AURORA ENERGY RESEARCH

Repowering or retiring: the wind fleet at a crossroads

March 2025

Public Webinar

Introducing the Aurora team

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Aurora provides market leading forecasts & data-driven intelligence for the global energy transition

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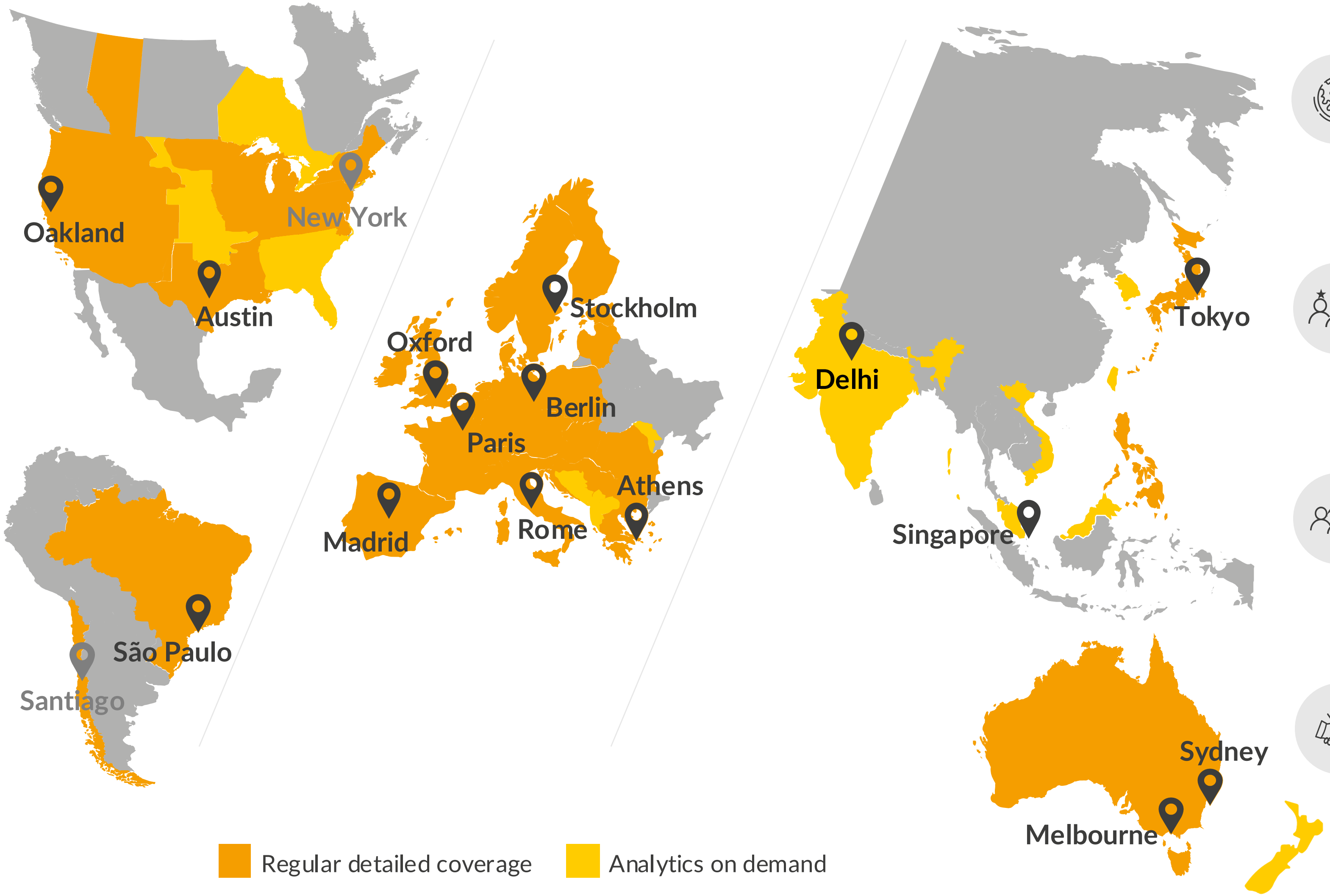

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900
market experts

850+
subscribing companies

150+
transactions supported in 2024

Source: Aurora Energy Research

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Spanish Grid Curtailment Forecast

Understanding grid constraints, protecting returns

Comprehensive curtailment modelling, providing nodal-level insights into congestion risks and financial impacts.

Investment-ready analytics, delivering curtailment-adjusted capture price forecasts for asset valuations and financing.

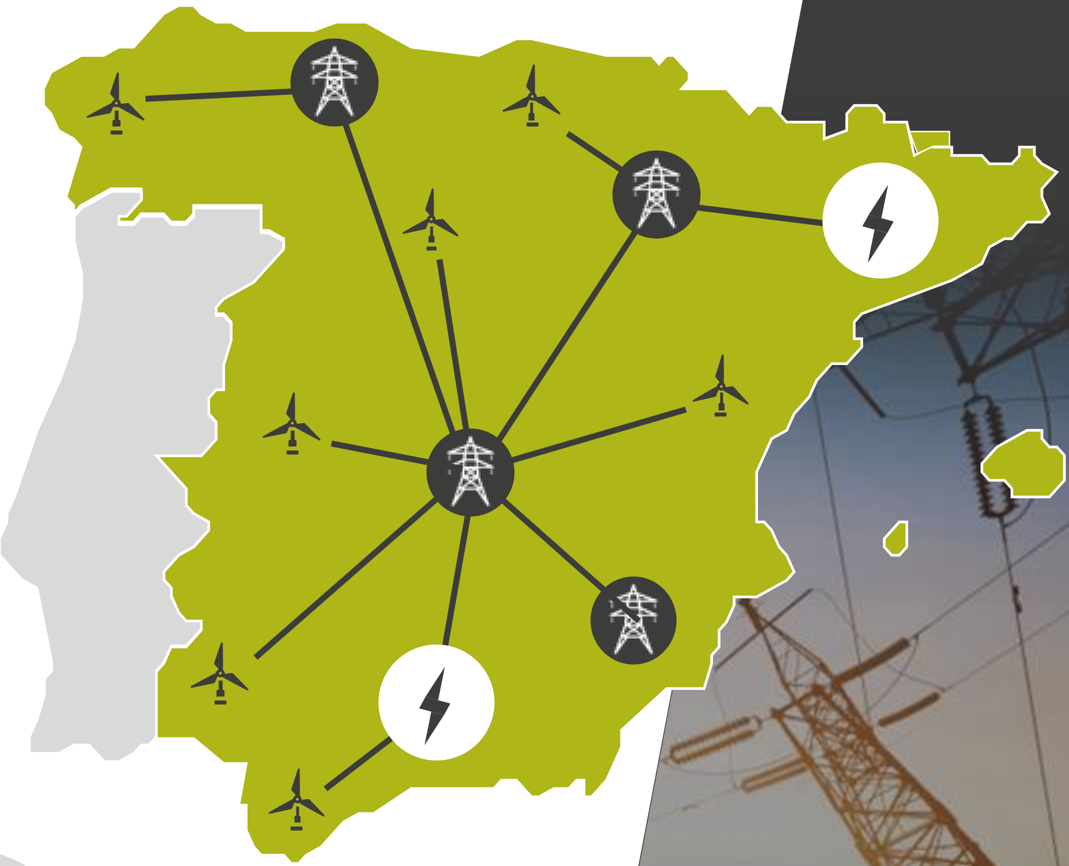
Scenario-based assessment, tracking curtailment risks under different grid expansion and infrastructure delay scenarios.

Key Benefits

Quantify financial exposure – Understand the impact of curtailment on revenues and asset profitability.

Improve investment confidence – Integrate grid risk insights directly into financial models and due diligence.

Future-proof your strategy – Assess how grid reinforcements and demand shifts will shape curtailment risks through 2030.



