AURORA
ENERGY RESEARCH

Unlocking Incremental Revenue Streams for Renewables

Public Report

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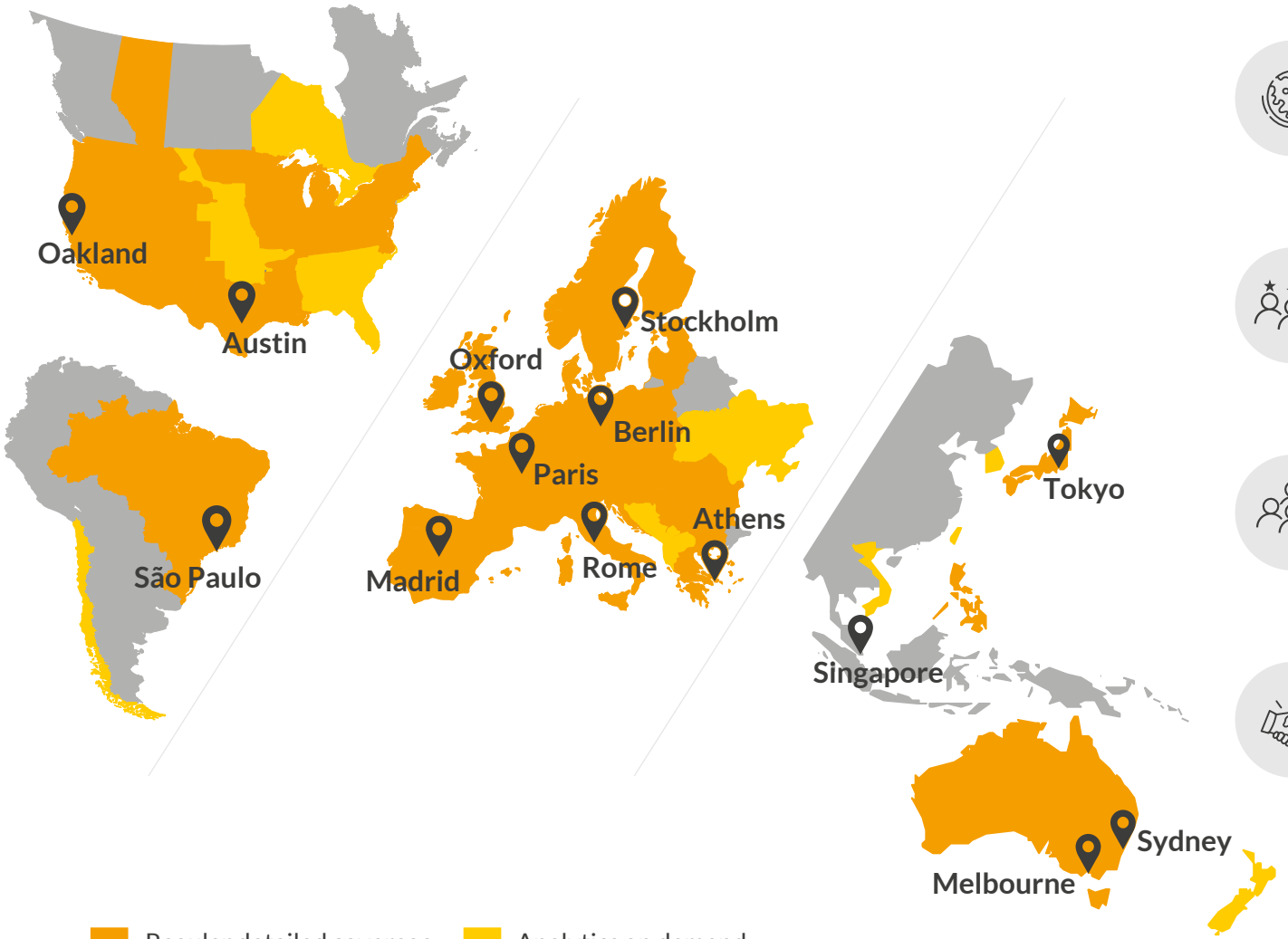

14 Offices

600+
market experts

850+
subscribing companies

150+
transactions supported in 2023

Source: Aurora Energy Research

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I. Introduction

II. Available markets for renewable assets

III. Historical analysis of the renewables revenue stack

IV. Aurora's renewable assets dispatch forecast

V. Key takeaways

The deployment rate of RES capacity is expected to continue to be high, posing cannibalisation risk and decreasing revenues

