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Below zero: Understanding Negative Power Prices in Iberia

Public Report by Aurora Energy Research

February 2025

Introducing the speakers

AURORA

Christina Rentell

Research Lead
France and Iberia

Javier Pamos

Research Associate

David Corcoles

Research Associate

Alejandro Zerain

Advisory Lead

Guillermo Burillo

Advisory Associate

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- Hydrogen H_2
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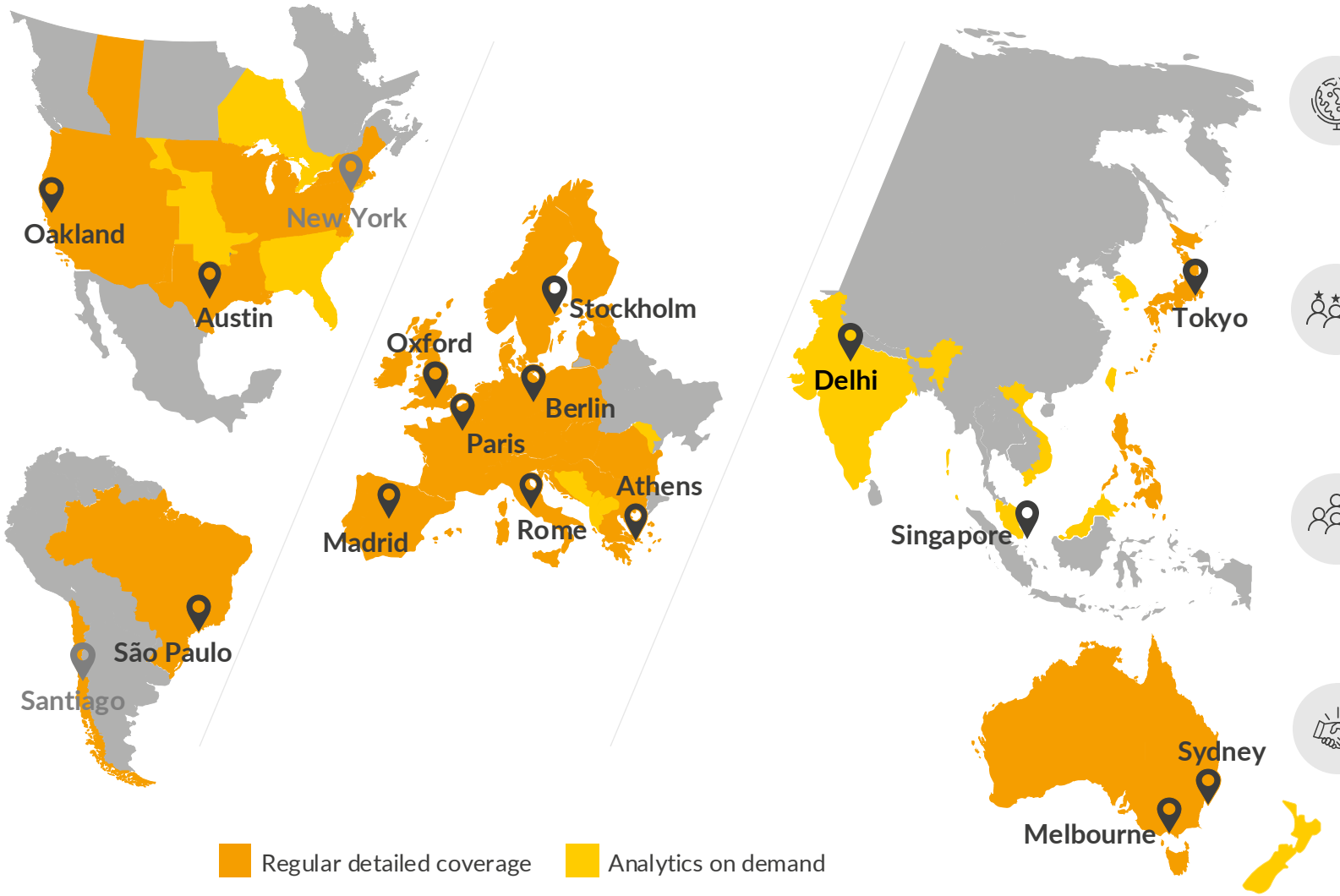
- Natural gas



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Aurora's **Spain Grid Curtailment Add-on** will provide you with our view of curtailment evolution until 2030

Spain Grid Curtailment Add-on

Report

Report

- Overview of the market framework for Technical Restrictions and policy developments
- Historical assessment of grid curtailment in Spain, focused on renewable assets
- **Biannually updated – Next update Q3 2025**

Historical data Dashboard

Historical data dashboard

- All historical curtailment data in Spain, per province and per programming units available as dashboards on our EOS platform. Updated daily.

Data

Data

- The following deliverables will be given for the Central scenario in the until 2030:
  - Demand per province
  - Capacity stack per province
- The following deliverables will be given for each curtailment group[1]:
  - Grid curtailment [%]
  - Grid curtailment [GWh]
  - Weighted average price of curtailment [€/MWh]
- Sensitivities
  - Grid development (additional lines, transformers and substations) is a key driver of future curtailment. Given the uncertainty, we provide a sensitivity considering a higher percentage of planned improvements to the grid.
- **Biannually updated – Next update Q3 2025**

Grid Modelling

Grid Modelling integration

(From February 2025 update)

- Spanish power flow grid model that forecasts upcoming grid congestions in the system through 2030
- Integrates the expected network evolution based on the latest National Network Development plan
- The deliverables covers all provinces located in Peninsular Spain

For more information, please reach out to

Mar Escobedo

[mar.escobedo@auroraer.com]

Source: Aurora Energy Research

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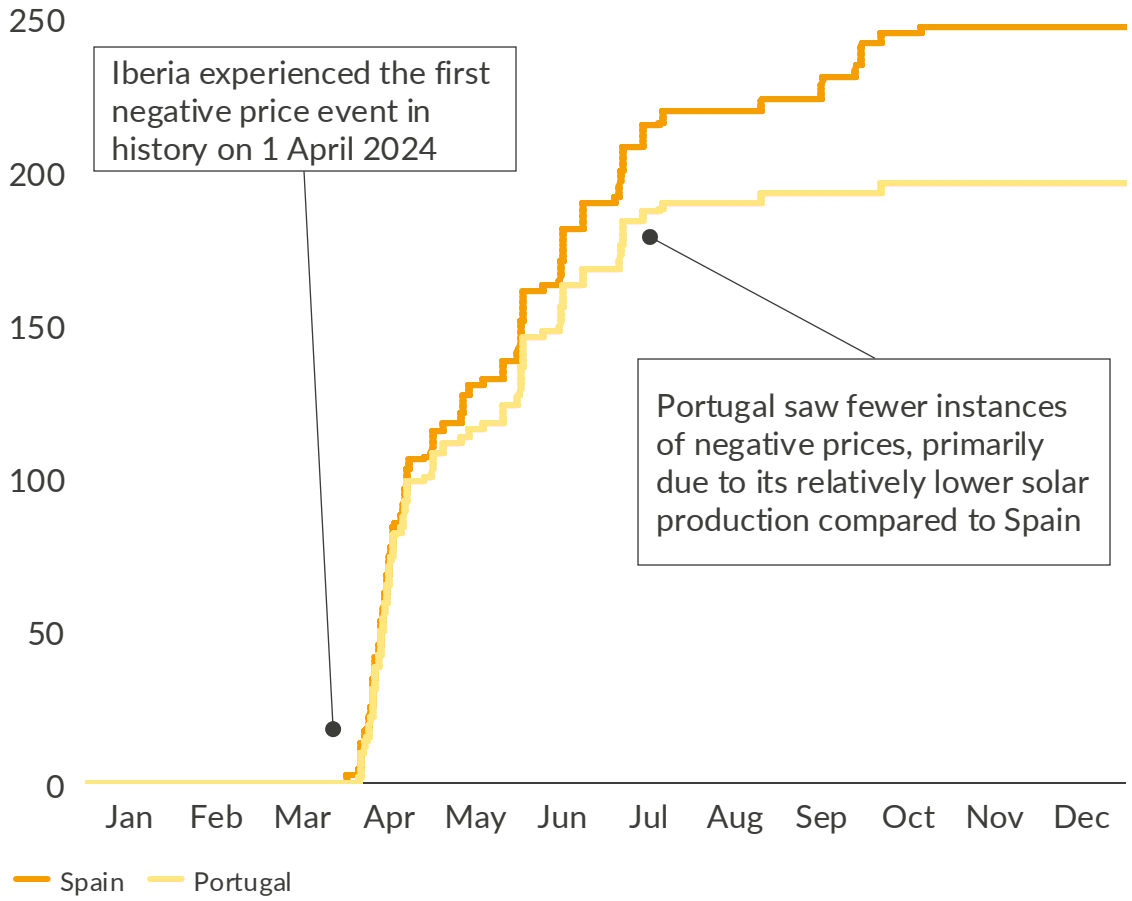
[mar.escobedo@auroraer.com]

In April 2024, the Iberian Day-Ahead Market saw its first-ever negative price, a trend that continued throughout 2024 during periods of RES oversupply

In 2024, the Spanish Day-Ahead Market recorded 247 instances of negative prices, while the Portuguese one registered 196 negative prices