GRID ADD-ON

Contact **Felipe van de Kerkhof** to learn how the Grid Curtailment Forecast can maximise returns and minimise risks in the Spanish market.
felipe.vandekerkhof@auroraer.com

AMUN The true value of your wind site

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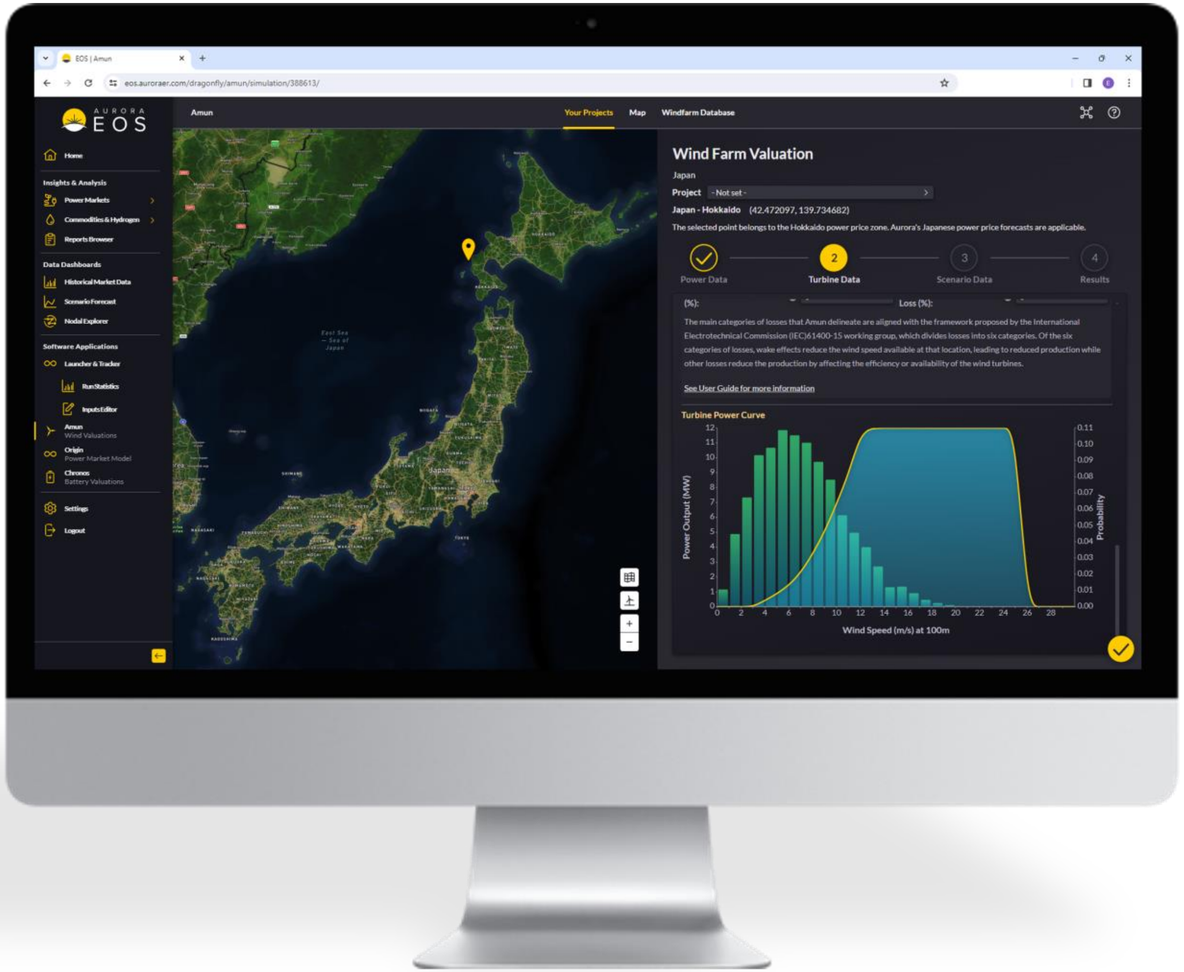

Transactions | Site Selection and Optimisation | Portfolio Valuation | PPAs

Agenda

I. Introduction

II. Drivers and challenges

1. Regulatory barriers
2. Asset economics

III. Scenario results

IV. Key takeaways

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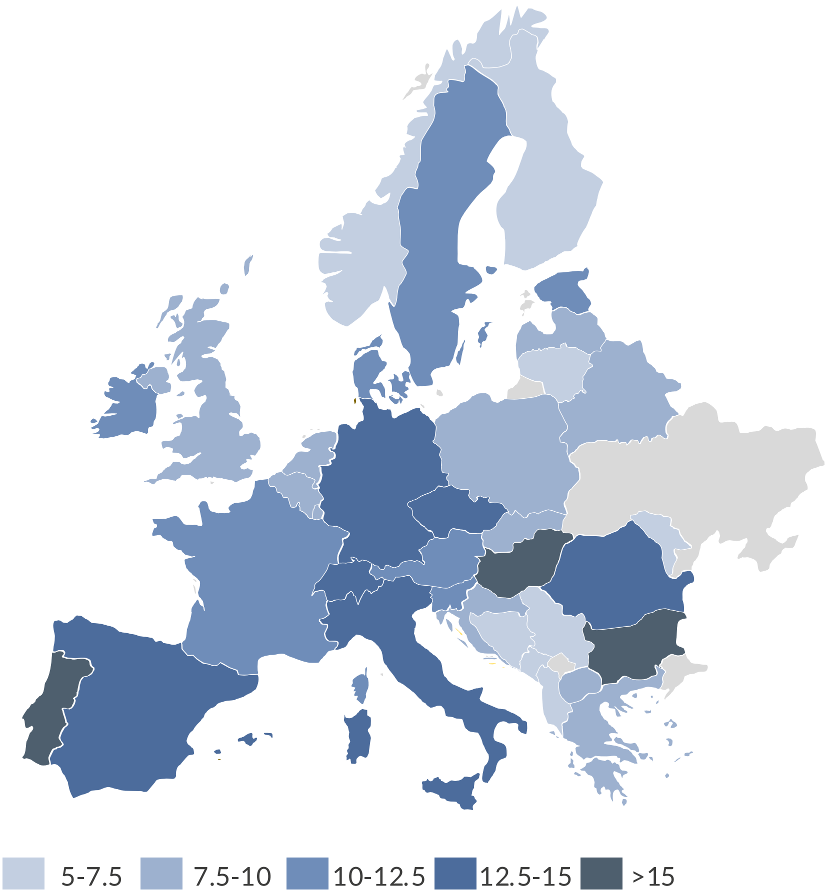
As one of Europe’s oldest and largest, the Iberian wind fleet is key to the energy mix, making its renewal essential

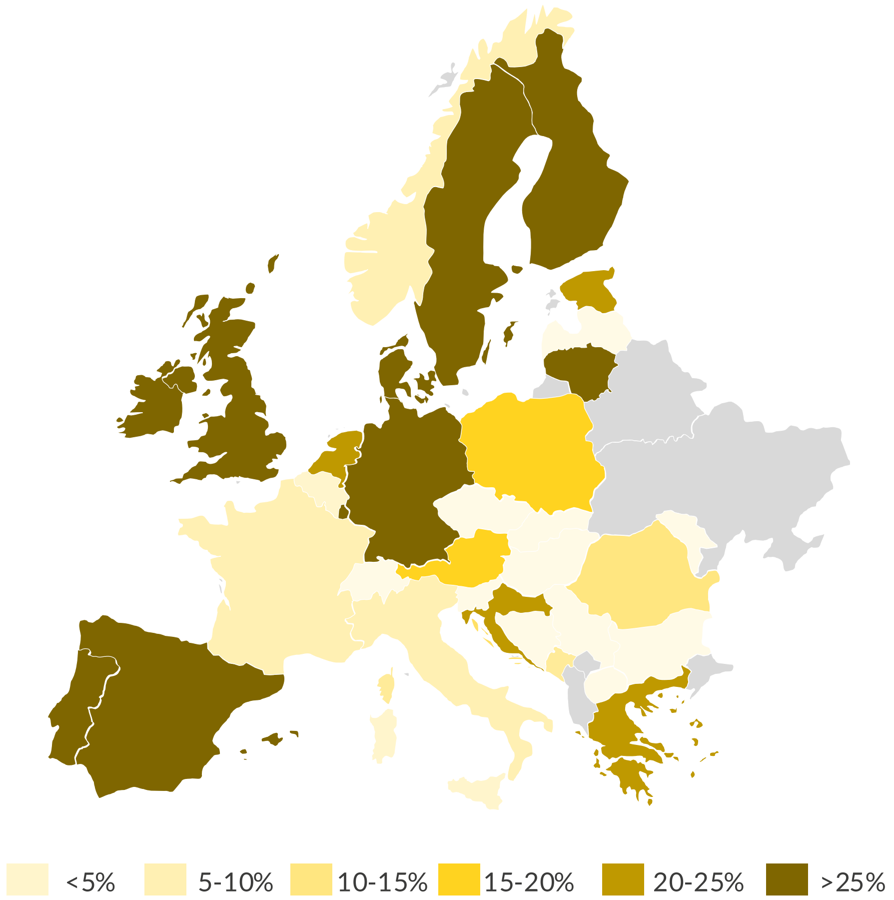
The Iberian wind fleet is among Europe’s oldest, being one of the first fleets to undergo a period of repowering