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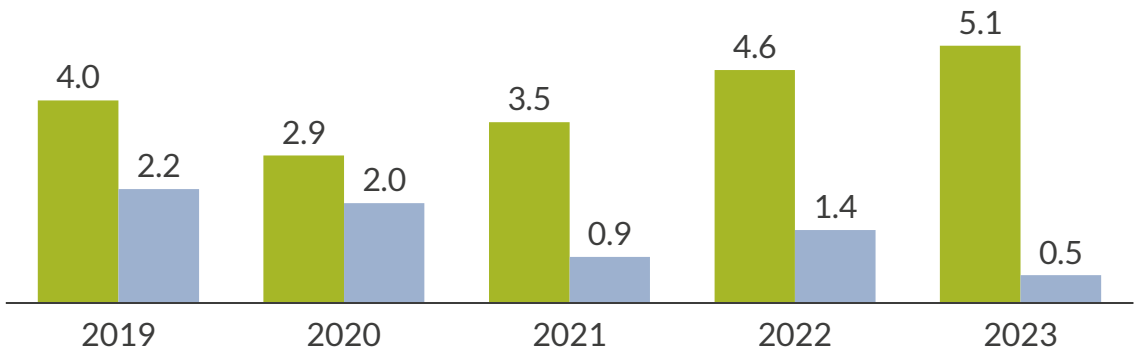
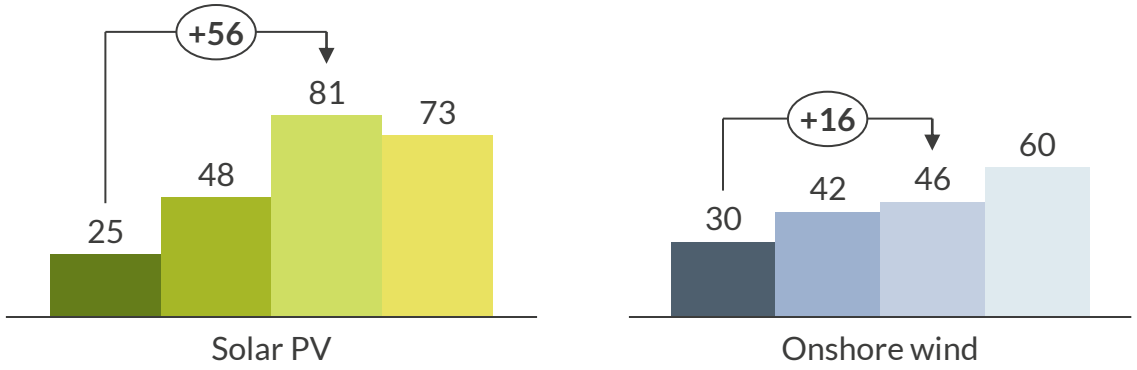
Solar PV growth accelerated in 2023 with ground-mounted solar PV buildout reaching a historical maximum of 5.1 GW

Historical annual capacity buildout, GW/year



Given the large pipeline of Solar PV, we expect the discount to baseload to continue to increase for this technology through 2030

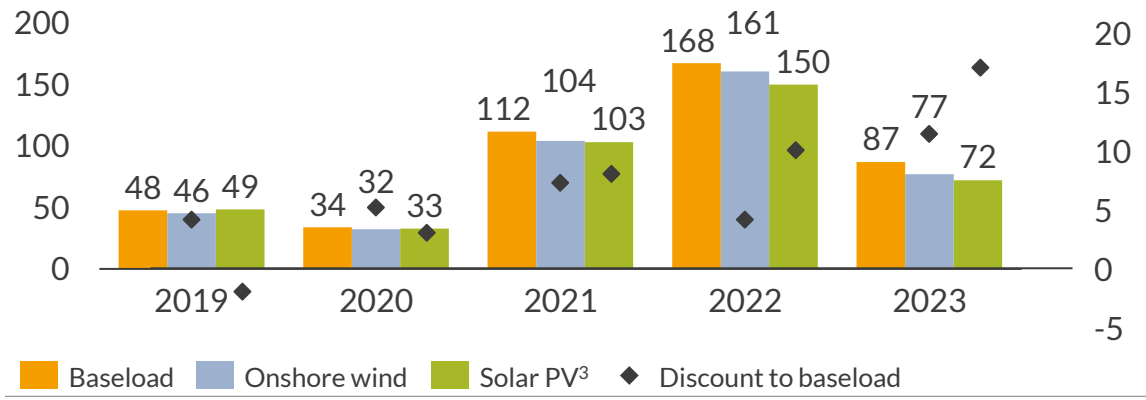
Capacity, GW



The increase in renewables deployment is leading to higher discounts to baseload for both wind and solar technologies

Historical baseload, renewables capture prices €/MWh (nominal)

Discount to baseload %



Rapid renewable buildout, combined with an extensive project pipeline, poses a risk of market cannibalisation, particularly for solar

- Renewable capacity, particularly Solar PV, has grown significantly in the Spanish market, with 20 GW, of the current installed 25.6 GW, being deployed in the last five years.
- This surge has led to an increase in the discount to baseload, with solar PV and onshore wind reaching 17% and 11% in 2023, respectively.
- Increasing solar generation is the biggest driver of solar cannibalisation, therefore the large pipeline poses a high cannibalisation risk for this technology.

