



Atmosphere. Photo: José Ramón Luna de la Ossa.

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Spain's renewable-based power supply reached 50.3% of total power consumption in 2023 [1], 15.1 percentage points higher than the previous year. This has mainly been due to the increase in hydropower and solar PV production in relation to 2022.

Wind power maintained its position as Spain's largest electricity generation source, with a relative generation growth of 2.2%. According to the Spanish National Integrated Energy and Climate Plan 2021-2030 (NECP) [5], the government is committed to installing about 50 GW of new wind capacity, which will cost about EUR 28.86 billion (USD 30.97 billion) to meet European targets for 2030.

The Spanish wind sector installed 0.6

GW during 2023 [2]. Wind power is the number one technology in Spain (24.5%) regarding installed power capacity on the Spanish peninsula.

The Spanish government approved the first Offshore Wind Roadmap in 2021. It aims to kick-start the deployment of offshore wind with a vision to have up to 3 GW operating by 2030. Given Spain's geography, all of it is planned to be floating offshore wind. Ports and shipyards across Spain

Table 1. Key National Statistics 2023: Spain.

Total (net) installed wind power capacity	30.42 GW
Total offshore capacity	0.005 GW
New wind power capacity installed	0.607 GW
Decommissioned capacity	GW
Total electrical energy output from wind	62.59 TWh
Wind-generated electricity as percent of national electricity demand	23.5%
Average national capacity factor	23.33%
Target (by 2030)	50.26 GW
National wind energy R&D budget	16 million EUR (17.17 million USD)

already play a key role in the rest of Europe. The new Roadmap will stimulate the further development of Spain's floating wind supply chain.

National investments for wind-related R&D totalled around EUR 16 million (USD 17.17 million) in 2023.

Highlight(s)

- Wind Power is the largest energy technology (24.5%) of the Spanish continental power system's total installed power capacity (124.49 GW) in 2023.
- Renewable energies generated more than half of all electricity demand in Spain (50.3%) for the first time.
- Wind energy was the largest energy generator, covering 23.5 % share of demand.
- Most new onshore wind projects are hybrid, and many old wind farms will be hybridised with solar PV.

Market Development

Targets and Policy

In June 2023, the Council of Ministers approved the draft of the Integrated National Energy and Climate Plan 2023-2030 (NECP) [5]. This new plan increases the penetration of renewable energies to 81% of electricity generation and 48% of final energy usage. It also increases the wind power target from 50 GW to 62 GW installed capacity by 2030.

The Spanish Maritime Spatial Plan (MSP) was adopted on five marine demarcations, totalling 5,000 km² (the Royal Decree 150/2023). However, offshore regulation is still pending despite being a pivotal instrument to achieve the objectives of the offshore wind energy roadmap to reach 3 GW of installed offshore wind power by 2030.

In July 2023, around 9 GW of wind projects with the right of access and connection to transmission and distribution networks were completed. A positive Declaration of Environmental Impact awaited the Administrative Authorisation for the wind farm construction. New environmental and social requirements forced the developers to incorporate substantial modifications to their

projects, which caused a delay that could result in exceeding the deadline. The Royal Decree-Law 8/2023 approved the inclusion of non-economic criteria in the auctions of the Renewable Energy Economic Regime. It extended several temporary measures whose validity expired at the end of 2023. For the wind sector, the most important outcome is the extension of the milestones established in RDL 23/2020: Developers are allowed to apply for an extension of the deadline for obtaining the definitive Administrative Authorisation to operate for up to eight years. This regulation will prevent many projects from failing to operate.

Finally, by Order TED/1375/2023, the government is beginning to design the electricity grid development with a horizon of 2025-2030, considering the scenario foreseen in the NCEP 2023-2030 update.

Progress and Operational Details

Spain installed 607.2 MW of new wind power capacity in 2023. These installations included 307 MW in Aragon, 92 MW in Castille La Mancha, 60.48 MW in Catalonia, 50 MW in Extremadura and 36 MW in Andalucía.