Average age of the wind fleet[1]
Years



Wind is a large contributor in the UK, Germany, the Nordics and Iberia, making this technology key for European systems

Share of wind production in the electricity mix[1]
%



1) Includes onshore and offshore wind.

Sources: IRENA, Aurora Energy Research

- Iberia was one of the pioneer regions in deploying onshore wind in Europe with the first plants being installed in the 1990s.
- Driven by favourable wind resources and attributed subsidies, Iberia was an early adopter and is currently one of the regions where wind contributes the most to the power mix.
- During 2024, onshore wind was the main contributor to the power mix representing 27% and 25% in Portugal and Spain, respectively.
- Given the age and high contribution to the mix, the repowering of the Iberian wind fleet is key to the evolution of the system.
- Other countries such as Germany or the UK might also face similar issues in the coming years.

Due to high buildout in the 2000s, Iberia is expected to face a repowering wave during the 2030s, with more than 23 GW being over 20 years old in 2030

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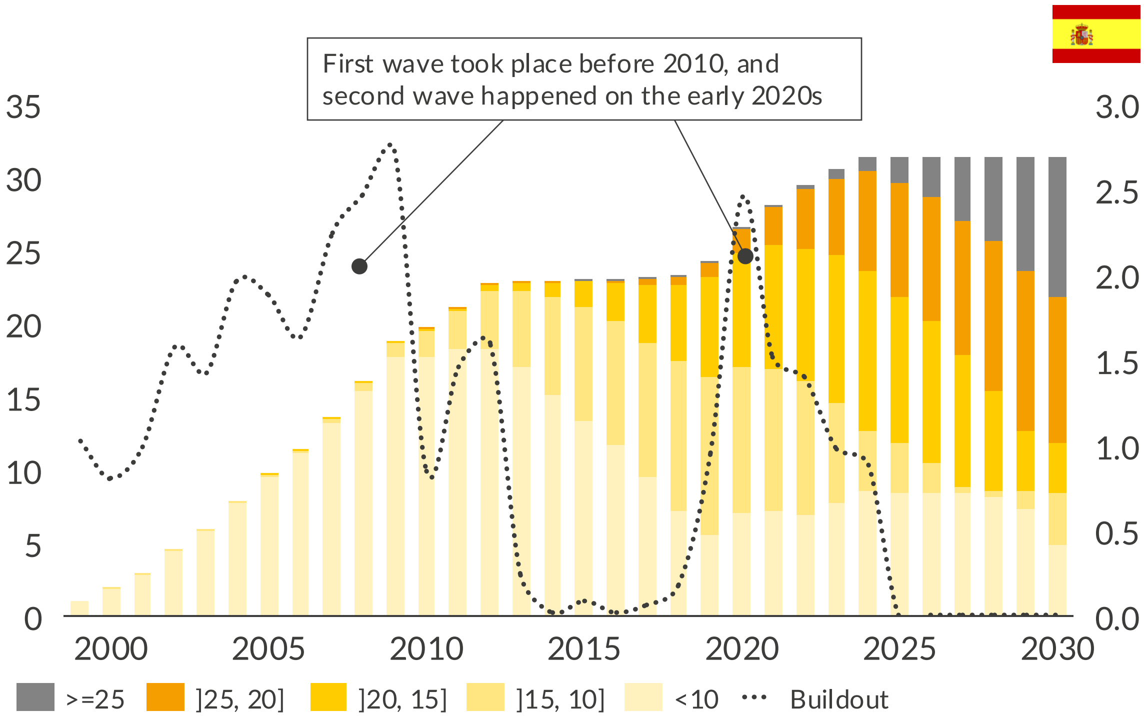
Spain had two wind buildout waves; by 2030, 10 GW in Spain will be over 25 years old and 20 GW over 20 years old

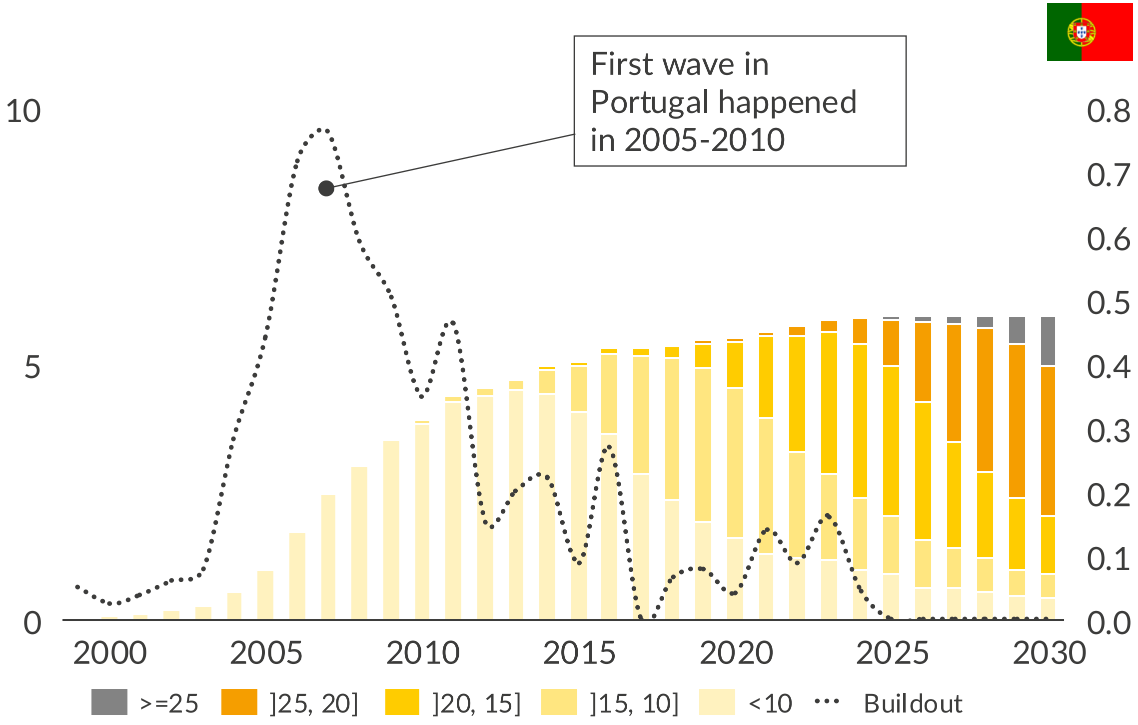
Accumulated wind capacity by age, GW | **Historical wind buildout**, GW



- The first wind buildout wave occurred in the 2000s and was incentivised by feed-in tariff subsidies; the second wave occurred after 2018, incentivised by RRE[1] auctions.
- The period between both waves coincides with the Spanish power market reform, which caused uncertainty for investments.

During the 2010s, Portugal experienced high wind buildout rates and therefore 4 GW of onshore wind will be over 20 years old by 2030

Accumulated wind capacity by age, GW | **Historical wind buildout**, GW



- The first wave of wind buildout occurred in the 2000s, slightly later than the first Spanish wave and motivated by feed-in-tariff subsidies.
- Wind buildout has been decreasing since the peak in 2006, thus the age of the Portuguese fleet has been increasing, reaching an average fleet age of 15.4 years old, higher than the Spanish age of 14.5.