Installed in 2023 | Aurora Central (2030) | Pipeline[1] | NECP (2030)[2]

1) Refers to the pipeline of projects with an approved Environmental impact assessment as of January 2023. 2) National Energy and Climate Plan (i.e., PNIEC in Spain). 3) Includes solar ground-mounted PV.

Sources: Aurora, REE, MITECO.

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Whilst renewables mainly sell energy in the Day-ahead Market, participation in additional markets can provide additional revenues

Years → Hours → Minutes → Seconds

CM Capacity Market

- Ensures security of supply by procuring a sufficient level of firm capacity to meet peak electricity demand.
- Payments are made on a capacity basis in kW/year and derated based on contribution to security of supply.
- If allowed to participate, renewables will be highly derated due to their intermittent production thus decreasing potential revenues.

WM Wholesale Markets

- **Day-ahead (DA):** provides a platform to buy and sell power to meet demand on an hourly basis.
- **Intraday (ID):** procured through auctions and continuous trading from the closure of DA until dispatch time.
- Volumes in these markets are contracted from Day-ahead to T-1 hour trading.
- RES assets can adjust their Day-ahead positions closer to real time in the Intraday Markets.

AS Ancillary Services

- Ancillary Services ensure balance is maintained between generation and demand in real time.
- Ancillary Services are categorised from short (seconds) to long (minutes) response times to cover imbalances sequentially depending on the length of the imbalance.
- In order of dispatch, Ancillary Services in Iberia are Secondary (2R), Tertiary (3R) and Replacement Reserves[1].
- While RES can face challenges in providing Ancillary Services due to their intermittent nature, sophisticated operating systems and predictive analytics enable RES to participate in Ancillary Services.
- Additionally, their near-zero ramping rates and low minimum dispatch levels can provide rapid response and flexibility across all Ancillary Services.

GO Guarantees of Origin (GoOs)

- GoOs can offer an additional revenue stream for RES producers by certifying the renewable nature of their energy.

TR Technical Restrictions

- Additional trading markets exist to procure non-frequency Ancillary Services to maintain grid operability.
- RES assets equipped with flexible technologies, like battery storage, or those capable of providing grid-supportive functions (e.g., synthetic inertia, voltage support), can actively participate in mitigating technical restrictions. These assets can offer services such as frequency regulation, voltage control, and congestion management.

1) FCR (i.e., Primary Reserve) is not remunerated in Spain. Secondary, Tertiary and Replacement Reserves correspond to aFRR, mFRR and RR services, respectively.

Sources: Aurora Energy Research

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Renewables volumes increased by 10% in Intraday auctions and 20% in the Continuous Intraday Market over the last five years

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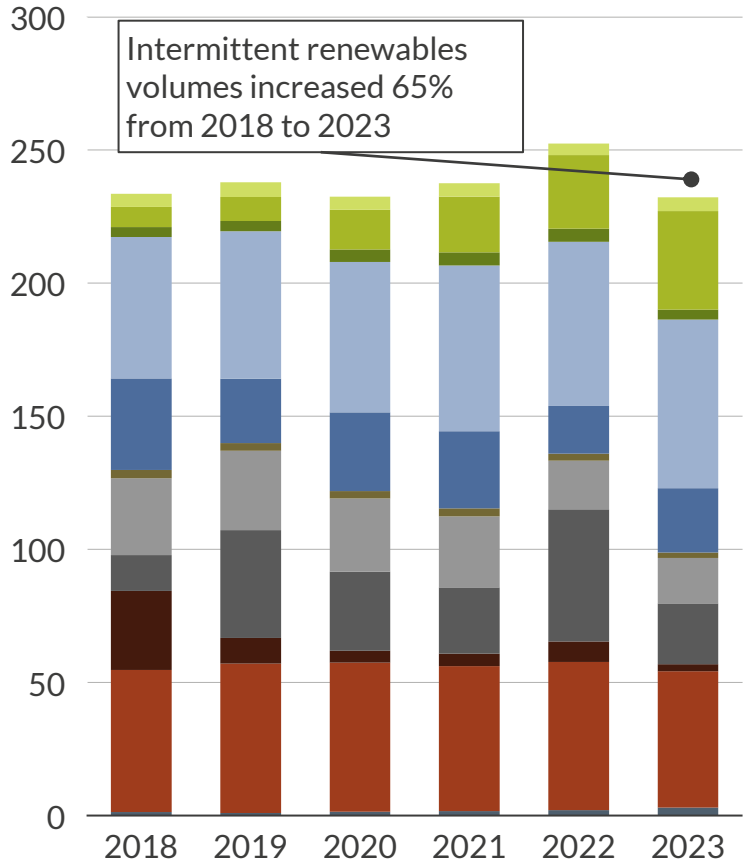
Wholesale Market

