total installed storage capacity of 22.5 GW by 2030 [60].

The PNIEC plan outlines the 2030 energy storage landscape, which includes 8 GW of hydroelectric pumping systems (mostly existing), 4 GW of distributed energy storage systems (smaller scale storage systems integrated with residential, primarily photovoltaic plants—many of which are already in place), and 11 GW of stand-alone utility-scale storage facilities (yet to be developed). Consequently, Italy requires battery energy storage systems (BESS). The Italian market for BESS is seeing tremendous growth, currently reaching a capacity of 2.3 GW. However, this industry is predominantly focused on residential-scale systems that are primarily connected to small-scale solar plants with a capacity of less than 20 kWh. In mid-2023, Italy had a total of 311,189 storage systems, with a combined power of 2329 MW and a maximum capacity of 3946 MWh. Terna, the operator of the high-voltage grid, also possesses energy systems with a combined output of 60 MW and a total capacity of 250 MWh. The majority (92%) of the systems have a capacity of less than 20 kWh, with a significant number falling between 5 and 10 kWh (33%) and between 10 kWh and 15 kWh (36%) [60].

The “DC generation side” configuration is the most common, accounting for 88% of the total, followed by the “AC generation side” at 5% and the “post generation side” at 8%. A solar plant is paired with 99.9% of the systems; these are almost exclusively (99.6%) residential-scale installations. The most installed systems are in Lombardy (62,222, totaling 448 MW and 753 MWh capacity), followed by Emilia-Romagna (31,382, totaling 240 MW and 379 MWh capacity) and Veneto (44,661, totaling 330 MW and 608 MWh capacity). In contrast, the utility-scale industry is still in its infancy and faces challenges related to rising costs, uncertain regulations, and availability. However, because of Italy's lofty PNIEC ambitions, considerable development is anticipated in the upcoming years. Data from 2022 and early 2023, which show many rising requests to link utility-scale energy storage systems

to the national electrical network—nearly tripling in just six months—confirms growth projections [60].

To establish large-scale electricity storage facilities, the Italian Government implemented a program that received approval from the European Commission in late 2023. Italy aims to encourage investments in large-scale electricity storage projects, with a target of achieving a capacity of at least 70 GWh and a value exceeding 17 billion euros during the next decade. Terna, the operator of Italy's high-voltage grid, will get the additional storage capacity through the issuance of tenders. The upcoming tender will be issued in 2024. Currently, the acceptable storage options for the tenders include lithium-ion batteries and hydroelectric pumping, as well as additional technologies accounting for 10% of the total. However, Terna will regularly review and update its analysis of reference technologies at least every two years [60].

10. Challenges

Italy imports a sizable portion of its power, which has a direct influence on public spending and the cost of finished goods. In addition, the spread of renewable energy facilities may have positive effects on the environment, the economy, and society. In conclusion, the strategic rearrangement of plants and the establishment of energy societies—where people take on the roles of producers and consumers, or "prosumers"—ensure the medium-term growth of a sustainable economy and strengthen community bonds [61]. According to projections for 2030, solar energy is predicted to earn around 31.5 billion in investment (2020–2030), with wind, hydro, and geothermal energy following closely after. Nonetheless, scientific research shows that private as well as public investments—such as those made by green venture capitalists—can promote the growth of the green economy [62].

Italy, despite its abundant renewable energy resources, faces significant obstacles in switching to a cleaner energy outlook. While the country has made progress in recent years, several hurdles remain, including:

(1) High dependence on fossil fuels: Italy still heavily relies on fossil fuels, with natural gas and coal accounting for over 50% of its energy consumption [59]. This dependence makes it difficult to reduce CO_2 emissions and achieve climate goals. Additionally, it exposes the country to fluctuations in global energy prices, as seen during the recent energy crisis.

(2) Complex permitting procedures: The lengthy and bureaucratic permitting process for renewable energy projects is a major obstacle to their development. This can delay projects for years, discouraging investment and hindering progress. Streamlining the permitting process is crucial to expedite the transition to renewable energy.

(3) Grid integration challenges: One of the biggest challenges in integrating sources of clean energy like wind and solar power into the system is their intermittent nature. The mismatch between energy production and consumption necessitates robust grid infrastructure and storage solutions to ensure a stable and reliable power supply.