1) Specific Remuneration Scheme ('Regimen Retritibutivo Específico'), was a subsidy scheme based on reasonable return on investment and auctions occurred during 2016 and 2017.

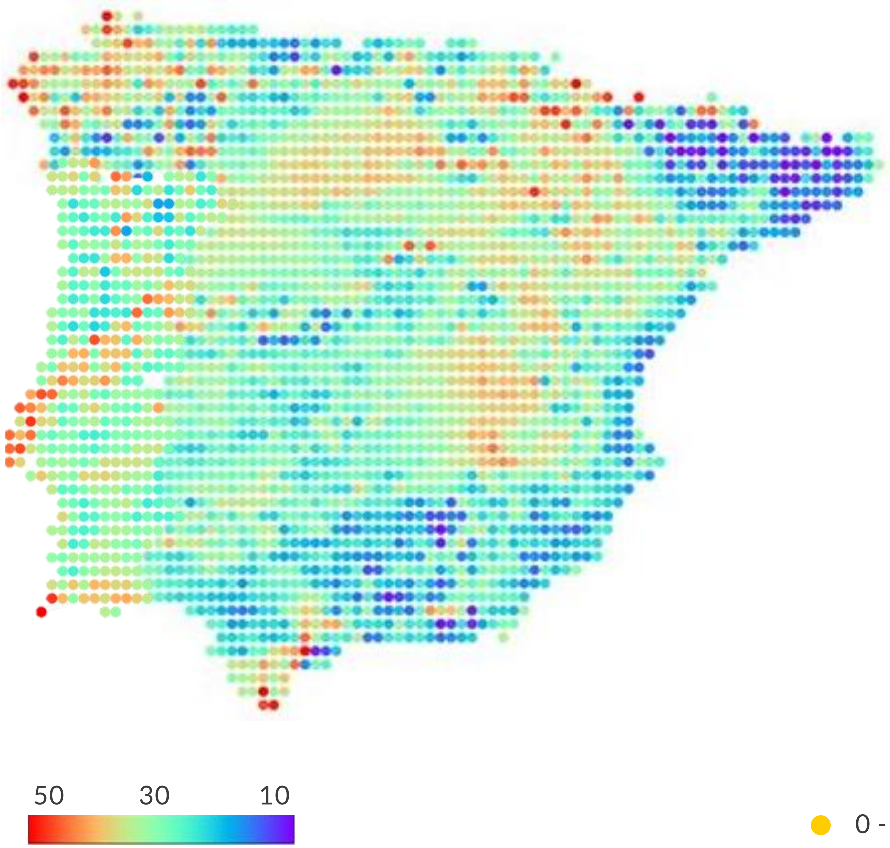
Sources: Aurora Energy Research, REE, ESIOS, REN, DGEG

The potential for greenfield development is limited as few high wind resource sites remain unexploited in Iberia

Resourceful locations are limited in Iberia, concentrated in the North-West, Tejo Valley and mid-East peninsula

Iberian wind resources

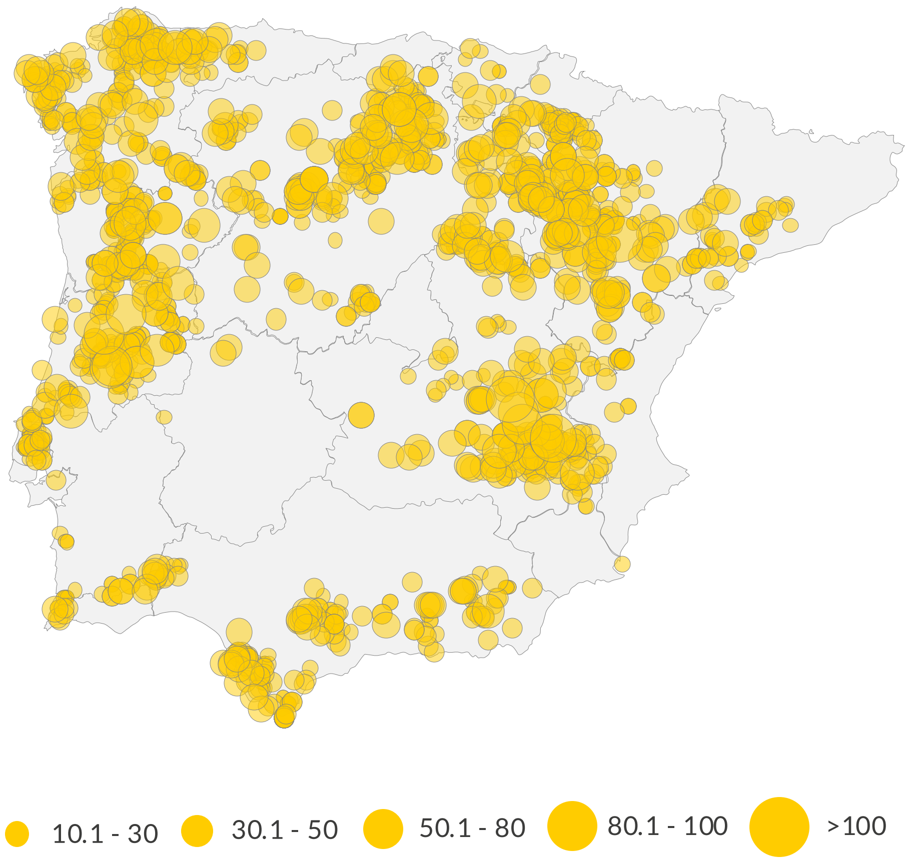
Load factor[1], %



The most favourable wind resource regions are already taken by existing plants, creating land scarcity

Iberian wind asset's location

Capacity, MW



1) Load factors calculated using Aurora's proprietary Amun model for the illustrative operation case of a Vestas 150m/4.5MW model.

Sources: Aurora Energy Research

- The best wind locations in Iberia are concentrated in the North-West and Inner East in regions like Galicia, Asturias and Aragon in Spain, and in the North and Tejo Valley in Portugal.
- Existing plants are placed in the most resourceful wind locations. These plants are as well the oldest. The average wind fleet age in Galicia is 18.8 years old, in Castilla-la Mancha 16.2 years old and in North Portugal 17.2 years old.
- Better turbines made investments in moderate wind speed sites possible as their power curve allowed for more production with lower wind speeds. For example, in a mid-resource region like Aragón, 65% of the installed capacity (3.3 GW) is less than 10 years old.

Agenda

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Repowering presents an opportunity for CAPEX savings, but lengthy permitting processes can create significant challenges

Repowering reduces CAPEX by saving on grid connection and civil infrastructure costs. It also enables the installation of more powerful turbines in sites with high wind resources and existing grid connections. However, lengthy permitting processes and supply chain constraints pose a challenge for repowering.

Repowering Drivers

Cost savings

Repowering projects reduce CAPEX by saving on civil construction, infrastructure, and grid connection costs.

Existing grid connections

The availability of an existing grid connection is a key advantage, especially in congested grid areas.

Wind resources

More powerful turbines enhance wind energy output compared to the existing plant, even occupying less land.

Repowering Barriers

Regulatory challenges

Lengthy permitting procedures can impose additional burdens if simplified pathways for repowering projects are not offered.

Subsidy schemes

Subsidy programmes do not incentivise repowering, as many have limited regulatory lifetimes and do not account for repowering needs.

Supply chain constraints

Manufacturing, transport, and construction limits may restrict annual turbine installations.

Sources: Aurora Energy Research

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Environmental permits remain the main regulatory barrier for wind repowering in Spain, as they follow the same process as new build plants

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Repowering in Spain does not qualify for any simplified permitting route compared to a greenfield project. The classification of repowering as a non-substantial modification of the project would substantially reduce permitting duration and incentivise the renewal of the current fleet as existing permits are simpler to renew.

Access and connection permit[1]

Ordinary EIA

Applicable to all wind projects that are not eligible for the Simplified EIA.