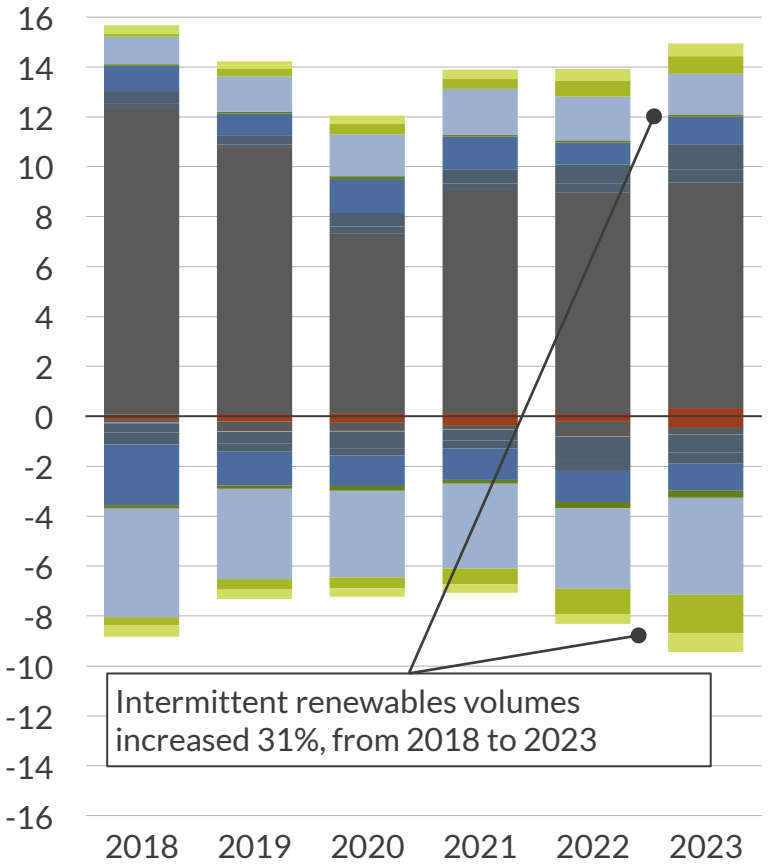
RES[1] generation in the DA[2] market increased from 42% to 54% as 27 GW of RES were deployed

Day-ahead volumes, TWh



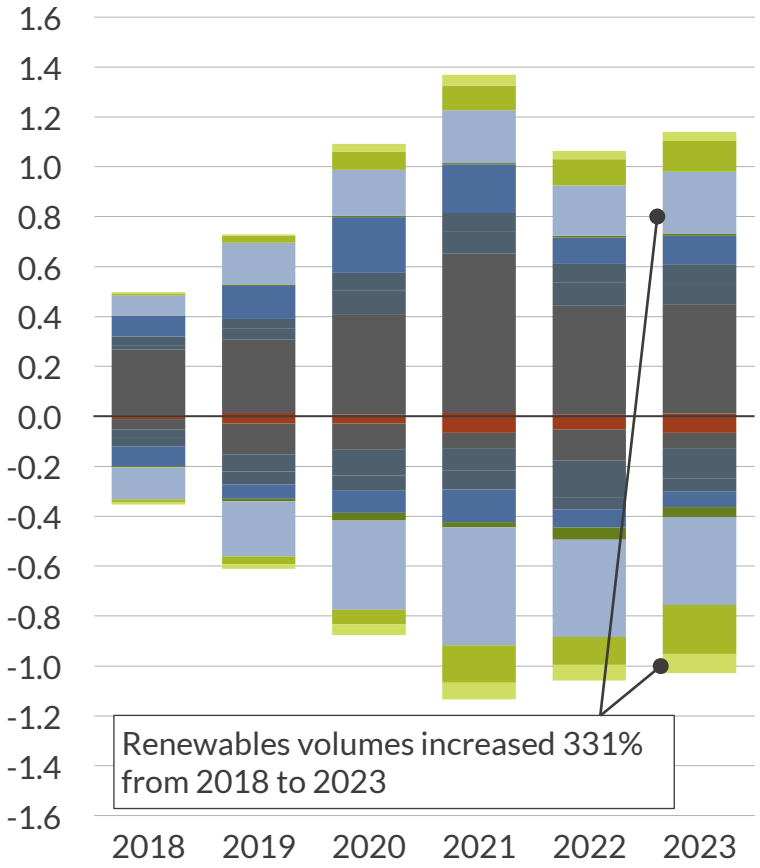
RES participation in ID[3] represented 68% and 19% of downwards and upwards volumes respectively in '23

Intraday auctioned volumes, TWh



Renewables represented 50% of volumes in the Intraday Continuous market in 2023

Intraday continuous volumes, TWh



Solar CSP | Solar PV[4] | Other RES[5] | Onshore wind | Hydro | Waste | Other thermal[6] | CCGT | Coal | Nuclear | Pumped storage

1) Renewable Energy Sources. 2) Day-ahead. 3) Intraday Market. 4) Includes solar ground-mounted PV. 5) Other RES includes biomass and renewable cogeneration. 6) Other thermal includes fossil fueled cogeneration.