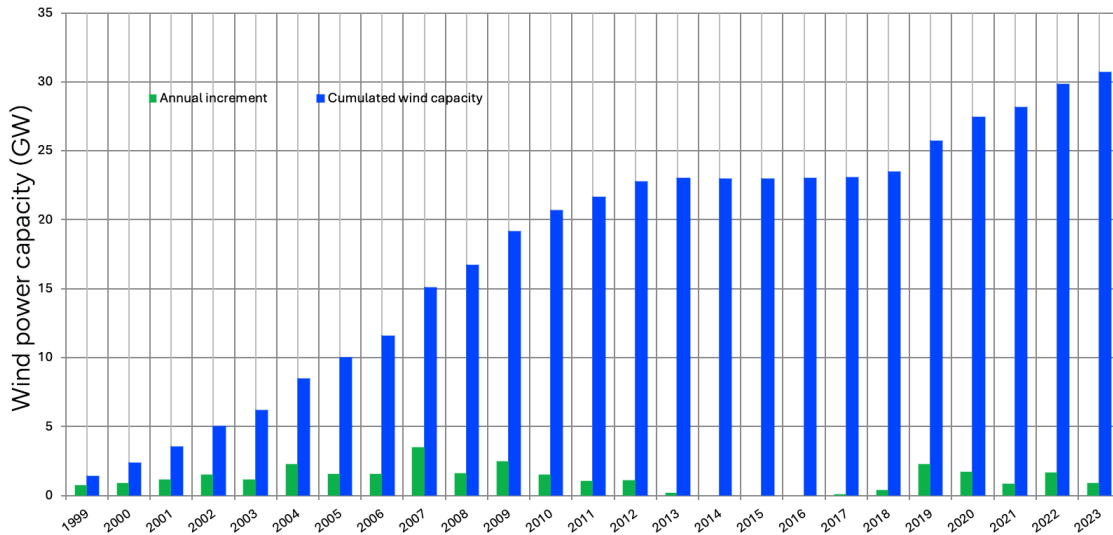


Figure 1: Annual and cumulative installed wind power capacity in Spain. Source: AEE.

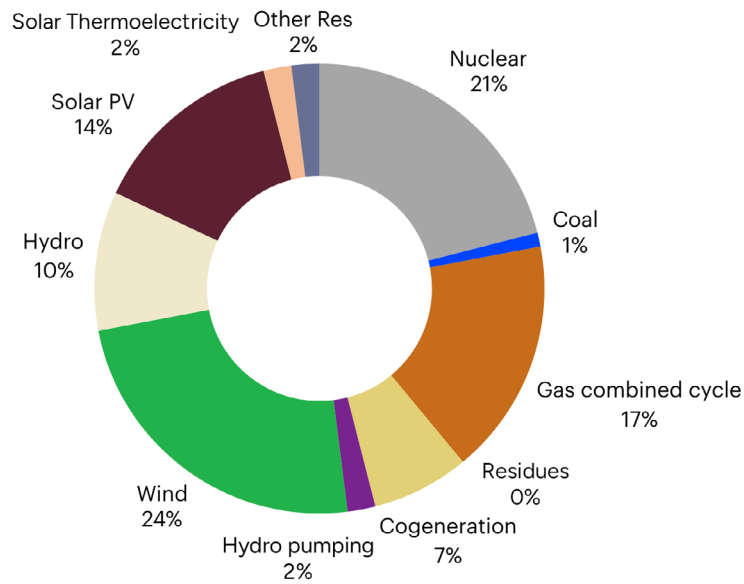


Figure 2: Sources of the 2023 power supply in Spain. Source: REE.

Land-based wind power capacity increased from 607.2 MW to 30.42 GW in 2023 (Figure 1). Wind-based electricity generation was responsible for 62.59 TWh/yr, representing 23.5% of total electricity generation (which experienced a decrease of 2.4%). Wind-based electrical generation increased 2.2% and was Spain’s largest electricity generation source (Figure 2).

In relation to the participation of wind energy in the electricity balance market, wind power has been the

only renewable technology, excluding large hydropower, which has actively participated in the balance services, which demonstrated its ability to contribute to the security of the power system [3]. In 2023, its participation in Replacement Reserves (RR), Technical Restrictions (TR) and Tertiary Regulation (mFRR) has increased significantly.

Regarding Replacement Reserves, in 2023, wind energy participated in up-regulation (increase in energy) of 209 GWh and in down-regula-

tion (decrease in energy) of 952 GWh, which represents an increase compared to 2022 of +3% and +125%, respectively.

The year 2023 has been characterised by the general increase in technical restrictions in the Spanish electrical system; for example, the evolution of the technical restrictions in the Daily Reference Program of Operation (PDBF) to lower the wind power set point increased 79% in 2023 (694 GWh), but the price in EUR/MWh decreased from 144.86

(155.43 USD/MWh) in 2022 to 76.28 (81.85 USD/MWh). In the real-time operation, this restriction reached 575 GWh (with an average price of 289.87 EUR/MWh (311.03 USD/MWh)) to reduce the wind power generation and 0.3 GWh (with an average price of 18.5 EUR/MWh (19.85 USD/MWh)) to increase the wind power generation. Adding both restrictions, an increase of almost 100% has been produced compared to 2022.