Cumulative instances of DAM[1] negative price hours in Spain

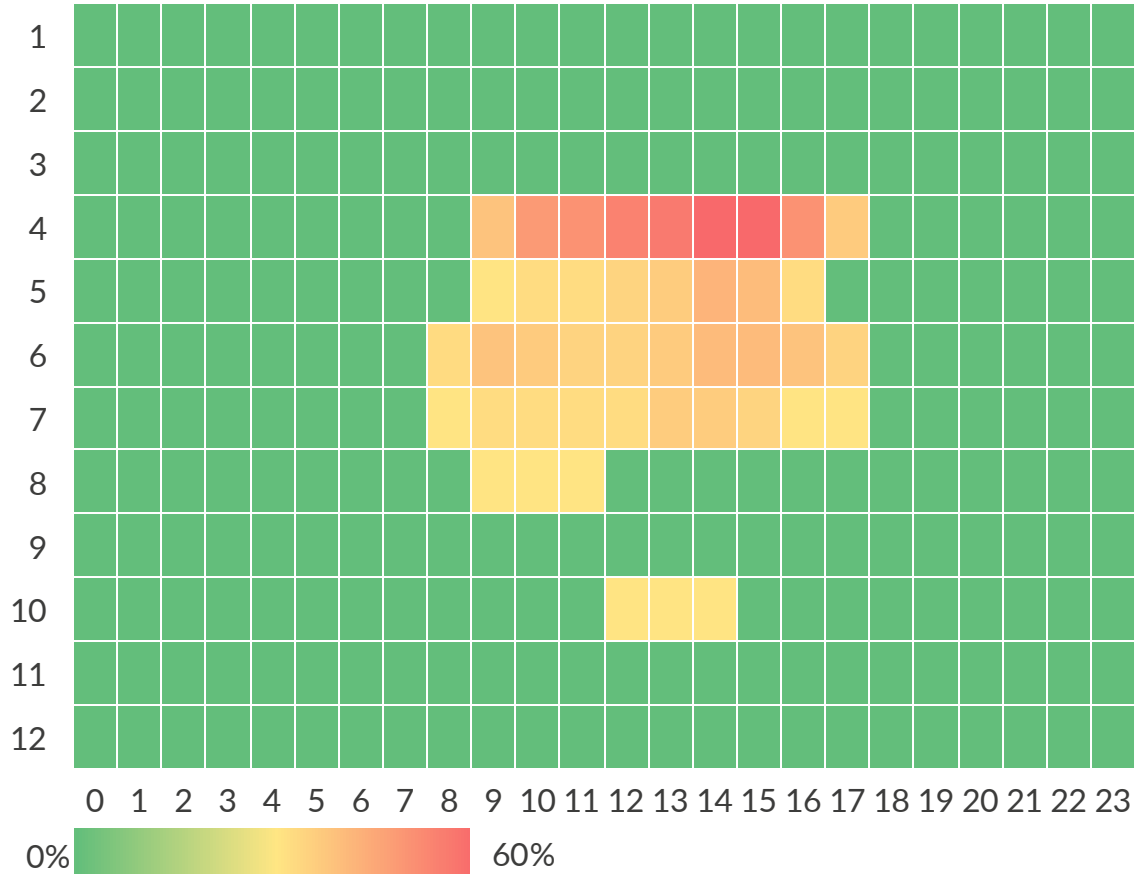
Hours[2]



Negative price hours occurred only during daylight hours and were frequent during low-demand periods, particularly during Spring and Sundays

Heatmap of negative prices in Spain by hour (X-axis) and month (Y-axis)

Total % of hours 2024[1]

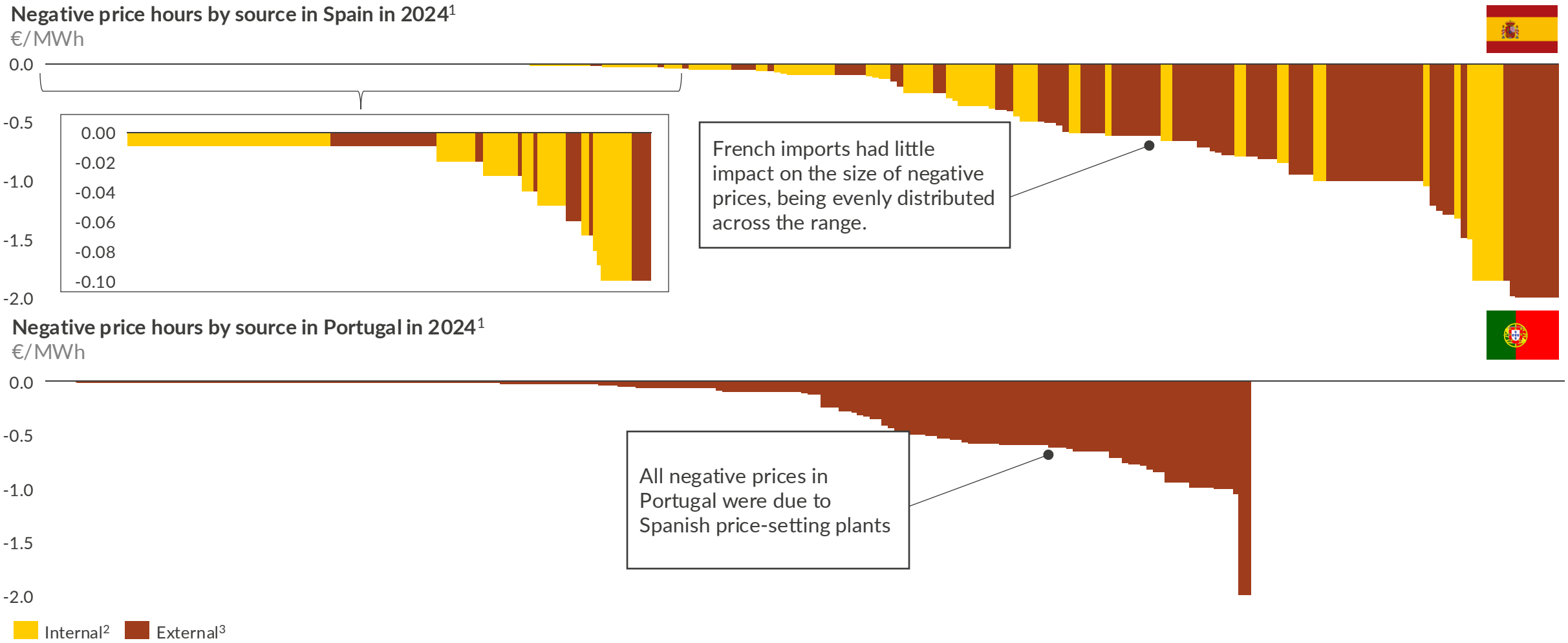


1) Day-Ahead Market. 2) Data refers to day-ahead market.

Sources: Aurora Energy Research, OMIE

There are two clear types of negative prices in Iberia – those caused by internal bidding and those caused by neighbouring countries

Interconnections play a crucial role in Iberian negative price events, as all negative prices in Portugal were set by Spanish plants, while 46% of Spanish negative prices were driven by French imports. Additionally, the Iberian market decoupled on 51 occasions, resulting in positive price in Portugal while Spain experienced negative price



1) Data refers to day-ahead market. 2) Referring to hours with negative prices where the electricity exported by Spain or Portugal has a higher volume than the one imported. 3) Referring to hours with negative prices where the electricity imported by Spain or Portugal has a higher volume than the one exported.

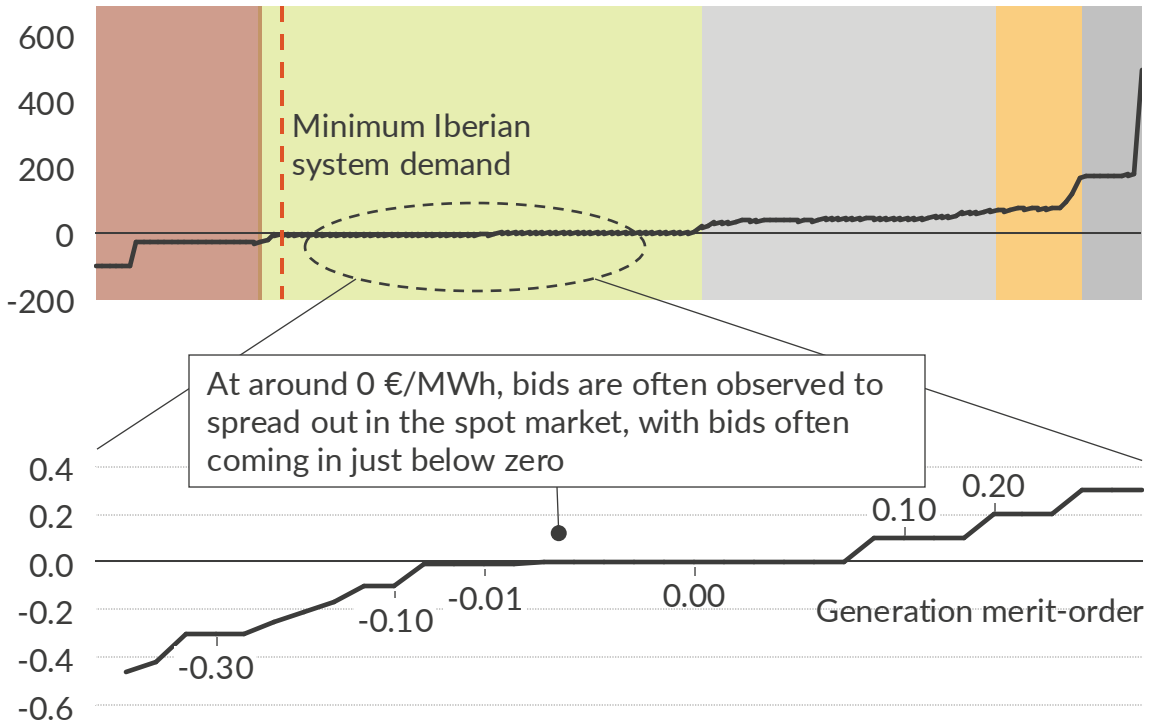
Sources: Aurora Energy Research, OMIE, REE, REN.

Renewables bid below zero to secure Day-Ahead Market participation and thus unlock revenue streams such as subsidies, PPAs[1], GoO[2], and participation in AS[3]

Prices fluctuate around 0 €/MWh as assets have different financial strategies incentivising them to bid just below, at or above 0€/MWh

- Almost 90% of negative price hours in 2024 have been between 0 and -1 €/MWh as the majority of RES plants bid between 0 and -3 €/MWh.

Illustrative day-ahead merit order – Price vs Generation Supply bids



Negative bids result from five bidding strategies designed to ensure participation in the Day-Ahead Market for economic and technical reasons

Inflexible generation

- Assets unable to modulate production bid negative to secure acceptance in the merit order and avoid imbalance costs

Contracts incentivising production (e.g. PPAs[1])

- Contracts such as PPAs might require a certain level of production, leading to negative bids to ensure acceptance

Guarantees of Origin

- Merchant RES or RES plants under PPAs might bid slightly under zero to ensure production for the issuance of GoOs[1]

Subsidies

- Assets bid negatively to secure subsidies tied to production, even during low-price periods

Participation in Ancillary Services

- Plants bid negative to secure volumes in the DAM[4], which allows them to regulate down in AS[3] and receive additional revenues

1) Power purchase agreements. 2) Guarantees of Origin. 3) Ancillary services. 4) Day-Ahead market.