If Simplified EIA fails to obtain authorisation, an Ordinary EIA is required.

Simplified EIA

Less than 50 turbines[3]

Lower than 30 MW[3]

Distance of more than 2 km from another wind plant with AAC or EIA.

31 months[2] Environmental Impact Assessment (EIA) | Simplified or Ordinary

34 months[2] Preliminary administrative authorisation (AAP)

49 month[2] Administrative authorisation for construction (AAC)

8 years[2] Operating permit (AAE)[4]

EIA Phase	Ordinary EIA	Simplified EIA[5]
Scoping or screening request	*1-3 months[6]*	*1-2 months[6]*
Scoping report or Screening decision	*3 months*	*3 months*
Environmental Impact Study	6-12 months[6]	2-4 months[6]
Study's submission	-	-
Public Consultation	30 days	30 days
Review and Additional requests	3-6 months[6]	-
Environmental Approval	4-6 months	3 months
Total	18-31 months[6]	6-13 months[6]

Permitting for non substantial modifications to existing permits

- Would start the permitting process in the last phase (AAE).
- Only applicable to projects outside of the environmental assessment law[7] scope; wind projects are not eligible for non-substantial modification.
- The main condition for the connection permit to remain valid under the non substantial change framework is that the capacity increase cannot surpass 5%.

1) Legal deadline to apply for AAP is 6 months after obtaining access and connection permit. 2) Timelines refer to connection permits that have been granted between 2018 and 2023. 3) Around 66% of wind project in Spain fulfil these two conditions. The third requirement may lead to a lower percentage. If projects are located in protected areas, limits fall to 10 turbines and 6 MW, respectively. 4) Non substantial modifications permitting starts at this stage and a declaration of security requisites compliance is also needed. 5) Requests a detailed study justifying the simplified process. The simplified EIA process may conclude that an ordinary EIA for the project is needed. 6) Indicative timelines. 7) Law 21/2013.

Sources: Aurora Energy Research

In Portugal, the permitting process is simplified and repowering projects are allowed to increase the grid capacity, incentivising wind assets to repower

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In Portugal, Decree-Law 15/2022 classified repowering and overpowering as non-substantial changes to the production license and dismissed the need for EIA for repowering, facilitating the permitting process

- Access and connection permit[1]
- Environmental Impact Assessment (Case by case or General)

Permitting for non substantial modifications

- Repowering and overpowering are classified as non-substantial changes.
- In a non-substantial modification of the production license, entities that issued opinions during the original permitting process can be consulted on the changes under request.
- Overpowering may be subjected to mandatory EIA[2] if the capacity is higher than 50 MW or the land area is larger than 100 ha[3].

3 months[4]	Production License
4-6 months[5]	Construction License
1 year[4]	Operation License[6]

Repowering permitting

Example case of Repowering + Overpowering

Original Plant	Capacity	100
	Grid	100
Repowered Plant	Capacity	100
	Grid	100
Repowered + Plant	Capacity	100, 20
	Grid	100, 20
Overpowered Plant	Capacity	100, 20, 20
	Grid	100, 20

! Repowering additional energy is unsubsidised

! The portion of energy[7] attributed to repowering is the share of additional capacity added, which can be up to 20%

! Overpowering can be legally separated from the original plant

1) TRC – "Título de Reserva de Capacidade", achieved under general access, direct agreement, or auction. 2) Environmental Impact Assessment. Depending on project technology, capacity (size) and if it is in a sensitive area. 3) Limits are 20 MW and 10 ha, respectively, for highly sensitive areas. 4) Since repowering request submission. 5) As per the general urbanistic permits Decree Law 555/99; independent from other deadlines 6) This deadline can be delayed by 3 months by DGEG. 7) Separation of the additional energy produced by a repowered asset with an up to 20% increase in the original grid capacity.

Sources: Aurora Energy Research

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We have simulated the asset economics of a wind plant in Portugal, considering new turbines, the repowering regulation and CAPEX savings

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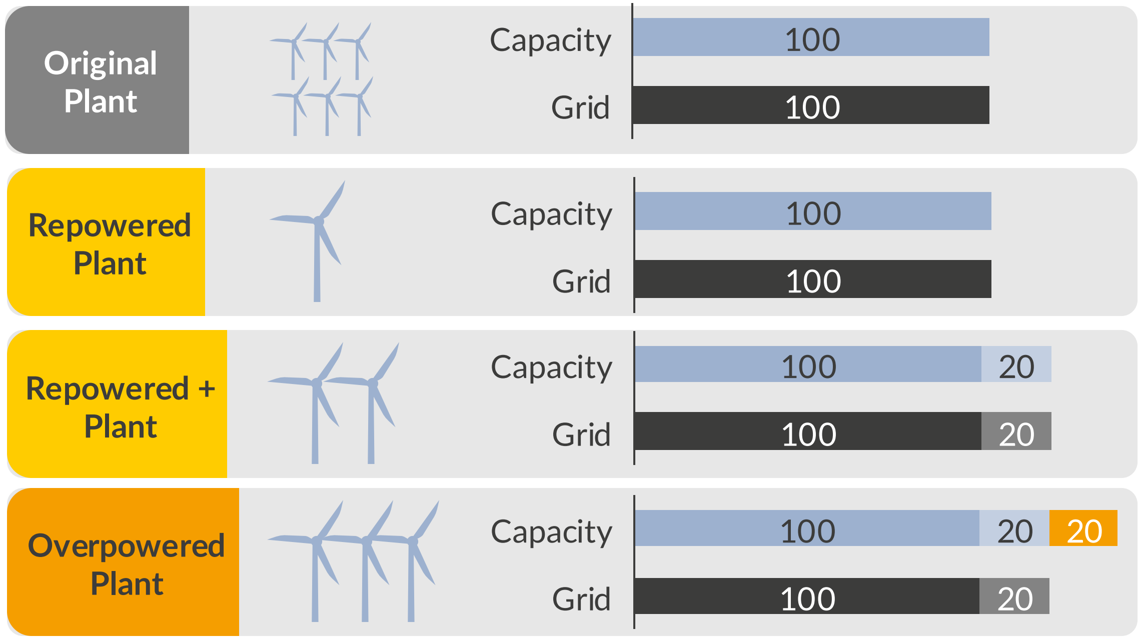
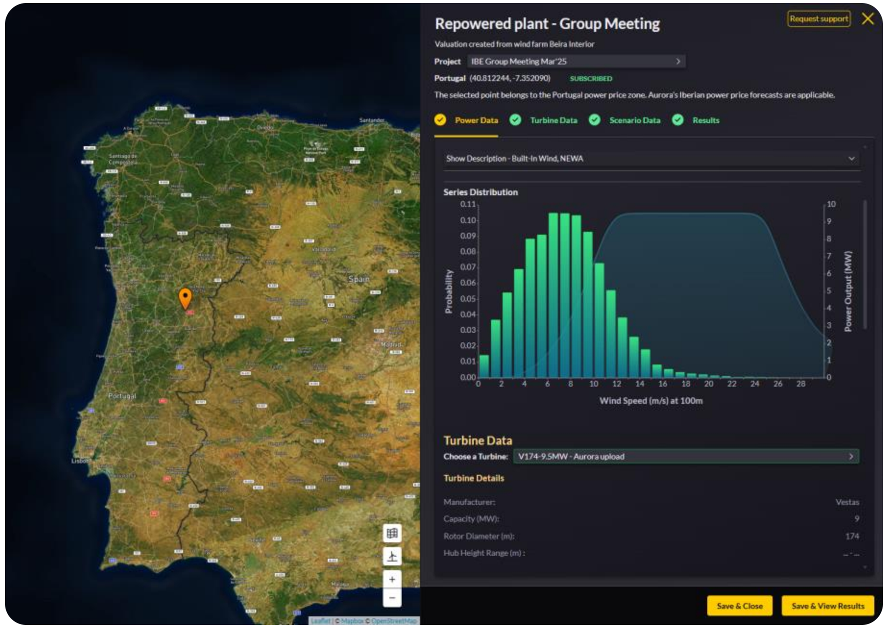
We have analysed the asset economics of a 55 MW wind plant in the North of Portugal and its repowering with modern turbines. We have considered a range of repowering configurations as the Portuguese regulation allows for capacity increases when the asset is repowered, both for the asset and the grid connection.