Sources: Aurora Energy Research, REE

Renewables are able to adjust their generation in multiple Intraday sessions, facilitating their participation in Ancillary Services

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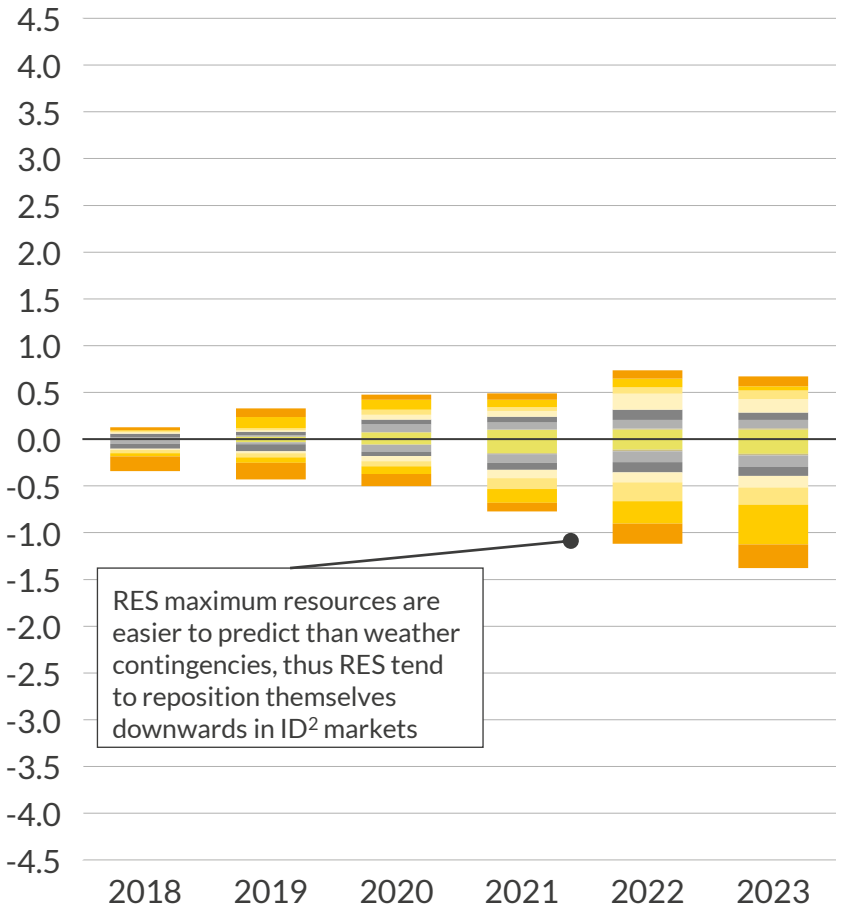
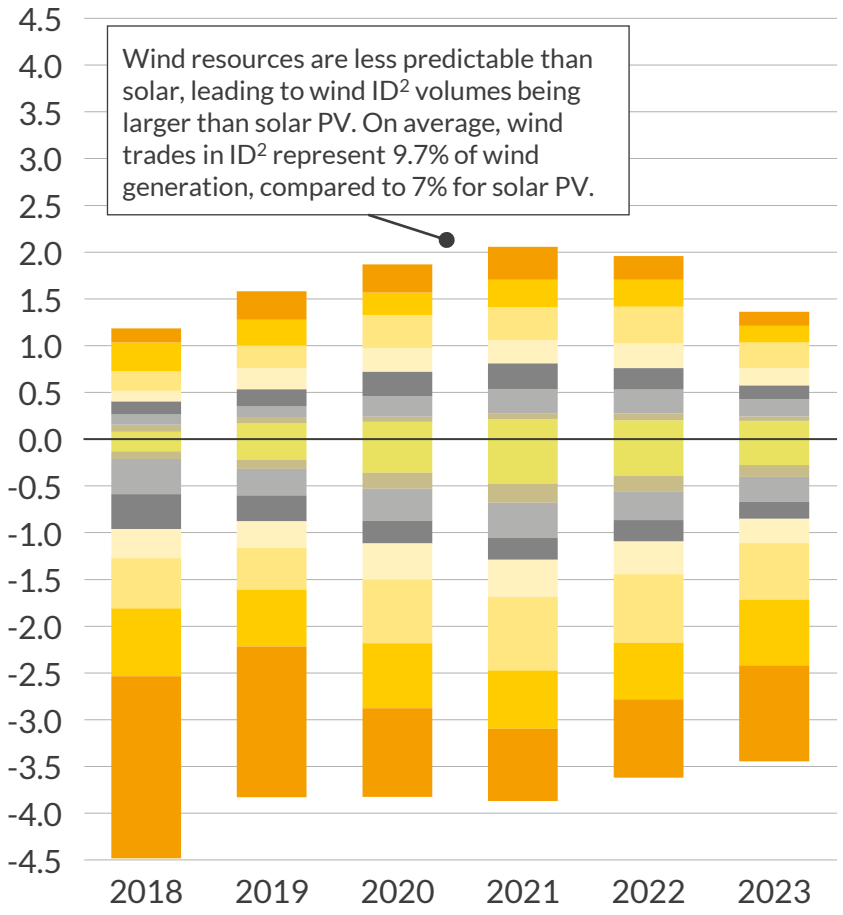
Wholesale Market

Solar PV Intraday volumes[1]
TWh



Onshore wind Intraday volumes
TWh



ID²-1 ID²-2 ID²-3 ID²-4 ID²-5 ID²-6 ID²-7 ID² Continuous

1) Refers to utility scale solar ground-mounted PV. 2) Intraday Market. Sessions four to seven consider fewer hours for each session.