Sources: Aurora Energy Research, MITECO, REE

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[mar.escobedo@auroraer.com]

Negative price bids in Iberia rose by up to 25% in 2024, primarily driven by RES bids, increasing the likelihood of negative price events in future years

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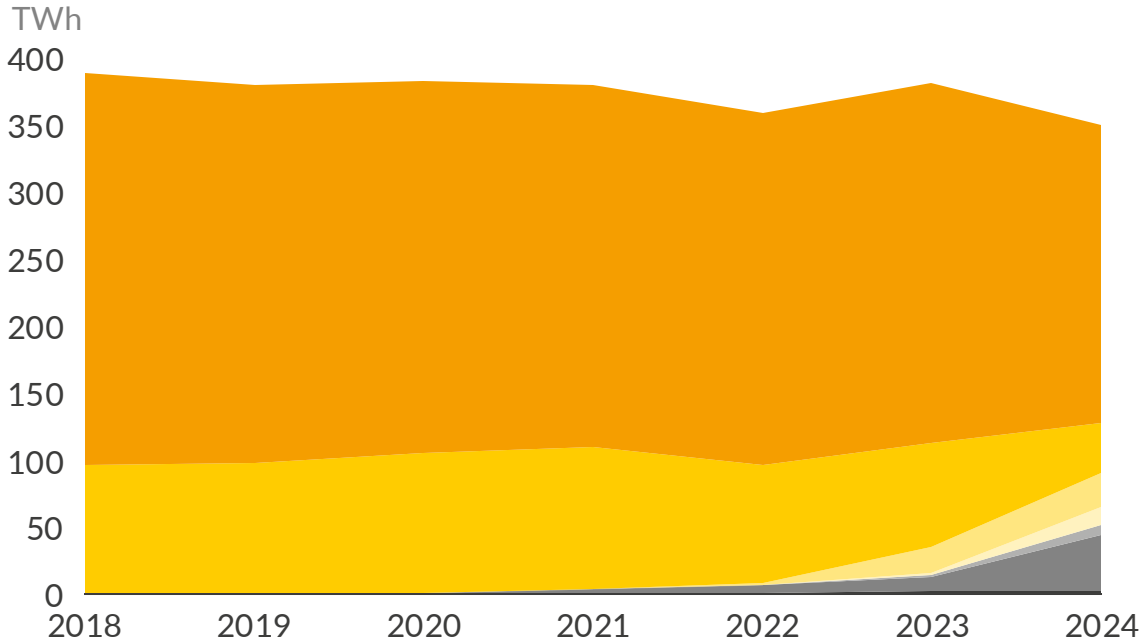
Although the first negative price occurred in 2024, negative price bids have been present and increasing since 2020, leading to 25% of the bids in 2024

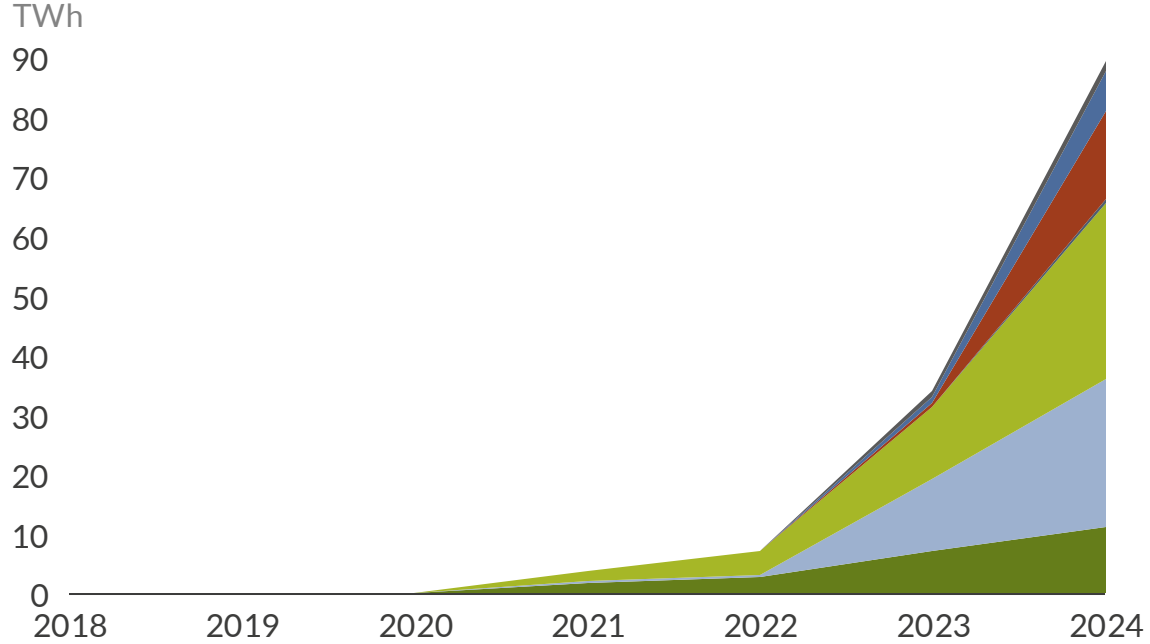
Volume offered in the Iberian DA[1] market by price range[2]



- Negative bids began to emerge in 2021 as some solar plants with additional revenues started to submit negative bids and biomass plants shifted their bidding strategy to consider their must-run constraints.
- By 2024, the total volume of electricity offered at negative prices surpassed the volume offered at zero, driven by a threefold increase in the former.

Volumes offered at negative prices reached 90 TWh in 2024, primarily offered by solar (33%) and wind (27%)

Volumes offered at a negative bid in the Iberian DA[1] market by technology[2]



- Until 2023, only renewables volumes were offered at negative prices. However, this trend shifted in 2023, when nuclear, coal, and CCGTs also began submitting bids below zero due to must-run constraints.
- Solar plants and onshore wind account every year for the largest volumes of bids at negative prices.

1) Day-ahead. 2) Data until 10 October 2024. 3) Solar includes solar PV and solar CSP. 4) Other RES includes biomass and renewable cogeneration.

Source: Aurora Energy Research, OMIE

Renewables adopted negative bidding to unlocking access to additional revenue streams; nuclear adapted to zero prices due to must-run constraints

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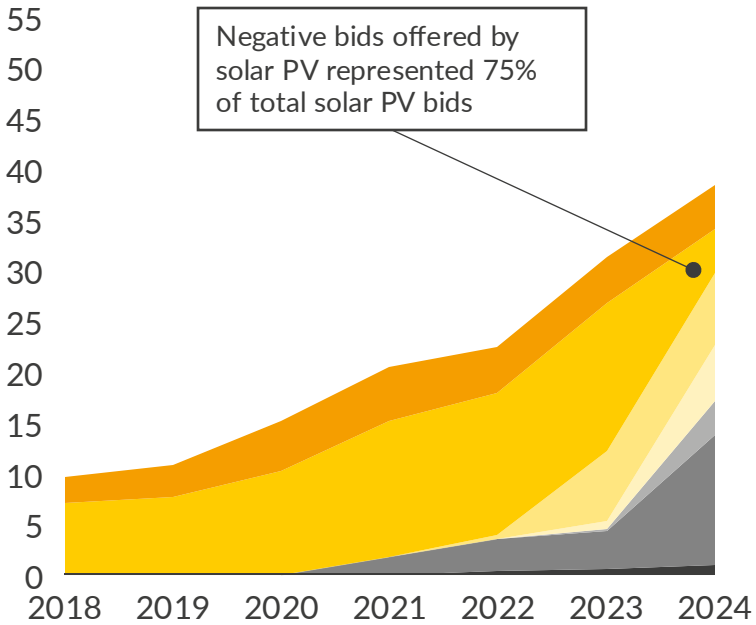
In 2024, 75% of solar volumes were offered at negative prices, a 115% increase from 2023

Volume offered by solar plants[1] in Iberian DA[2]

TWh

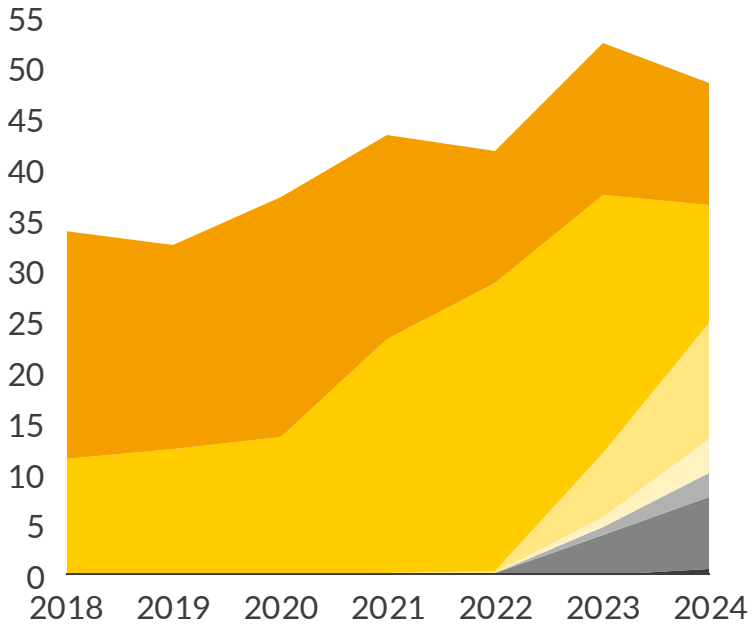


- The growth of solar negative price bids outpaces the growth of total solar bids, indicating a shift in strategies for both new and existing assets.
- During 2024 53% of solar negative bids falling within the range of 0 to -3 €/MWh.