Site	Wind turbine	Hub height	Load factor	CAPEX[1] | Savings[2]	Market Scenario
Beira, North Portugal	Vestas V47 vs V150	80 vs 200 m	28% vs 38%	1,800 €/kW | 19%	January 2025 Forecast

Asset configurations



Amun simulation software



1) CAPEX for new build onshore asset, including turbines, balance of system, development and grid connection costs. 2) Savings correspond to only the cost of turbines and balance of system. The value is also aligned with client quotes.

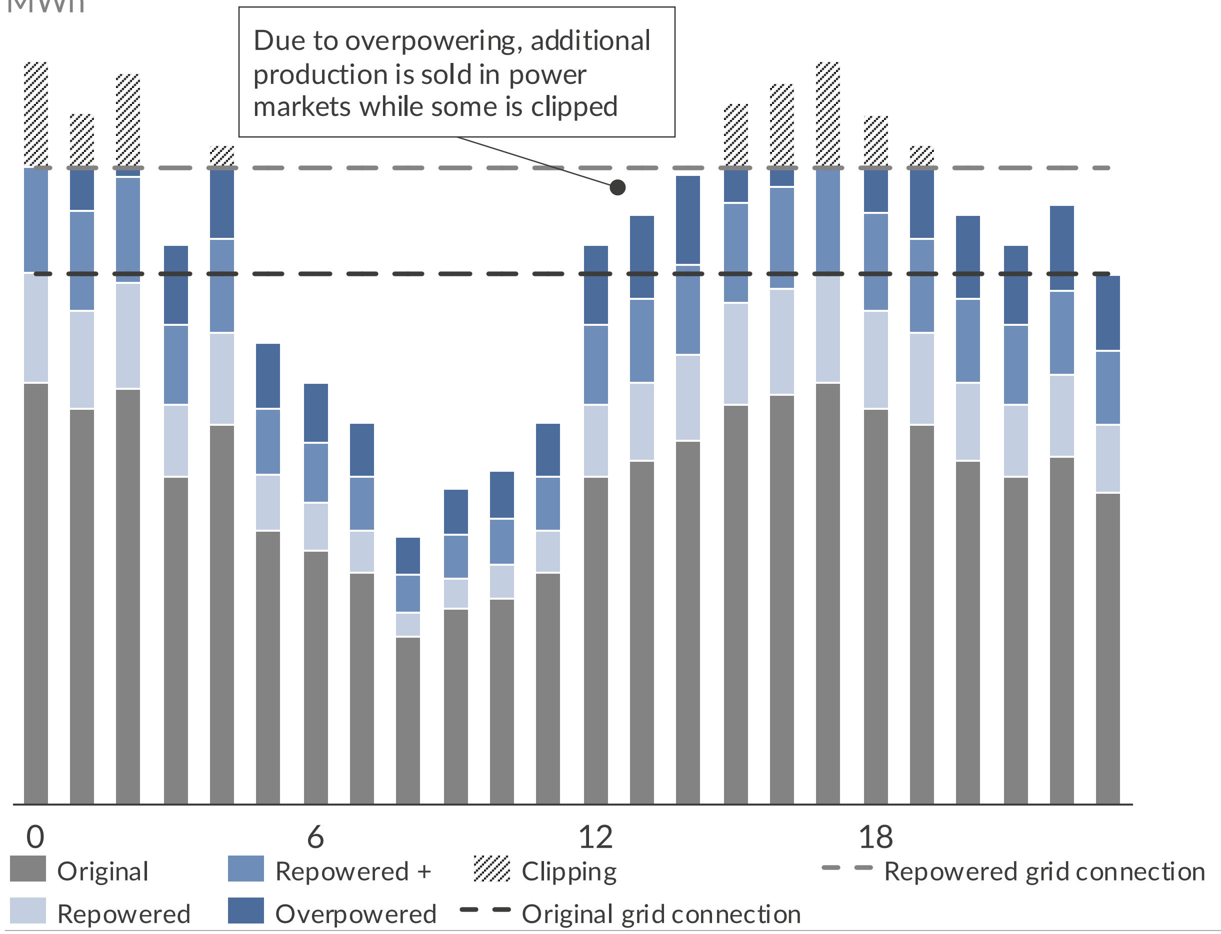
Sources: Aurora Energy Research

Repowering significantly improves asset economics due to higher load factors and CAPEX savings from using existing infrastructure

Modern turbines increase production, improving the economic case for repowering; overpowering results in clipping losses with lower returns

Illustrative volumes for different scenarios[1]

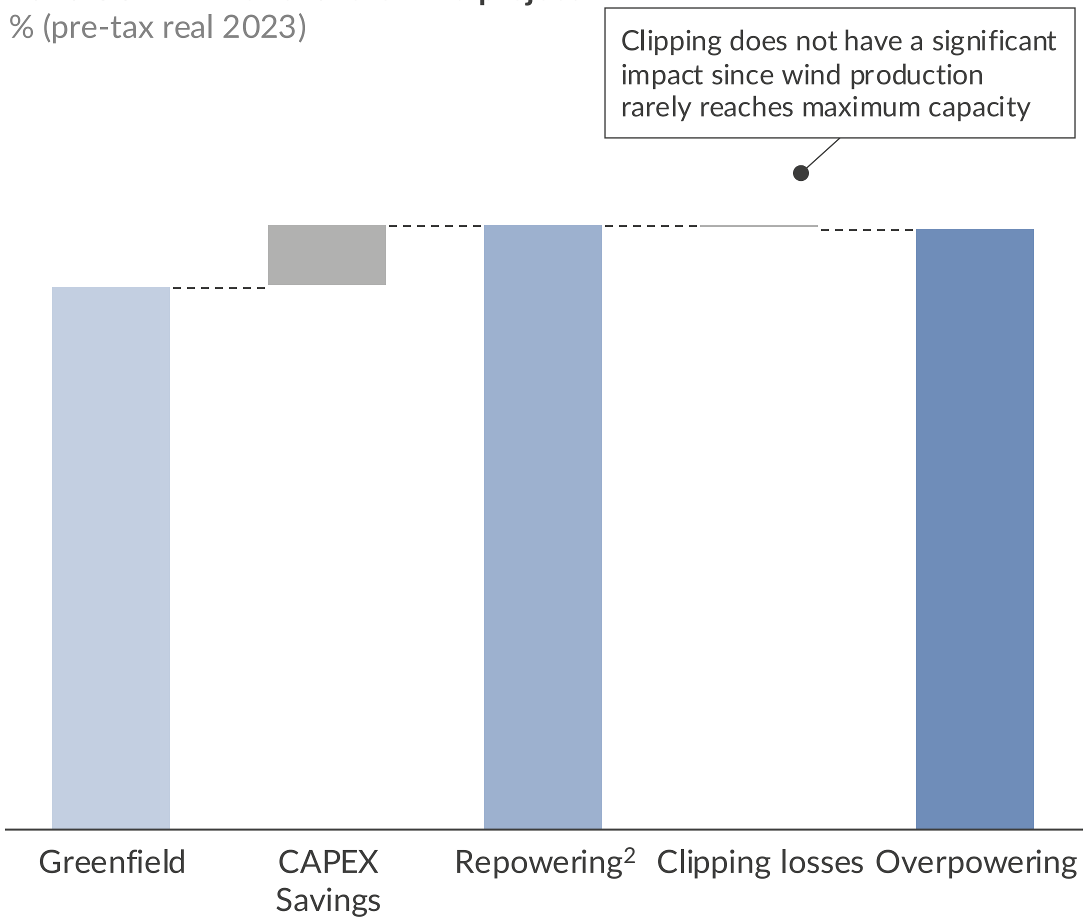
MWh



Repowering is more profitable than greenfield projects due to CAPEX savings; overpowering is similarly profitable due to minor clipping losses

2026 COD IRR for onshore wind project

% (pre-tax real 2023)



1) Example day to illustrate how the different asset configurations could be impacted by the connection point. The impact on clipping is minor since wind plants rarely reach maximum nominal capacity. 2) Valid for the 'Repowered' and 'Repowered +' case as the grid connection capacity increases in the same ratio as the nominal capacity and no differences in CAPEX savings.