Sources: Aurora Energy Research, REE

- Renewable plants use Intraday Markets to reposition their generation in the Wholesale Market due to weather forecast changes close to real time.
- As weather events are more likely to decrease generation (i.e., clouds or lack of wind), plants reposition themselves downwards more often than upwards.
- As a consequence, downwards volumes are higher in Intraday Markets than upwards volumes.
- The three first Intraday sessions concentrate most downwards volumes as these sessions consider the upcoming 24-hour period[2].
- Renewables participating in Ancillary Services use the ID²-2 and ID²-3 to reposition after Secondary and Tertiary Markets close, respectively.

Hydro plants and CCGTs supply the majority of Ancillary Services volumes, although renewable participation is increasing

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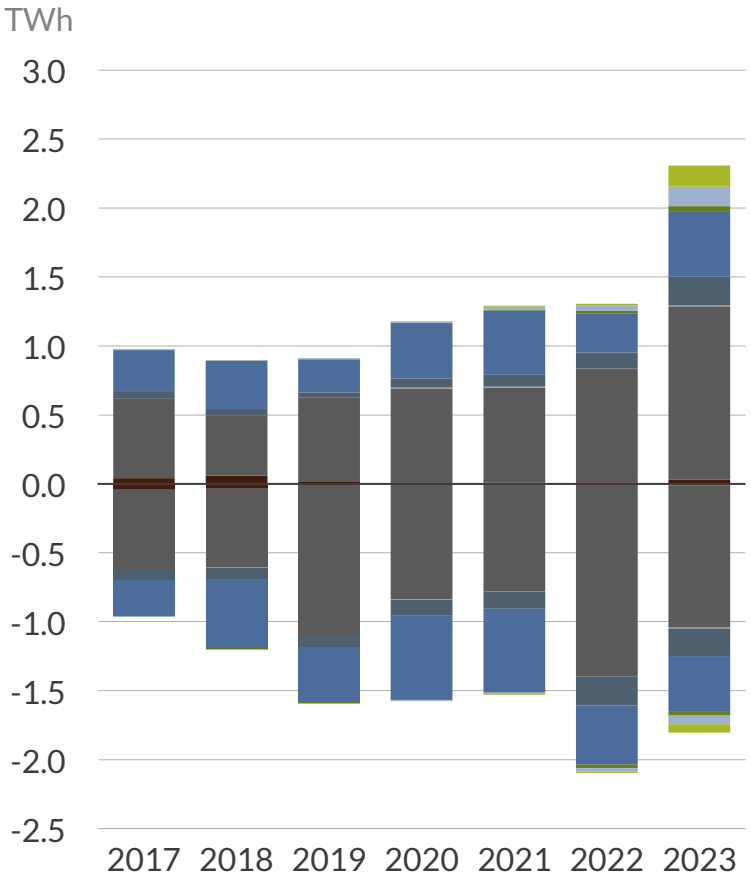
Ancillary Services

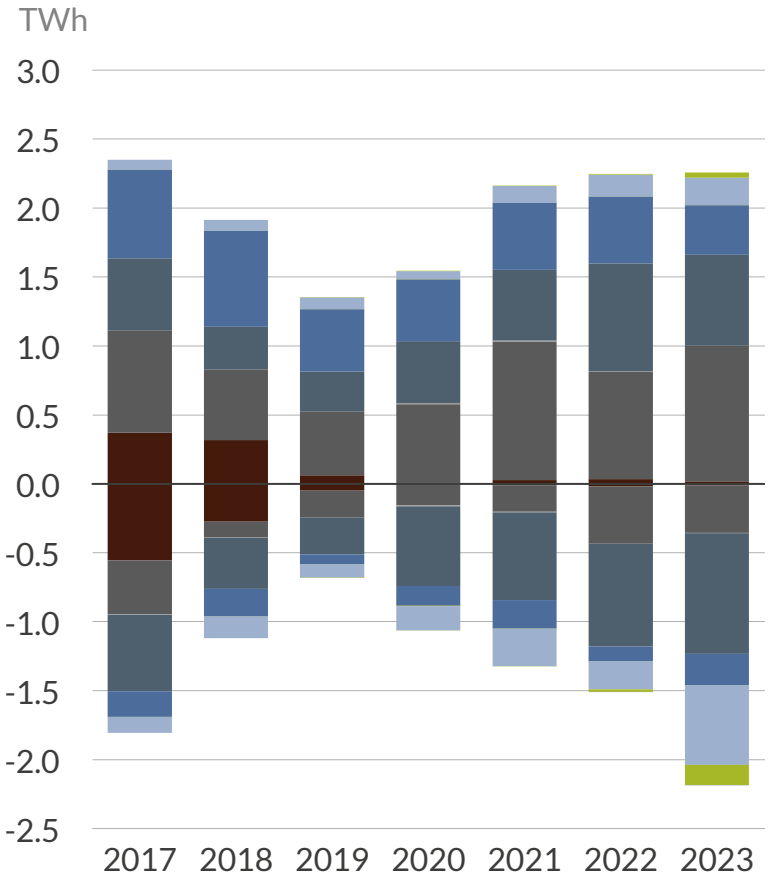
RES[1] increased its participation in Secondary Reserve from 0% to 12% in the last two years