Onshore wind negative bidding began in 2023, with negative bids rising by 107% through 2024

Volume offered by onshore wind in Iberian DA[2]

TWh

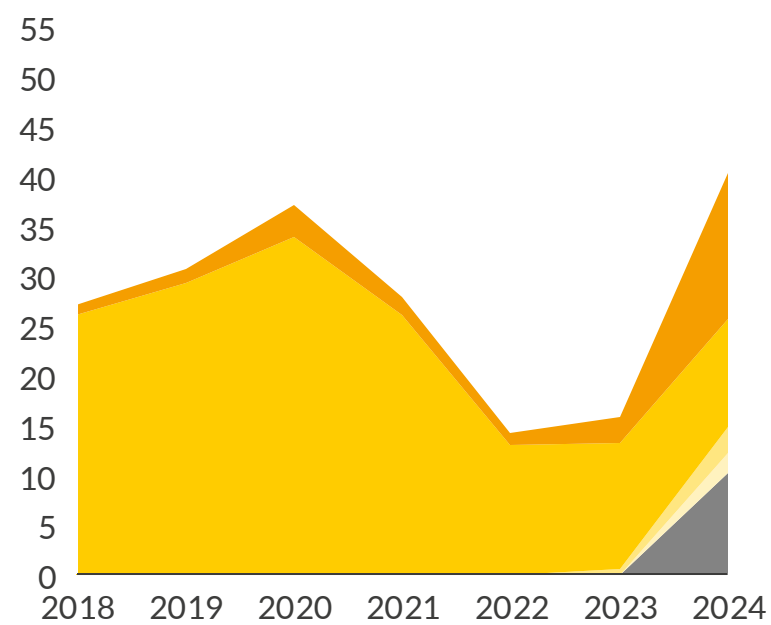


- In 2024, 51% of wind volumes were bid at negative prices, marking a significant increase from 22% in the previous year.
- In 2024, wind negative bids totalled 22 TWh, with 69% falling in the -3 €/MWh to 0 €/MWh range.

Nuclear strategy shifted to negative bids during central hours to ensure participation in the market

Volume offered by nuclear plants in Iberian DA[2]

TWh



- In 2024, 37% of nuclear volumes were offered at negative prices.
- Negative price volumes were offered primarily during daylight hours from July onwards to ensure market participation during times of low demand.

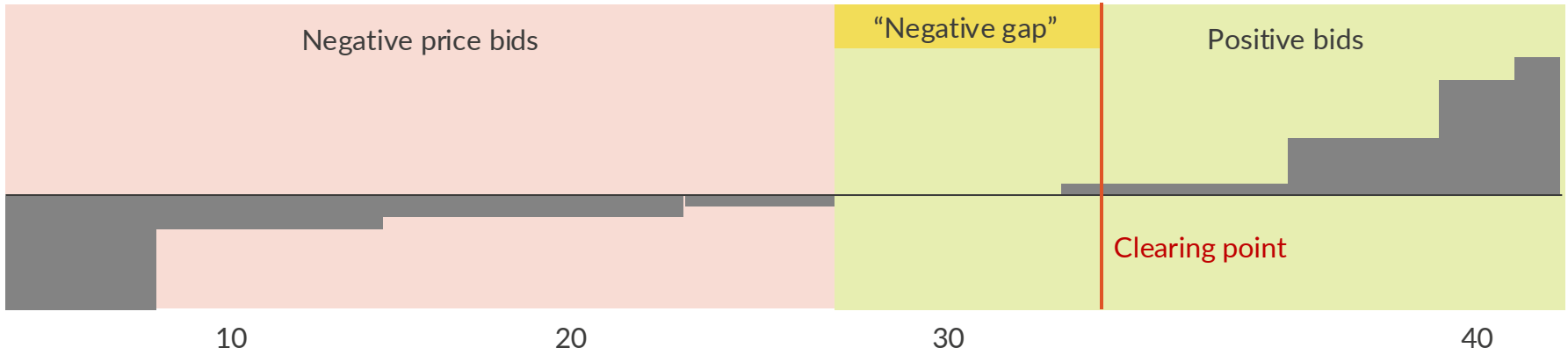
(-∞; -50 €/MWh) [-50; -3 €/MWh) [-3; -2 €/MWh) [-2; -1 €/MWh) [-1; 0 €/MWh) 0 €/MWh (0 €/MWh; +∞)

1) Solar includes solar PV and solar CSP. 2) Data until 10 October 2024; it refers to day-ahead market.

Source: Aurora Energy Research, OMIE

During 2024, the Day-Ahead Market clearing point was around 10 GW away of closing at negative prices in 778 hours

Illustrative difference between clearing bid and closest negative price bid in 2024
€/MWh (Y-axis) vs GW (X-axis)



Difference between clearing bid and closest negative price bid in 2024[1]
Number of hours (Y-axis) vs GWh (X-axis)

1) Data refers to the Iberian day-ahead market and is until 10 October 2024.

Source: Aurora Energy Research, OMIE

- The "negative gap" represents the gap between clearing point and the closest negative bid. This metric assesses how close the market came to clearing a negative price, whether due to lower demand or an increase in negative bids.
- In 2024, roughly 778 hours, 9% of hours, were less than 10 GWh away from negative clearing prices. Specifically, 185 hours, i.e. 2% of the hours in 2024, were less than 5 GWh away from negative prices.
- During these 778 hours, solar generation was higher than the average solar production, indicating that high solar generation enlarges the negative price range in the merit order due to solar PV negative price bids.

Negative prices are likely to remain near zero, occurring mainly during peak solar hours, depending on wind generation to a lesser extent

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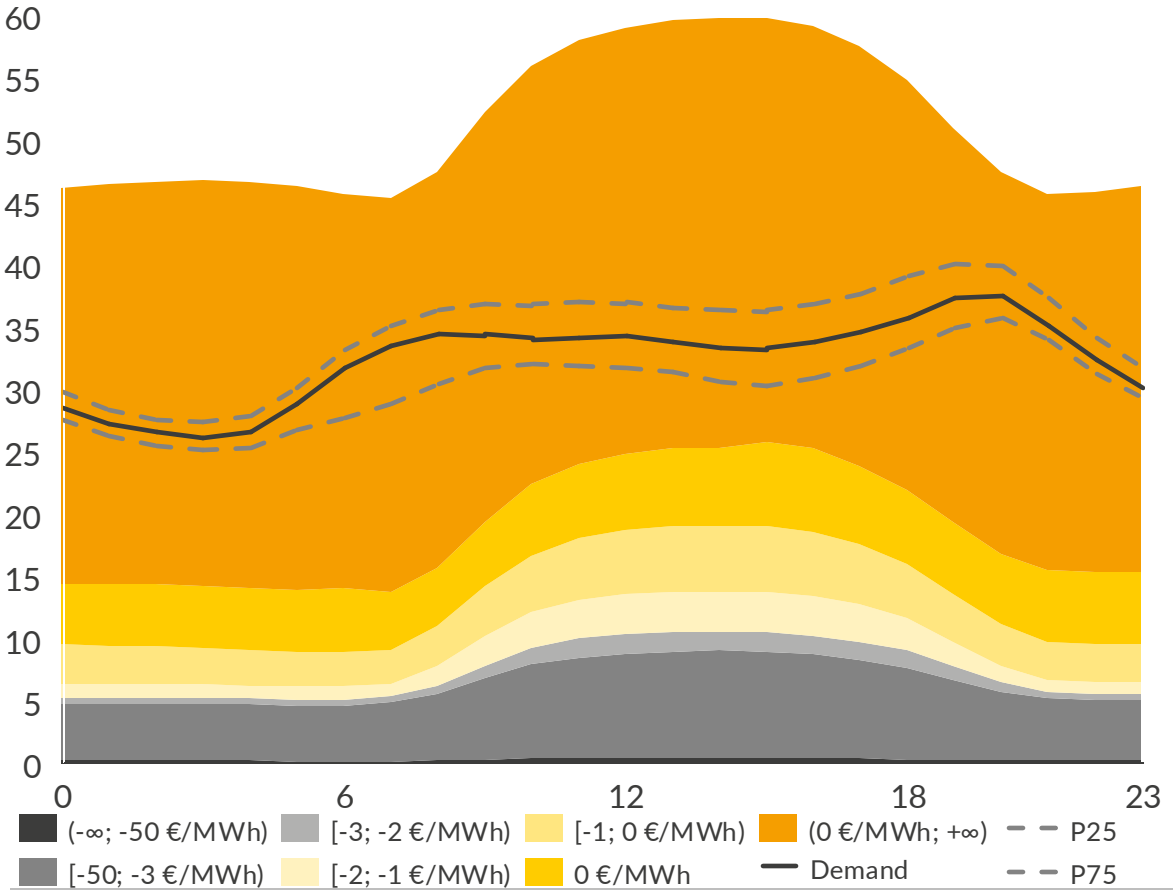
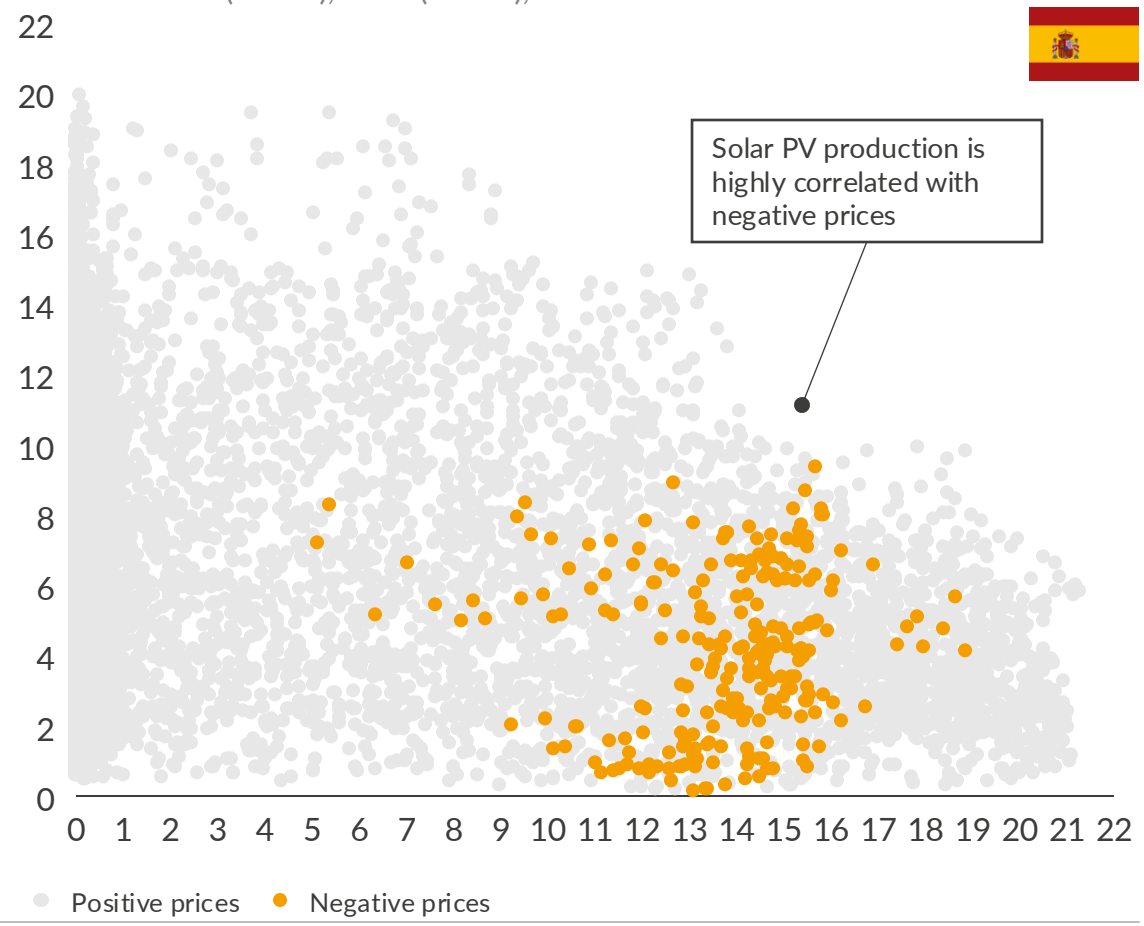
Demand is likely to reach near-zero price bids during central hours but remains far from extreme negative levels, making such prices unlikely