Sources: Aurora Energy Research

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We have simulated two scenarios, a repowering case and a retiring case, to capture the impact of different repowering strategies on the system

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The repowering scenario assumes repowering of the existing fleet based on the buildout rates at which it was originally developed. In this scenario, accumulated installed capacity may increase or decrease depending on these rates. This contrasts with our previous market forecast, which did not account for repowering dynamics.

Repowering Scenario

Existing fleet is repowered

The permitting process is simplified, and the existing fleet is repowered following the timeline of historical buildout waves.

Extended buildout capabilities

The Iberian system can undergo repowering waves as well as building new capacity. Buildout capabilities are therefore higher than historical.

Retiring Scenario

Existing fleet is retired

Permitting for repowering remains restrictive, resulting in the decommissioning of wind projects.

Limited buildout capabilities

The Iberian system maintains the historical level of buildout capabilities. Lower repowering efforts do not lead to higher buildout of new sites.

Sources: Aurora Energy Research

In the retirement scenario, the wind share decreases 7% by 2040, causing an increase in prices and higher emissions as existing plants retire

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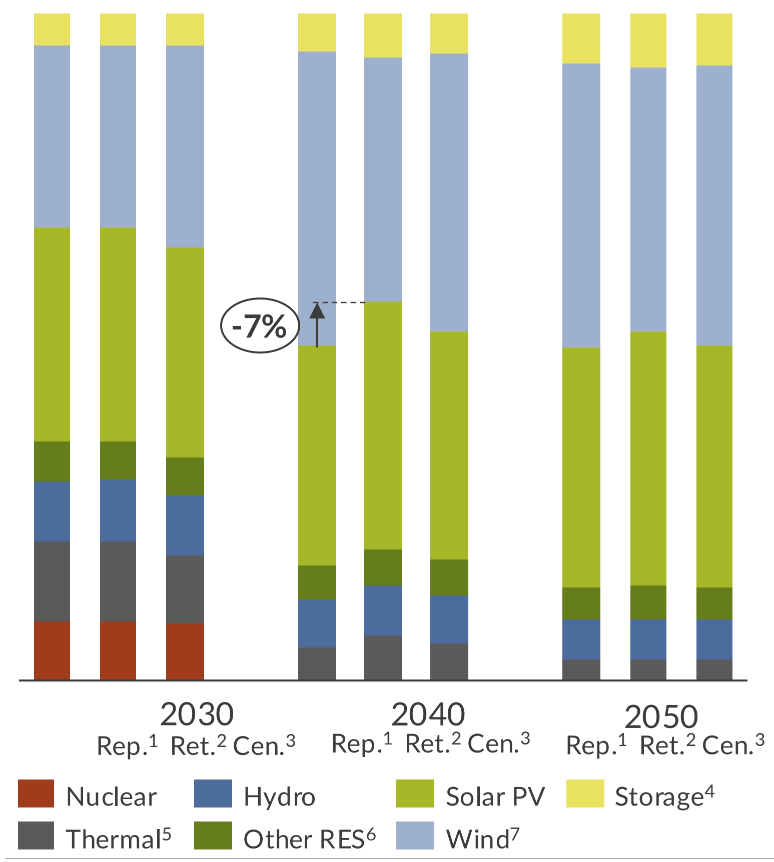
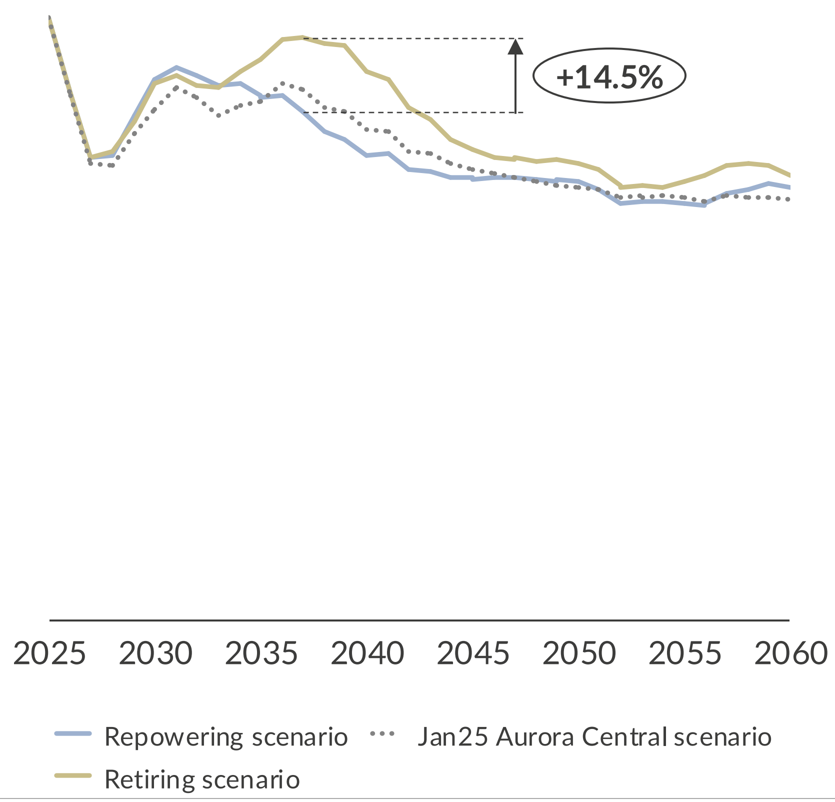
The retiring scenario shows more conventional generation in 2040 as plants retire

Generation mix
%



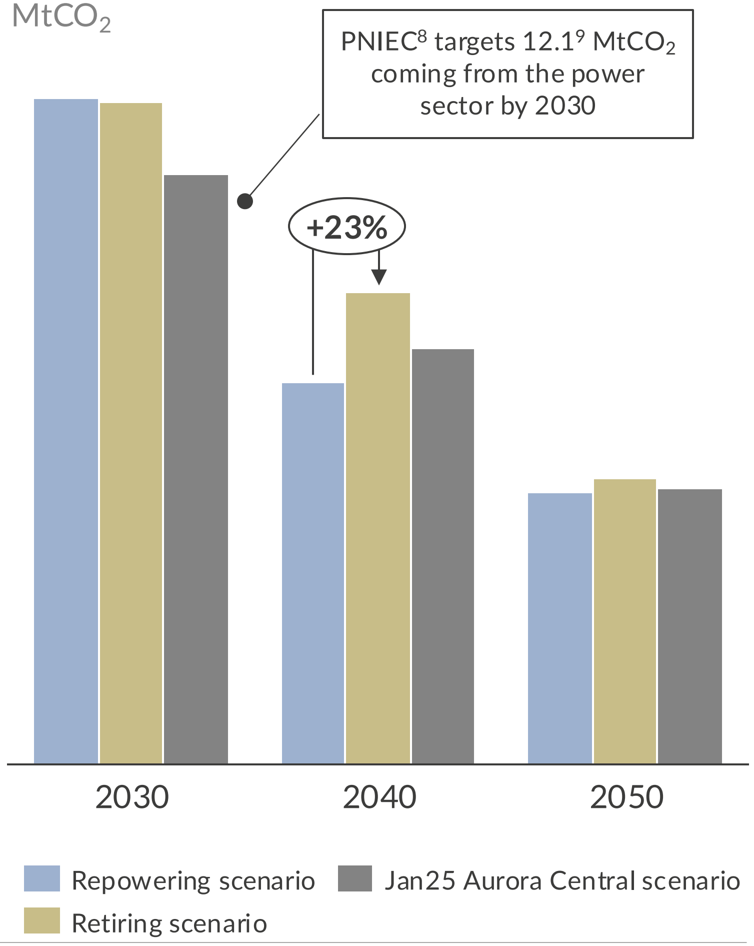
Prices increase in the late 2030s in the retiring scenario compared to the repowering scenario