Secondary Reserve energy volumes[4]



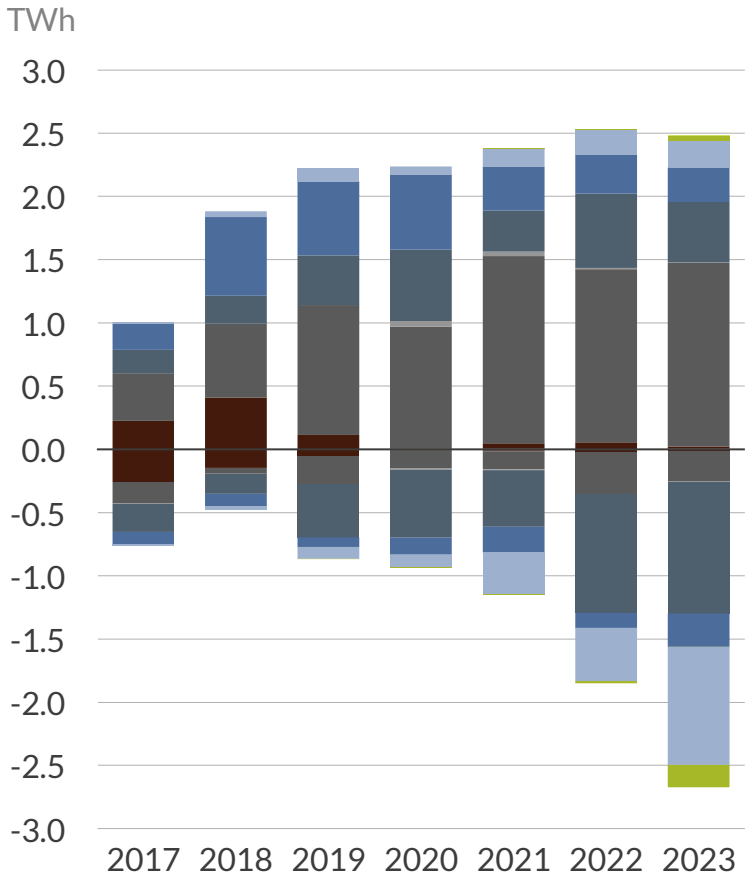
RES[1] penetration in 3R[2] has been increasing, reaching 33% of downwards volumes in 2023

Tertiary Reserve volumes[4]



In 2023, wind downwards RR[3] volumes increased 118% driven by negative prices and high imbalances

Replacement Reserve volumes[4]



Solar CSP | Solar PV[5] | Onshore wind | Other RES[6] | Hydro | Pumped storage | Other thermal[7] | CCGT | Coal | Nuclear

1) Including only intermittent renewables (i.e., solar and onshore wind). 2) Tertiary Reserve. 3) Replacement Reserve. 4) Slight variations in volumes might exist due to missing information in I90DIA and I3DIA reports files 5) Includes solar ground-mounted PV. 6) Other RES includes biomass and renewable cogeneration. 7) Other thermal includes fossil fueled cogeneration.

Sources: Aurora Energy Research, REE

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III. **Historical analysis of the renewables revenue stack**

1. RES participation in Wholesale and Ancillary Markets
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3. RES revenue stack