Average volume offered in DA[1] market with demand in 2024 in Iberia by hour[2]
GW



Most negative prices occurred during high solar generation, with wind having a smaller impact, making solar a key driver of negative price events

Onshore wind and solar[3] hourly volume cleared in Spanish DA[1] market in 2024
Onshore wind (Y-axis), solar (X-axis), GWh



1) Day-ahead market. 2) Data until 10 October 2024. 3) Solar includes solar PV and solar CSP.

Source: Aurora Energy Research, OMIE

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In the next years, additional bids may shift into negative ranges as RES supply increases, leading to a higher frequency of negative prices relative to 2024

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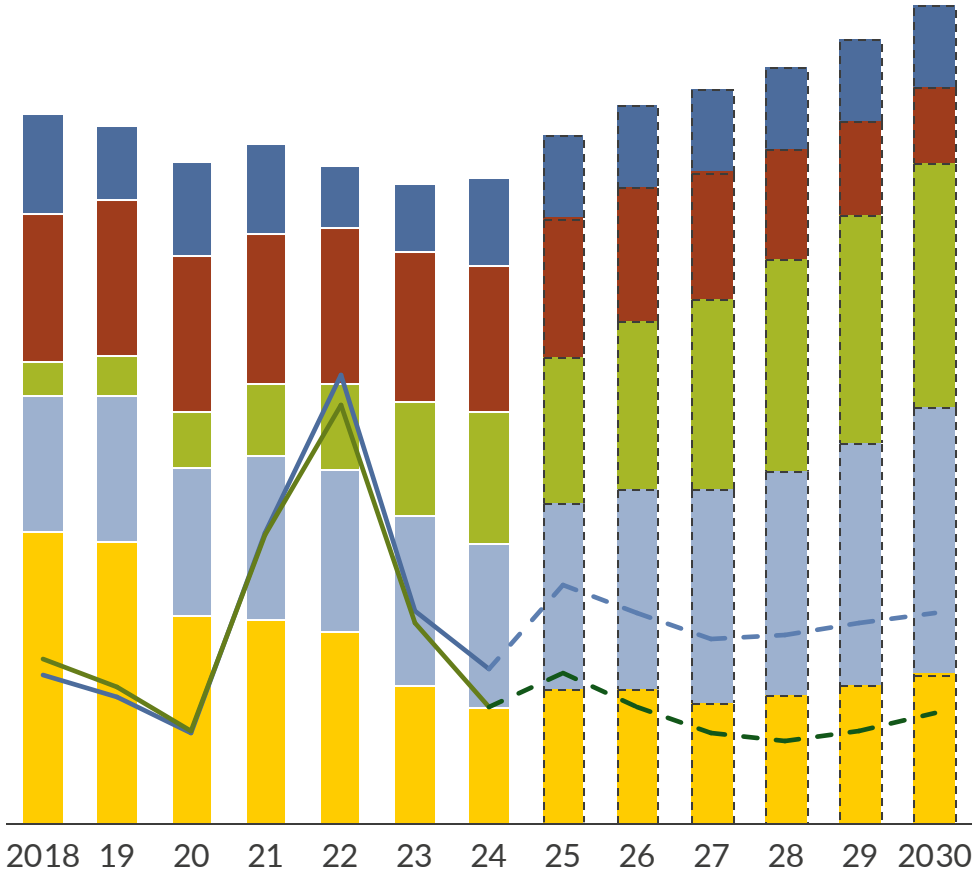
Yearly generation and residual demand
TWh

Capture prices
€/MWh



High RES growth and declining residual demand drive price cannibalisation, with RES more likely to set prices

- Renewable volumes, offered at both near-zero and negative prices, have increased and will continue to do so in the next years, following the expected renewable buildout.
- Renewable buildout outpaces demand growth, causing renewable bids to set the price more often.
- As a consequence, the number of zero and negative price events is expected to remain high in the coming years, until 2028.

Following price cannibalisation, renewable plants will look for additional revenues, incentivising a shift to negative price bidding

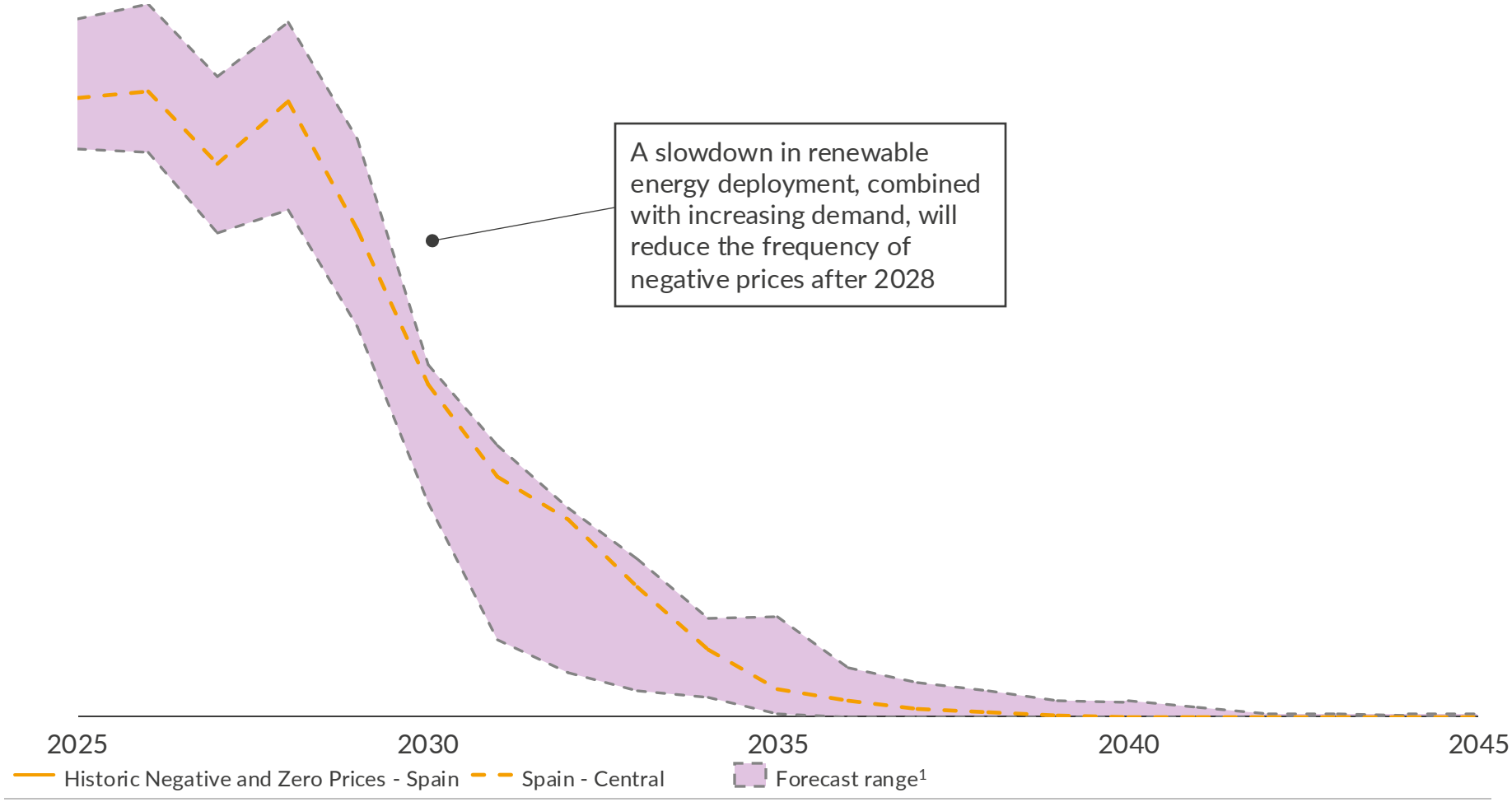
- Aurora expects the growth of renewable generation, with onshore wind and solar projected to exceed 150 TWh by 2028, to be a key driver of day-ahead price cannibalization in the near future.
- Renewable price cannibalisation in the coming years will drive renewable plants to explore alternative revenue sources, leading to a shift towards negative price bidding strategies to ensure Day-Ahead participation and revenues tied to Day-Ahead generation.

1) Forecast of capture prices.