Baseload price
€/MWh (real € 2023)



In the retiring scenario, carbon emissions increase by 2040 as thermal technologies replaces wind

Power sector annual carbon emissions
$MtCO_2$



1) Repowering scenario. 2) Retiring scenario. 3) January 2025 Aurora Central scenario. 4) Storage includes battery storage and pumped storage; represents energy exports. 5) Thermal includes coal, CCGT and other thermal. 6) Other RES includes biomass and other RES. 7) Wind includes onshore and offshore wind. 8) Spanish National Climate and Energy Plan. 9) The PNIEC target represents Spanish national emissions while Aurora forecast Spanish peninsular values.
Source: Aurora Research Energy

Zonal changes in wind capacity driven by wind decommissioning can have impacts on grid curtailment and asset revenues

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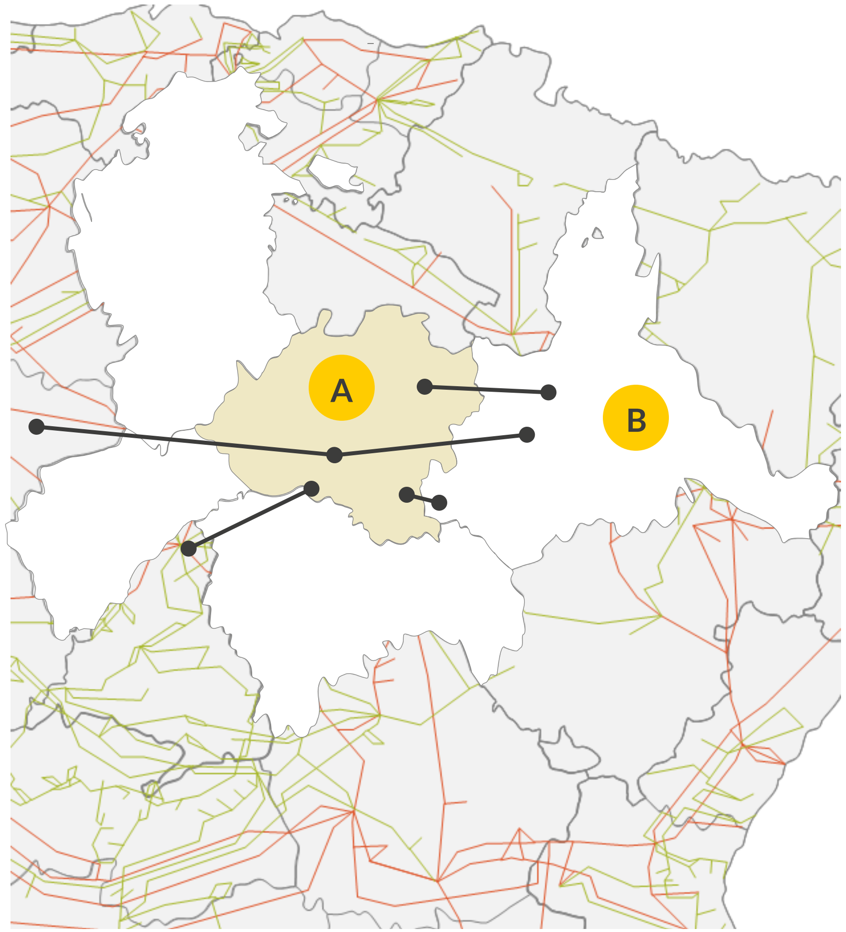
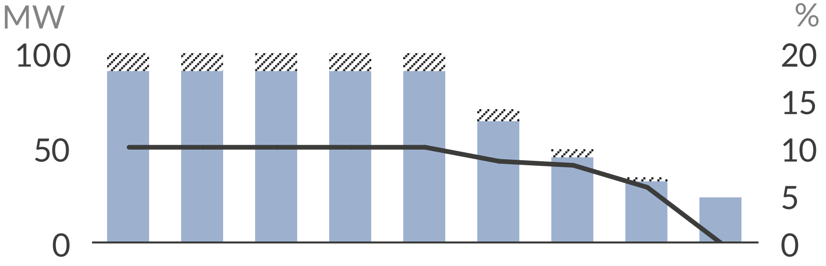
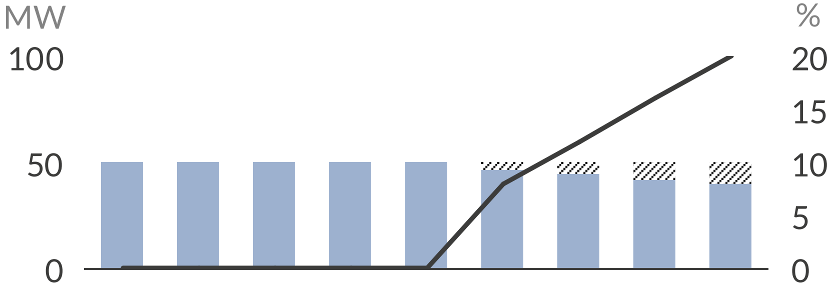
Peninsular high-voltage[1] transmission network topology



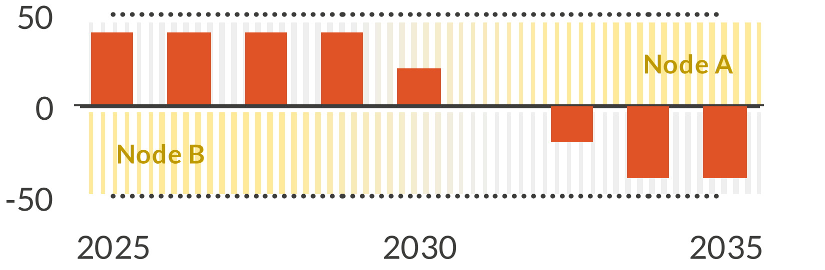
Illustrative wind power generation in A — **Curtailment**



Illustrative wind power generation in B — **Curtailment**



Illustrative net power flows from A to B and node position



Curtailment | Net Generation | Curtailment rate | Interconnection capacity | Flows A-B | Importer node | Exporter node

- In this illustrative example, region A is a net exporter to region B, due to higher wind capacity.
- As region A is a net exporter, wind in region A can experience grid curtailment due to limited export capacity.
- As capacity in region A is either retired or under repowering construction, region B becomes a net exporter to region A, as well as to other regions that previously received exports from A.
- As a consequence, region B starts experiencing grid curtailment as exporting lines are congested.
- At the same time, curtailment in region A is reduced as the region has less wind capacity and becomes a net importer region.

Source: Aurora Energy Research, REE, ENTSO-E.

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Key takeaways

1. The Iberian wind fleet is among the oldest in Europe; at the same time, it was the main contributor to the power mix in 2024, underscoring the importance of repowering. Between 2025 and 2035, Iberia will have to repower 17.1 GW (45% of the current fleet) to maintain the existing capacity. That equates to an annual repowering rate of 1.7 GW, requiring higher buildout capabilities than historical.

2. European regulation has recently undergone changes aiming to incentivise repowering. However, European regulation has not been yet fully transposed in Iberia. In Spain, regulation still stands as the main barrier for projects to be repowered as there are still regulatory aspects that must be developed. Portugal is more advanced in the process of transposing European regulation than Spain, including clear repowering definitions and simplified permitting.

3. Repowering projects can partially use existing infrastructure, lowering CAPEX and capitalise high load factor locations to boost project economics compared to new build assets. Moreover, early repowering offers further benefits as higher short-term revenues and lower OPEX compensate for CAPEX reduction.

4. Repowering the existing fleet would require increasing buildout capabilities in both Spain and Portugal to also allow for new build projects. After a period of construction in the early 2030s, the repowering of the existing fleet would decrease prices and emissions due to the renewed capacity having higher load factors.

5. If the current wind fleet isn't repowered and buildout remains at historical levels, systems would face a deficit of wind capacity during the 2030s, causing lower renewable generation, a significant increase in prices, higher emissions, and potential impacts on grid congestions and demand growth.

Sources: Aurora Energy Research

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Publication
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25 March 2025

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