In Tertiary Regulation, in 2023, wind energy participated in up-regulation (energy increase) with 201 GWh (an increase of 26% compared to 2022) and in down-regulation (energy decrease) with 596 GWh (192% increase compared to 2022). Wind energy accounted for 8.9% of the annual tertiary regulation to increase and 26.8% to decrease.

Matters Affecting Growth and Work to Remove Barriers

Curtailement of energy resources continues to be an ongoing issue within the Spanish energy network. The total wind energy curtailment reached 1,069.65 GWh in 2023 (58% higher than in 2022). In 2023, several network nodes located in areas with high wind resources, such as Aragón or Galicia, have been close to exceeding the 5% curtailment threshold recommended by the EU.

In 2023, some social platforms emerged to protest against implementing large wind farms in some regions of Spain. They argued that the current model poses severe threats to agriculture and local ecosystems, which does not create jobs and continues to concentrate power in large companies.

In 2023, the central government developed a tool that allows for the identification of the areas of the national territory that present the best environmental conditions for the implementation of renewable projects. A territorial model groups the main environmental factors which presents zones of environmental

sensitivity of the territory.

The Royal Decree-Law 8/2023 extended the milestones established in RDL 23/2020: The deadline to obtain the Administrative Authorisation for Construction of the project has been increased by six months, up to 49 months. In addition, promoters may extend the period from five to eight years to obtain the Administrative Authorisation for Exploitation of the project. Finally, the maximum time to comply with the milestone of obtaining the Definitive Operating Permit for offshore wind farms and pumped hydropower plants is nine years.

Grid access and connection were also modified to regulate access permits and connections to boost electricity demand, among other measures.

RD&D Activities

National RD&D Priorities and Budget

In September 2020, the Spanish Science, Technology and Innovation Strategy 2021-2027 [6] was approved with the main objective of doubling the amount of public and private investment in RD&I to 2.12% of GDP by 2027.

The impact of this RD&I strategy has been significant, especially in the development of new floating offshore wind solutions (Demosath, Pivot-buoy, W2Power and Wheel), also in improvement in efficiency in installation (Skylift and Nabrajoint) and O&M tasks (Nabla Wind Hub).

The Spanish government considers wind energy a national priority. R&D activities primarily focus on land-based applications: increasing O&M cost competitiveness, extension-of-life strategies for wind farms, optimised manufacturing processes, etc. Offshore wind R&D activities are increasing, especially for floating applications. National investments in wind energy R&D amounted to nearly EUR 16 million (USD 17.17 million) in

2023.

National Research Initiatives and Results

The main topics of the Low TRL Research Projects funded by the Spanish Energy Agency AEI in 2023 are:

- Grid integration of wind energy.
- Models (CFD, Energy, maintenance).
- Disruptive technologies (Floating offshore wind power, Airbornes).

In 2023, there are still several proposals under evaluation, but other projects have already been funded such as the following:

- Large-scale wind integration for the future digital power grid using innovative power electronics control and communication-based estimations by the Polytechnic University of Catalonia (2023-26, EUR 0.2 million, USD 0.21 million).
- Efficiency model to promote renewable and clean energy by Rovira I Virgili University (2023-26, EUR 0.18 million, USD 0.19 million).
- Test bench in the electrical subsystem laboratory of an air-transported wind energy generation machine by the Carlos III University of Madrid. (2022-2025, EUR 0.08 million, USD 0.09 million).
- Intelligent management of a flywheel for its integration into an isolated desalination system powered by wind energy by the University of Las Palmas De G.C. (2022-2025, EUR 0.12 million, USD 0.13 million).
- Deep neural networks to guide and improve computational fluid dynamics calculation by Polytechnic University of Madrid. (2022-2025, EUR 0.23 million, USD 0.24 million).

- Development of advanced algorithms for optimising the maintenance of floating offshore wind farms by the University College of Financial Studies, S.L. (2022-2025, EUR 0.05 million, USD 0.06 million).

Regarding High TRL Research Projects, the main topics are:

- Design and development of innovative components (Tower, platform, drive train, power converters, bearings).
- New cost-competitive procedures for manufacturing and installation of wind turbines.
- Advanced monitoring solutions for operation and maintenance of floating wind farms.