Source: Aurora Energy Research, OMIE

Aurora projects zero and negative prices to gradually decline from 2029 due to demand growth and slower RES buildout

Yearly occurrence in Spanish Day-Ahead Market
number of negative and zero hours per year



1) The forecast range accounts for various scenarios based on different weather years and market sensitivities.

Sources: Aurora Energy Research, OMIE, ESIOS

- Following a high RES capacity buildout in the 2020s and the resulting price cannibalisation, the pace of renewable deployment is expected to slow down in the late 2020s.
- Towards the 2030s, an increasing share of renewable generation operates on a merchant basis as price cannibalisation declines. This leads to a lower share of RES bidding at negative prices.
- With fewer RES additions, lower negative bidding share and rising demand in the late 2020s, the merit order displaces away from the negative price range.
- Consequently, the occurrence of negative prices begins to decline from the late 2020s and is expected to disappear entirely by 2040.

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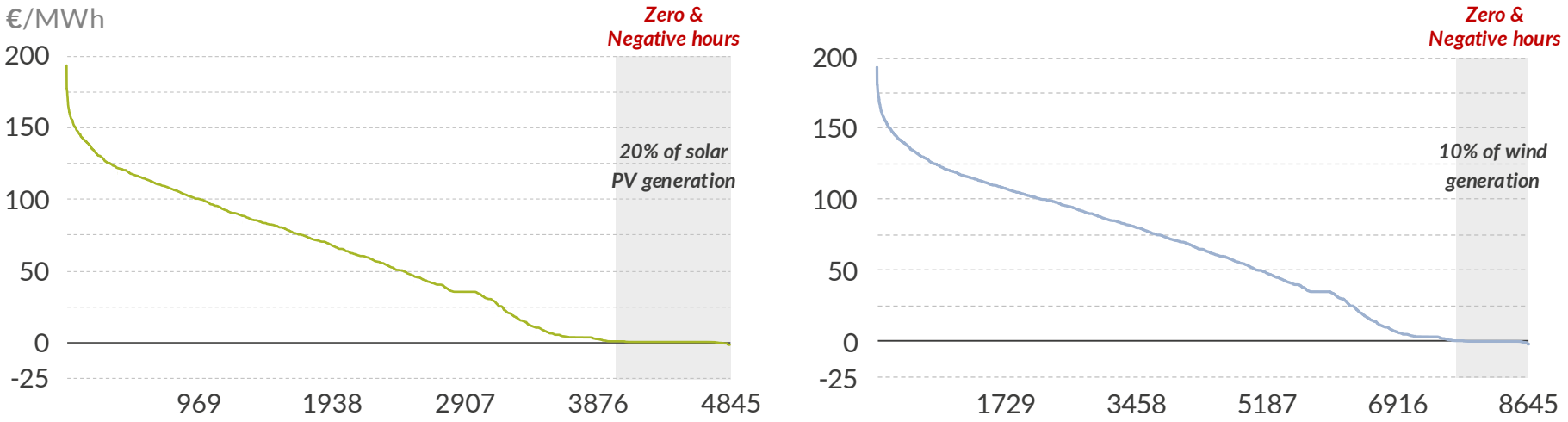
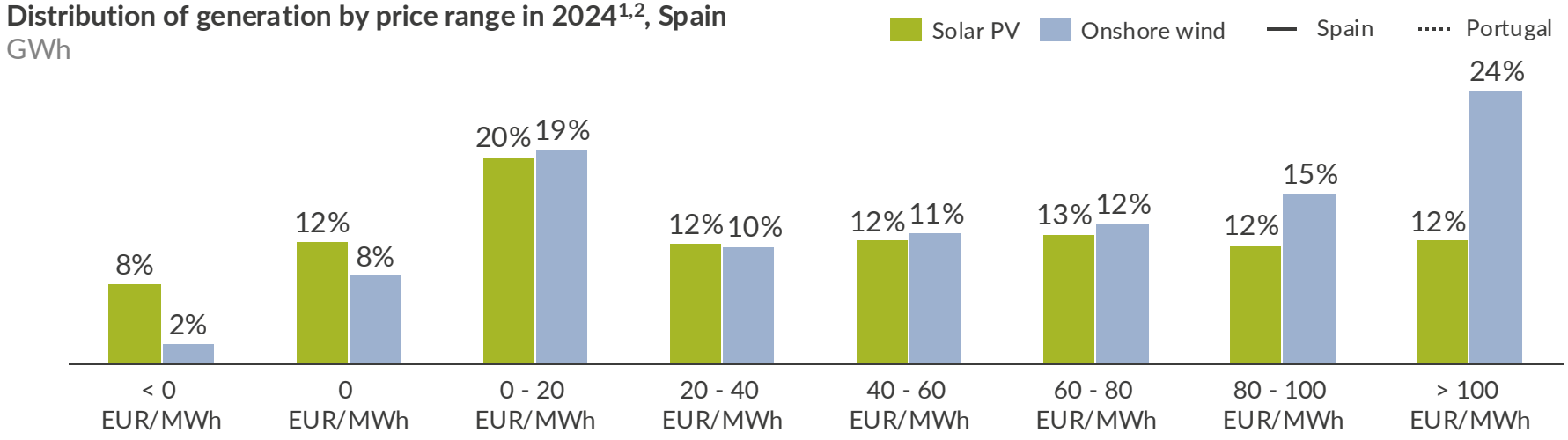
The impact of negative hours is heavier for solar PV assets, both on number of hours and generation, compared to onshore wind

Price duration curves for an illustrative asset in 2024[1,2]



Distribution of generation by price range in 2024[1,2], Spain



1) Illustrative onshore wind projects in SE-Spain and N-Portugal. 2) Illustrative solar PV projects in NE-Spain and SE-Portugal.

Sources: Aurora Energy Research, REE

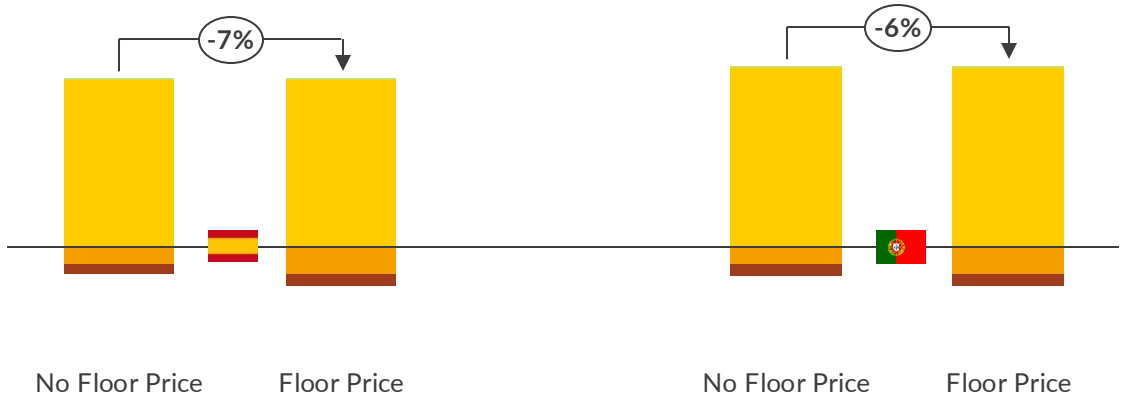
- Solar PV and onshore wind generate at different hours throughout the year, being affected differently by market prices.
- High solar PV capacity in Iberia, with concentrated generation at the midday hours, leads to a higher proportion of solar PV generation at negative hours.
- Onshore wind generates more hours throughout the year (>8600 hours for an illustrative asset) compared to solar (>4800 hours for an illustrative asset), but solar concentrates higher generation volume at low priced hours.
- As a result, solar PV assets in 2024 had a higher share of its generation sold at zero or negative prices than onshore wind.

Not accounting zero & negative hours in the PPA structure leads to~7% and ~14% revenue difference in 2024, for wind and solar respectively

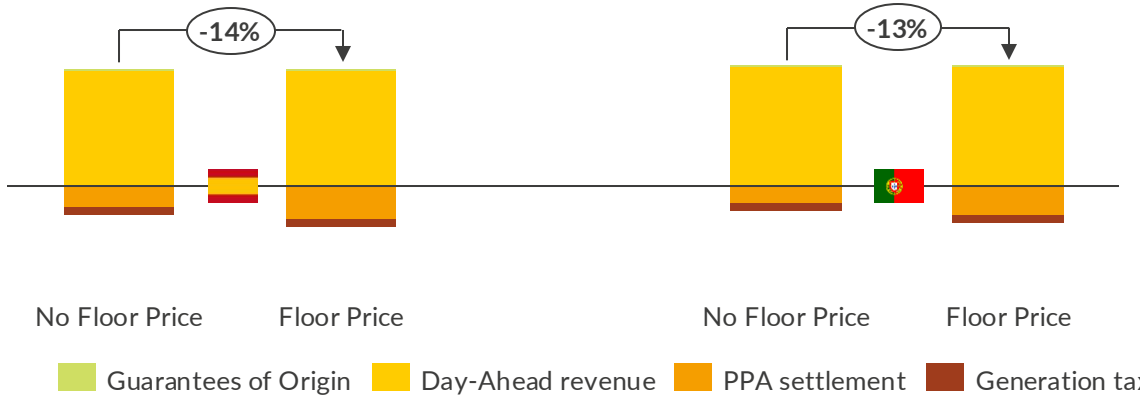
2024

Breakdown of asset revenues
€/MWh (nominal)

Onshore wind[1]
10-y PaP[3] PPA[4]
COD 2024



Solar PV[2]
10-y PaP[3] PPA[4]
COD 2024



PPA Settlement comparison

PPA with No Floor Price

PPA settlement valid if DA[5] price <= 0

PPA with Floor Price at 0

No PPA settlement if DA[5] price <= 0

- Based on historical data, in 2024 there was a total of 784 hours below or equal to zero in Spain, 9% of total hours, 8% for Portugal.
- Including a floor price in the PPA limits the offtaker's exposure by preventing settlement when prices fall below the threshold, shifting the risk of negative prices to the seller.
- The seller may continue to sell on the Day-Ahead market if they can access other sources of revenue (e.g. GOs).
- Solar sees a higher impact from a zero-price threshold reducing revenues in 2024 by 13-14%, whereas for onshore wind the revenue reduction is 6-7%.
- Lower number of negative hours in Portugal in 2024 reduced the impact of adding a floor price to the PPA clauses.