(4) Public opposition: Public resistance to the construction of renewable energy infrastructure, particularly wind farms and high-voltage transmission lines, is a persistent issue. Addressing concerns about visual and environmental impacts through effective communication and community engagement is essential for overcoming this challenge.
(5) Water consumption of hydropower: While hydropower is a pointed source of renewable energy in Italy, it also has the highest water consumption footprint. Balancing the development of other renewable energies like solar and wind farms with hydropower is crucial to promote water sustainability.
(6) Lack of investment: Despite government incentives, attracting sufficient private investment remains a challenge for the renewable energy segment in Italy. This can be attributed to factors like perceived risks, regulatory uncertainty, and the need for long-term policy stability.

Finally, regarding investment value forecasts, it is certain that Italy's renewable energy sector has a bright future. To ensure the implementation of innovative, more effective, and efficient technologies, including the relocation of plants to support low-emission electricity in countryside regions, more funding must be allocated to research and development.

11. Conclusions

This study aims to provide a comprehensive synopsis of the condition and future scenario of renewable energies in Italy. Italy has witnessed a swift proliferation of renewable energy in the last ten years, mostly driven by governmental regulations at both national and European levels, as well as significant investments from public-private subdivisions. Nevertheless, the dissemination of the virus remains sluggish and inconsistent. This issue is associated with significant factors that can be categorized into two domains: political and economic. In the realm of politics, the existence of myopic, frequently disjointed, and intricate policies can create difficulties in the process of making decisions, which might deter investors and potential new stakeholders. The occurrence of economic difficulties and the COVID-19 epidemic have hindered the rate of inducements and financings on the economic front. Nevertheless, both in governmental spheres and within individual companies, there is a widespread recognition of the significance of renewable energies. There is also a consensus on the necessity to streamline current laws and regulations, as well as to encourage the implementation and widespread use of innovative, cost-effective technology.

Italy has the potential to become energy self-sufficient by enhancing its energy infrastructure and implementing plant conversion methods, according to its favorable geographical position. The analysis demonstrates that investing in renewable energies not only yields social and employment benefits but also promotes the growth of environmentally friendly jobs, hence creating significant development prospects for rural regions that frequently face issues such as depopulation and limited work options. Nevertheless, a primary concern arises from the scarcity and challenging accessibility of funding sources. The creation of a new energy infrastructure necessitates substantial upfront expenses, which are

gradually recovered over an extended period. Policymakers should actively support the expansion of renewable societies to encourage empowerment and awareness. This can be achieved through the implementation of tax incentives, feed-in tariffs, and regulations. Additionally, another noteworthy issue pertains to investments in research and development (R&D) and the imperative to adopt and promote the widespread use of cost-effective, highly efficient, easily implementable, low-maintenance, and greatly enhanced electrical capacity current technologies. Policymakers should prioritize these measures as the primary means to facilitate energy switch towards a low carbon future and achieve the determined EU goals. To summarize, the assessment offers valuable insights that policymakers may employ.

Firstly, it offers empirical proof of the financial and societal advantages of allocating resources to renewable energy, thereby serving as a basis for justifying additional investments in this domain. Furthermore, it emphasizes the difficulties associated with funding and the necessity for governmental involvement to promote the expansion of renewable groups through efficient and specific approaches. Furthermore, it highlights the significance of allocating resources toward R&D to facilitate the advancement and widespread adoption of cost-effective, superior, and streamlined technologies. The implementation of renewable energy sources is frequently hindered by the technological intricacy of new patents, which typically take several years to reach optimal efficiency. Besides, the ongoing improvement of these technologies needs regular updates, which might impede the patent registration process by introducing difficulties and limits. Essentially, this study seeks to enhance the current scientific literature by detailing the energy condition in Italy and emphasizing the need to diversify renewable energies, promote the energy combination, and contribute to the development of a robust and sustainable energy structure. Nevertheless, it is crucial to consider certain significant constraints when interpreting the findings of this study. There is a scarcity of literature that addresses the Italian energy problem. Most of the studies primarily concentrate on the EU intensity, which limits the current investigation from carrying out a thorough comparison with the current scientific literature. Ultimately, the limited availability of data, which is sometimes caused by varying technological measurements, can only offer rough approximations and forecasts.

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Conflicts of interests

The authors declare no conflicts of interest.

Authors' contribution

Conceptualization: A.R.; methodology: A.R.; software: A.R. and M.R.; validation: J.R., T.T. and S.I.; formal analysis: A.R. and J.R.; investigation: T.T. and M.R.; resources: A.R., J.R.

and T.T.; data curation: A.R. and J.R.; writing—original draft preparation: A.R. and J.R.; writing—review and editing: T.T., S.I. and M.R.; visualization: A.R. and J.R.; supervision: A.R.; project administration: S.I.; funding acquisition: A.R. All authors have read and agreed to the published version of the manuscript.

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