In 2023, the Spanish innovation agency CDTI financed the following ten projects, totalling a budget of around EUR 15.4 million (USD 16.52 million) funded mainly by loans and some subsidies:

- Development of a technological solution for the wind sector with high technical performance and greater energy efficiency aimed at the ecological transition by CEMVI Catena Elevacion Manutencion VICINAY SA (2023-25, EUR 0.35 million; USD 0.37 million).
- Modular and adaptable monitoring system for offshore infrastructures by DRAGADOS OFFSHORE, S.A. (2023-25, EUR 0.88 million; USD 0.94 million).
- New compact power train for onshore wind turbines – POWERCOMP by GAMESA ELECTRIC S.A. (2023-25, EUR 1.4 million; USD 1.50 million).
- New advanced solutions for internal structural elements for wind superstructures by GRI R&D ENGINEERING SL (2023-25, EUR 0.7 million; USD 0.75 million).

- Development of a new medium voltage (MV) power conversion system for offshore turbines up to 17 MW with advanced diagnosis and prognosis capability by INGETEAM POWER TECHNOLOGY S.A. (2023-25, EUR 2.1 million; USD 2.25 million).
- New high-reliability bearings through hybrid testing for offshore wind turbines +20 MW by LAU LAGUN BEARINGS SL (2023-25, EUR 0.6 million; USD 0.64 million).
- New installation and maintenance system for reducing the cost of offshore wind energy by LINDEN COMANSA SL (2023-25, EUR 3.4 million; USD 3.64 million).
- New quick installation system for the latest generation of wind turbines to reduce the cost of energy (COE) by NORDEX ENERGY SPAIN SA. (2023-25, EUR 2.1 million; USD 2.25 million).
- Development of a business plan for urban wind turbines by ROSEO EOLICA URBANA SL. (2023-25, EUR 0.5 million; USD 0.53 million).

Test Facilities and Demonstration Projects

In 2023, the subsidy for investment in pilot projects, testing platforms and infrastructure for marine renewables amounted to more than 100 million Euro (USD 107.30 million) granted for floating offshore wind (Next GenEU Funds).

The Call RENMARINAS-DEMOS, developed by the IDAE (Institute for Energy Diversification and Energy Saving), is divided into four subprogrammes.

Subprogramme 1. “Test platforms for marine renewables by research organisations” (EUR 30 million; USD 32.19 million) max subsidy per action):

- PLEMCAT - Marine Energy Research Platform of Catalonia for the RD&I of floating wind technologies in natural operating conditions in the western Mediterranean. (Energy Research Institute of Catalonia-IREC, Budget: EUR 50 million; USD 53.6 million).
- RENMARINAS Arinaga – Infrastructure update of the Port of Arinaga (Gran Canaria Island) for applied research in marine energies (Floating Solar PV, Wave and Offshore Wind). (Technological Institute of Canary Islands-ITC, Budget: EUR 3.2 million; USD 3.4 million).
- RENMARINAS Las Palmas – Testing infrastructure for offshore solutions for wave energy and floating Solar PV in La Luz and Las Palmas port areas. (Technological Institute of Canary Islands-ITC, Budget: EUR 1.4 million; USD 1.5 million).
- ElectroUP - Updating the electrical network to support the demonstration activities of R&D projects in the northern test bed of PLOCAN (Gran Canaria Island). (Platform of the Canary Islands-PLOCAN, Budget: EUR 20.4 million; USD 21.8 million).

Subprogramme 2. “Other testing platforms for marine renewables” (EUR 20 million; USD 21.46 million) max subsidy per installation):

- OLAGARRO – Improving simultaneous testing capabilities of marine renewable demonstrators in BIMEP (Basque country). Biscay Marine Energy Platform-BIMEP, Budget: EUR 2.6 million; USD 2.7 million).

- VALENCIAPORT - Testing platform in the Port of Valencia for demonstrators of marine renewable technologies. (Port Authority of Valencia, Budget: EUR 0.78 million, USD 0.83 million).
- Galician offshore wind experimental platform – A testing platform for offshore wind turbines and floats off the coast of Arteixo. (Energy Institute of Galicia-IEG, Budget: EUR 20 million; USD 21.4 million).
- PlugHarshLab – Installation of a dynamic subsea connection cable from HarshLab to BiMEP with multi-connector functionality (Tecnalia, Budget: EUR 0.22 million USD 0.23 million).