1) Illustrative onshore wind projects in SE-Spain and N-Portugal. 2) Illustrative solar PV projects in NE-Spain and SE-Portugal. 3) Pay-as-Produced. 4) Onshore wind and solar PV PPA prices estimated with Aurora's PPA valuation tool, Lumus, for a 10-year tenor and 75% contracted volume starting upon COD, in Spain & Portugal, respectively. PPA valuation is based on Aurora's current price forecast, which includes zero & negative price hours. 5) Day-Ahead Market.

Sources: Aurora Energy Research

Throughout the PPA duration, the impact of including zero & negative prices decreases, as their frequency declines over its tenor

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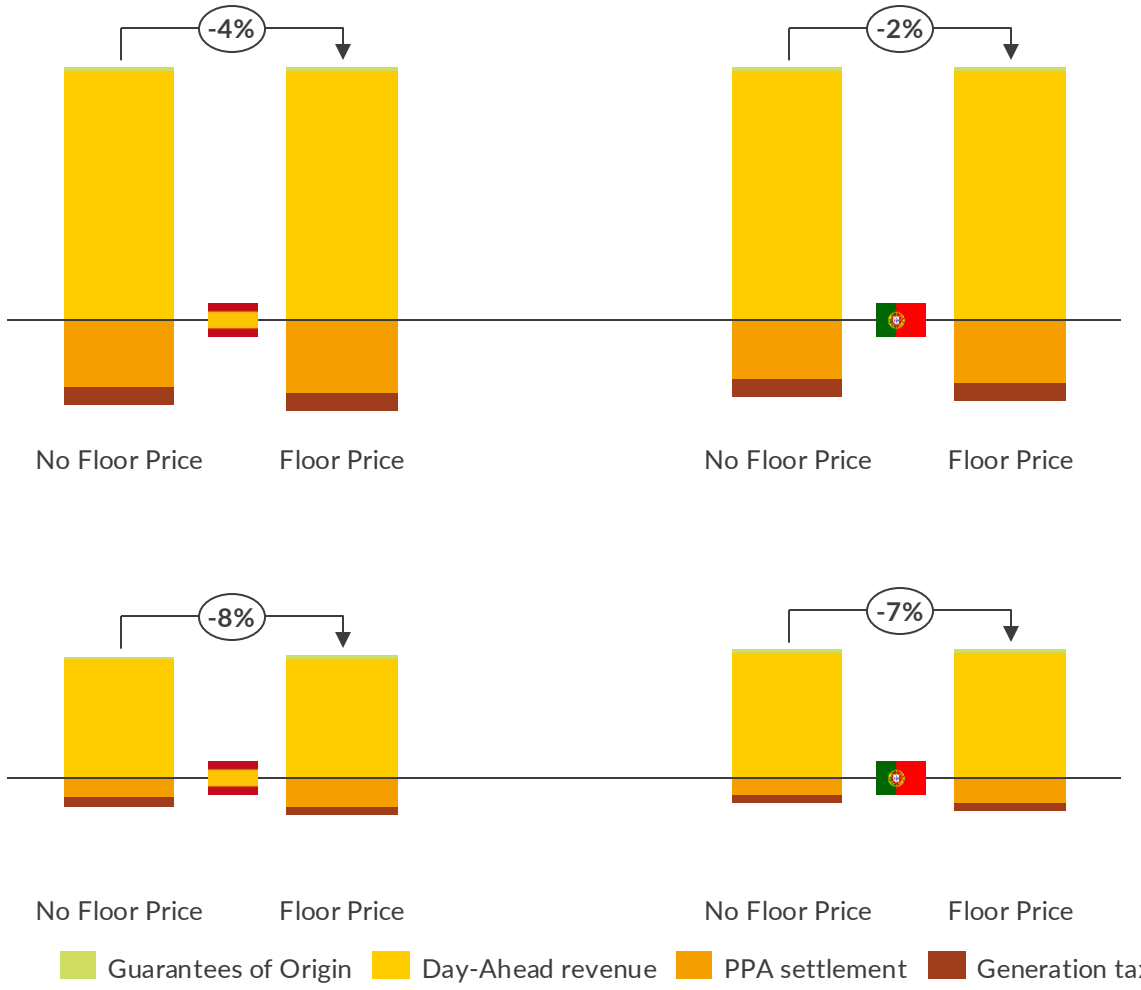
2026-2035

Onshore wind[1]
10-y PaP[3] PPA[4]
COD 2026

Solar PV[2]
10-y PaP[3] PPA[4]
COD 2026

Breakdown of asset revenues
€/MWh (nominal)



PPA Settlement comparison

PPA with No Floor Price

PPA settlement valid if DA[5] price <= 0

PPA with Floor Price at 0

No PPA settlement if DA[5] price <= 0

- As negative prices reduce and eventually disappear in Aurora's forecast, the effect of implementing a floor price threshold into the PPA clauses reduces over the PPA tenor.
- Solar sees a higher reduction in revenues of ~7% and onshore wind of 2-4% over the PPA tenor with the inclusion of a floor price.
- The impact is lower over the PPA tenor than in 2024 as we expect the frequency of negative prices to decline over time.

1) Illustrative onshore wind projects in SE-Spain and N-Portugal. 2) Illustrative solar PV projects in NE-Spain and SE-Portugal. 3) Pay-as-Produced. 4) Onshore wind and solar PV PPA prices estimated with Aurora's PPA valuation tool, Lumus, for a 10-year tenor and 75% contracted volume starting upon COD, in Spain & Portugal, respectively. PPA valuation is based on Aurora's current price forecast, which includes zero & negative price hours. 5) Day-Ahead Market.

Sources: Aurora Energy Research

Mitigation strategies, such as ancillary services participation and co-location, can reduce RES assets' exposure to negative prices and enhance profitability

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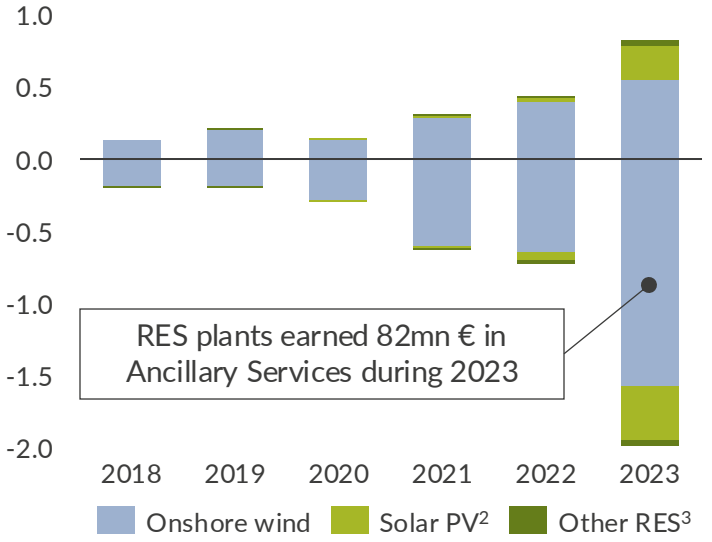
1 Participation in ancillary services

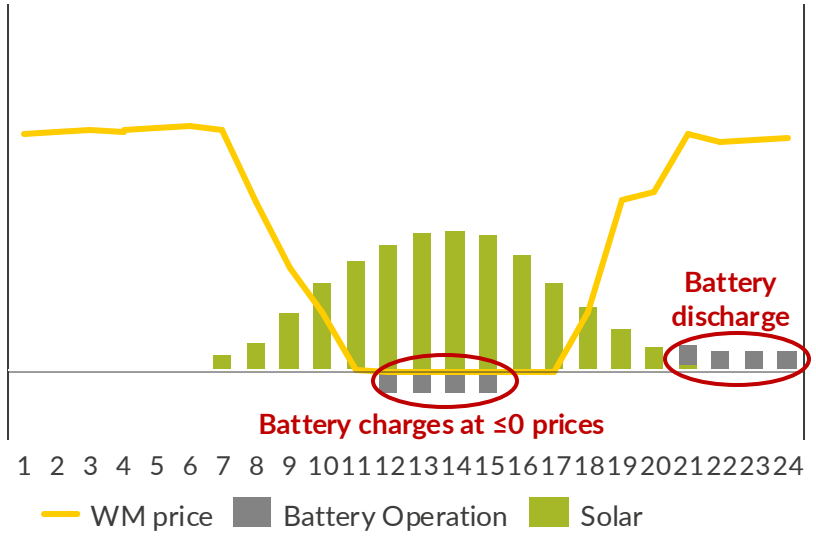
Total RES Ancillary Services volumes[1] in Spain



- Participation of RES in Secondary Reserve and real-time markets can help to mitigate cannibalisation in the Day-Ahead and provide additional revenues
- RES represented 2.8 TWh of the total Ancillary Services volume in 2023, a 10x increase since 2018

2 Co-location/hybridisation with storage or other technologies

Solar & BESS operations MWh — **Day-ahead prices** €/MWh



- Solar PV production concentrates at mid-day, with hours at zero or negative prices
- The hybridisation with onshore wind and / or batteries reduces energy spillage and allows for sale in high price hours

3 Risk sharing allocation under PPA between seller/offtaker

To allocate the risk of zero or negative prices between seller and offtaker, new PPA clauses may include:

1. **Price thresholds:** threshold at where the PPA does not settle and therefore the offtaker does not purchase the energy produced from the seller, determined in *€/MWh*.
2. **Volume cap:** annual settlement at zero or negative hours capped at a given volume, determined in *GWh/year*.
3. **Payment cap:** annual settlement at zero or negative hours capped at a given amount, determined in *€/year*.
4. **Consecutive hours:** limitations to price thresholds under certain conditions – i.e. floor price only applies when price threshold occurs consecutively for *n* hours.
5. **Benefit sharing mechanisms**: settlement payments with respect to PPA strike price lowered correspondingly to negative prices

Aurora can provide asset-specific assessments of these mitigation strategies as part of our Advisory services

1) Volumes in Secondary, Tertiary and Replacement Reserves. 2) Includes solar ground-mounted PV. 3) Other RES includes biomass and renewable cogeneration

Sources: Aurora Energy Research, REE.

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For more information, please reach out to **Mar Escobedo**

[mar.escobedo@auroraer.com]

Key takeaways

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1. Renewables bid at negative price to secure a place in the merit order, thus unlocking additional revenue streams like GoOs and PPAs, which depend on Day-Ahead market participation. As renewables increasingly secure revenue through these contracts, the share of RES-offered volumes at negative prices has risen from 0% in 2020 to 62% in 2024, leading to a higher volume of offers at negative price levels.

2. In 2024, Iberian hourly demand averaged 32 GW, occasionally dipping to 25 GW. The hourly volume offered at lower[1] negative prices did not surpass 12.3 GW, making it unlikely for those bids to be marginal as they are far from the typical clearing point. Negative bids closer to zero averaged 13.7 GW which, when stacked in the merit order, are closer to the clearing point and more likely to be cleared.

3. In the coming years, high renewable buildout and slow demand growth will lead to higher renewable production and price cannibalisation. Therefore, renewable plants will seek alternative revenue streams, adopting negative price bidding strategies to maintain Day-Ahead participation. Aurora expects the instances of negative prices to peak between 2025 and 2028 as renewable generation increases and shifts toward negative bidding behaviour.

4. After a period of low prices in the 2020s, demand is expected to rise towards the 2030s while a slow down of renewable buildout after 2028. Following higher demand and lower supply growth, the clearing point will shift, leading to a decrease in negative and zero price events from 2028 onwards and disappearing in the 2040s.

5. Although negative prices can impact renewable assets in the short term, their impact across the investment period is limited and can be mitigated by participation in ancillary services, hybridisation with batteries, or risk sharing clauses in the PPA.

1) Below -3€/MWh.

Sources: Aurora Energy Research

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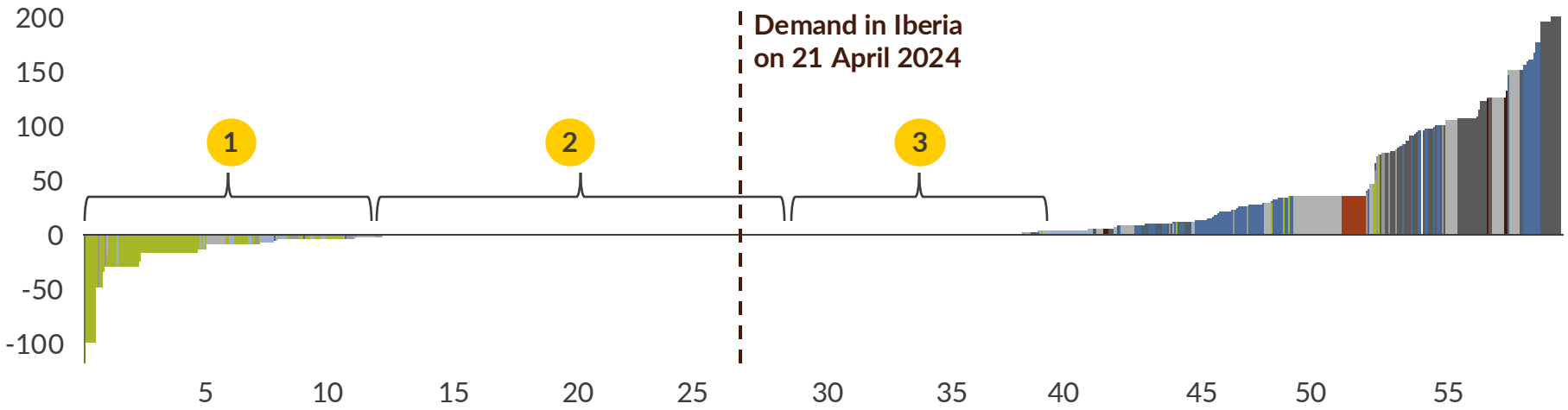
On 21 April 2024, the Day-Ahead Market cleared a negative price as negative RES bids were sufficient to supply power demand

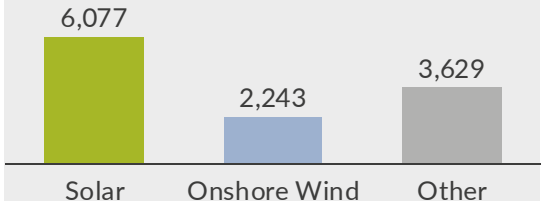
The Iberian merit order has significant capacity bidding near zero, both slightly positive and negative. On 21 April 2024 at 16:00, low demand and high RES production led to a negative price as 20 GW of RES bids were offered at negative prices

Iberian DA[1] market merit-order[2], €/MWh (Y-axis) vs GW (X-axis)



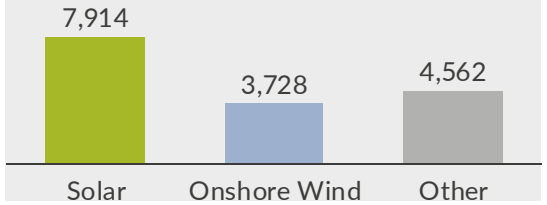
1 Price lower than -3 €/MWh

Bidding volume, MW



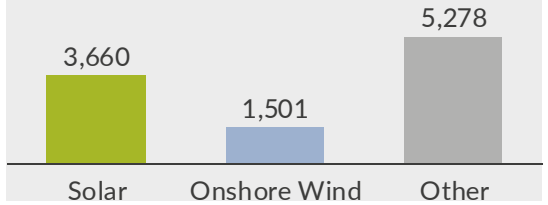
2 Price between -3 and 0 €/MWh

Bidding volume, MW



3 Price between 0 and 1 €/MWh

Bidding volume, MW



Hydro | Other RES[3] | Wind | Solar[4] | CHP | Pumped Storage | CCGT | Nuclear | Coal | Other[5]

1) Day-ahead market. 2) The chart represents the merit-order curve as of 16h on 21 April 2024 in Iberia. Bids lower than -120 €/MWh and higher than 200 €/MWh have not been included in the graph. 3) Other RES includes biomass and renewable cogeneration. 4) Solar includes Solar PV and Solar CSP. 5) Other includes bids from Regulated Rate CUR, Commercial Portfolio, and retailers.

Source: OMIE

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- In Iberia, renewables bid negative if they receive additional revenues such as PPAs or GoOs.
- On 21 April 2024 at 16:00, Iberian DA[1] power demand was on average low, totalling 26 GW due to mild weather and low air conditioning demand.
- Renewable negative bids reached 22.1 GW, combining 14 GW of solar, 5.9 GW of onshore wind and 2.2 GW of hydro.
- Almost 12 GW of negative bids were below -3 €/MWh, far from the clearing point and unlikely to be marginal.
- The final DA[1] price was -1.32 €/MWh in Spain and -0.10 €/MWh in Portugal.
- The interconnection plays a role whereby limited export capacity or high imports from France can lead to negative prices.

Negative and zero prices are less frequent in Portugal than in Spain due to a proportionally lower RES buildout, reducing their impact on PPAs contracts

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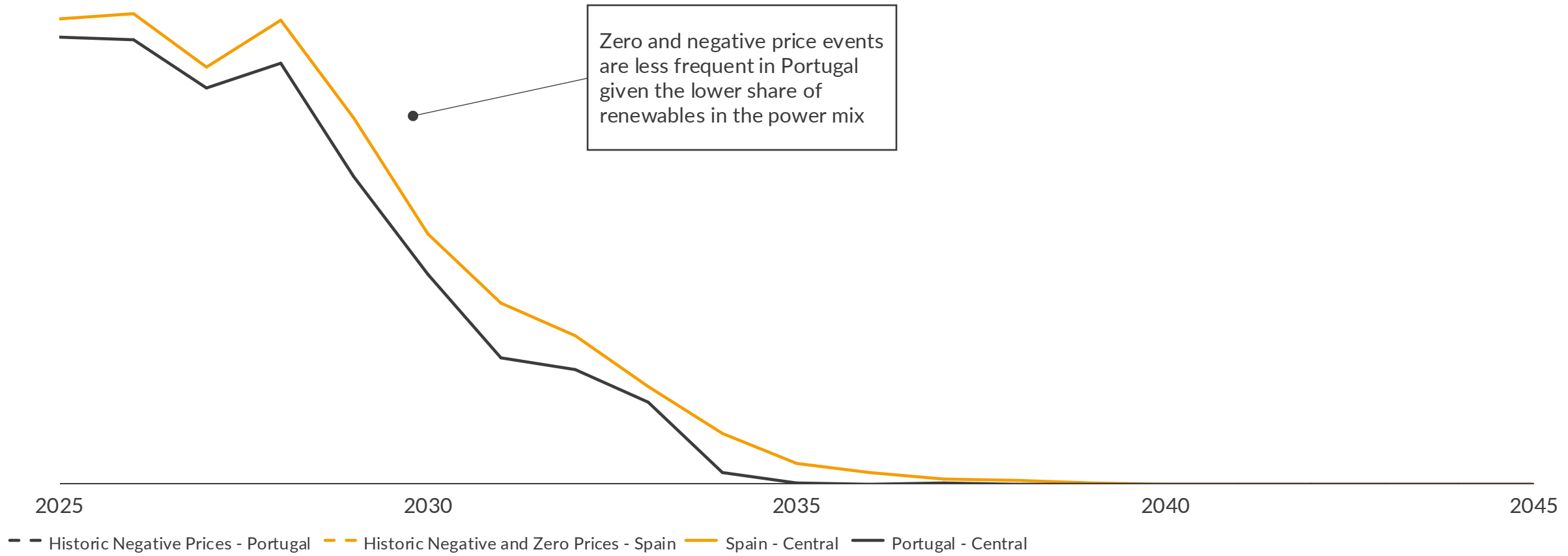
Yearly occurrence in Spanish Day-Ahead Market
number of negative and zero hours per year



1) The forecast range accounts for various scenarios based on different weather years and market sensitivities.

Sources: Aurora Energy Research, OMIE, ESIOS

Details and disclaimer

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Date
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Prepared by
Andrea Ragno
Guillermo Burillo

Approved by
Javier Pamos
Christina Rentell
Alejandro Zerain

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