Subprogramme 3. “Marine renewable technology demonstrators” (EUR 15 million; USD 16.10 million) max subsidy per installation):

- ALLENDE – 11 MW Acciona Offshore Floating Wind Demonstrator. (ACCIONA, Budget: EUR 10 million; USD 10.72 million).
- PRIMAVERA DEMOS – 11 MW floating wind platform demonstrator. (Primavera Offshore Wind/ENEROCEAN, Budget: EUR 8 million; USD 8.58 million).
- FLOW2GRID - Installation of a 2 MW floating wind platform connected to the Spanish electrical grid to research and monitor the impact on the marine environment.
- HIVEWIND – Construction and Installation of the HIVEWIND 11 MW Floating Offshore Wind Demonstrator at Catalonia’s Marine Energy R&D Platform. (HIVEWIND energy/SENER, Budget: EUR 15 million; USD 16 million).
- P-Demo - Demonstrator prototype with 5 MW wind and wave hybrid technology. (Floating Power Plant Canarias, Budget: EUR 7.5 million; USD 8 million).

- NEXTFLOAT-CAT –6 MW floating offshore wind platform. (Exponential Renewables, Budget: EUR 10.5 million; USD 11.26 million).
- W1ndWachPlatform - Offshore Environmental Monitoring and Electrical Generation Platform with a 2 MW floating offshore wind demonstrator. (Ferrovial, Budget: EUR 3.6 million; USD 3.8 million).

Subprogramme 4. “Joint projects for marine renewable technological testing platforms and demonstrators”, (EUR 15 million; USD 16.10 million) max subsidy per installation):

- ENERPROFUNDA - Wind Support Structure for Deep Water. Sub-phase of the “Mar de Canarias” experimental park with a 5 MW fixed foundation offshore wind demonstrator - (Enermar, Budget: EUR 4.6 million; USD 4.93 million).

Collaborative Research

Spain is participating in the following technological collaborative tasks:

- Task 11: Base Technology Information Exchange.
- Task 25: Power Systems with Large Amounts of Wind Power.
- Task 30: Offshore Code Comparison Collaboration, Continued with correlation and uncertainty (OC6).
- Task 37: Wind Energy Systems Engineering.
- Task 41: Enabling Wind to Contribute to a Distributed Energy Future.
- Task 46: Erosion of Wind Turbine Blades.
- Task 48: Airborne Wind Energy.

- Task 52: Large-scale Deployment of Wind LIDAR.

Impact of Wind Energy

In 2023, wind power was a key element to limit the price of electricity in Spain. According to the AEE figures, Spanish consumers save more than EUR 6.32 billion (USD 6.78 billion) on electricity bills. The reducing effect of wind power in 2023 was 20.41 EUR/MWh (21.90 USD/MWh). In other words, without wind energy generation, the average price of electricity in 2023 would have increased by 19%. The gross savings from wind power in 2023 were lower than in 2022, mainly because the cost per MWh in 2023 was 48% lower than in the previous year.

Environmental Impact

According to the AEE Annual report [3], during 2023, wind energy avoided the emission of 32.7 million tonnes of CO₂ (10.2% of the 2022 total CO₂ emissions (305 million tonnes CO₂)).

Economic Benefits and Industry Development

The Spanish wind sector employs 39,015 people annually. More than 287 companies work in Spain in 16 of the 17 Autonomous Communities. Wind Energy directly and indirectly contributes to 0.5% of the GDP of 5.89 billion Euro (USD 6.31 million). The sector exports (wind turbines and components) account for around 2.51 billion Euro (USD 2.69 billion) in 2023, making Spain the fifth greatest exporter in the world after Germany, Denmark, India and China [3].

Currently, 22,210 wind turbines are installed in 1,371 wind farms in more than 800 municipalities, occupying only 0.017% of the Spanish surface.

The leading wind turbine suppliers were Siemens Gamesa ER (206.45

MW, 34%), NORDEX-ACCIONA Wind Power (165.10 MW, 27%), GE RE (107.13 MW, 18%), Vestas (51.75 MW, 8.5%) and Enercon (37.10, 6%). These constituted 100% of the entire supply chain available in Spain, with a manufacturing capacity of 4,000 MW/year. Spain leads technology development, being the fourth country in the world [4] in wind power patents and the first in developing floating offshore wind prototypes.

The total wind energy sector R&D investments accounted for around EUR 16 million (USD 17.17 million), and the resulting patents place Spain in third place at the European level and sixth place at the world level [4].

Next Term

The 7,661 km of Spanish coastline allows the country to take advantage of offshore wind energy. Due to the characteristics of the Spanish coast, the most suitable offshore wind technology is floating offshore wind. In addition to the necessary continued development of onshore wind power to commit to the NECP 2023-2030 goals, the future will focus on the deployment of floating offshore wind farms. The planned offshore wind capacity is 3 GW by 2030 (only floating), mainly in the Canary Islands, the North West coast (Galicia) and North East coast (Catalonia). Finally, between 10 and 15 GW of wind capacity is expected to be repowered during the next decade.

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