IV. **Aurora's renewable assets dispatch forecast**

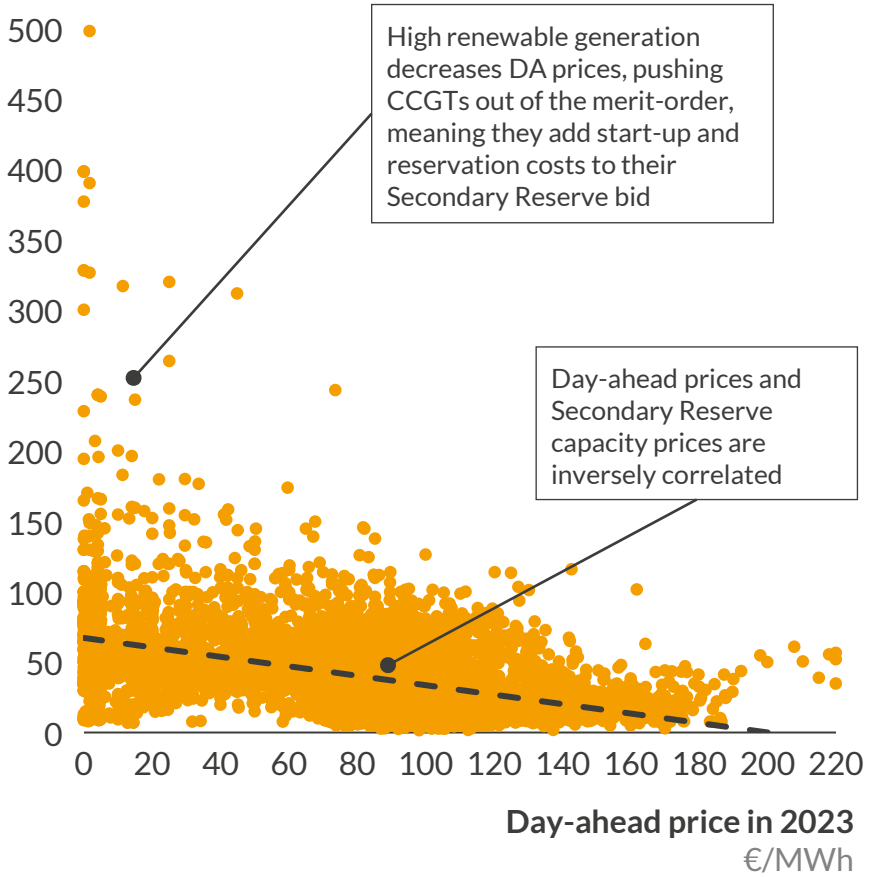
V. **Key takeaways**

During high solar generation hours it is more profitable to participate in 2R[1] and 3R[2] as Day-ahead prices are low

2R[1] capacity prices are negatively correlated with WM[3] prices, offering a hedge against cannibalisation for renewables

Secondary Reserve price in 2023

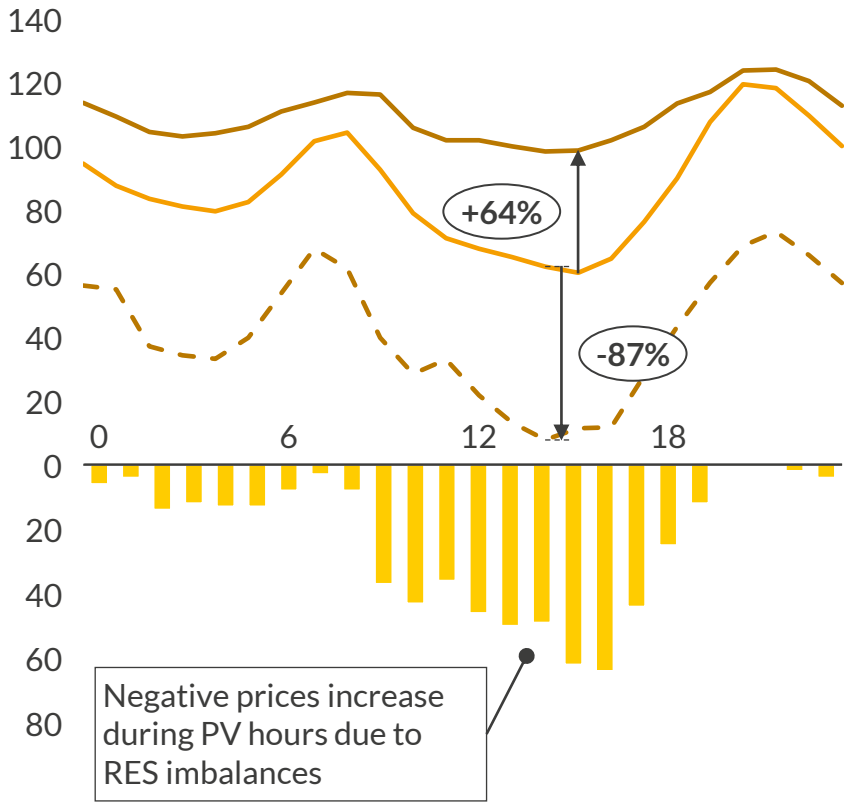
€/MW/h



Tertiary Reserve prices offer a spread to the Day-ahead, Market; negative prices occur in this market

Average price by hour in 2023 and negative price hours

€/MWh, hours



Day-ahead — Tertiary Reserve - Upwards — Tertiary Reserve - Downwards — Negative hours in Tertiary Reserve Downwards

- When renewables displace CCGTs out of the merit-order, Day-ahead market prices drop. Therefore, CCGTs in Secondary Reserve will increase their bid as they include start-up costs, increasing the price of Secondary Reserve.
- Renewable plants benefit from the inverse correlation as they participate in Secondary Reserve and hedge against low prices in the Day-ahead market.
- Upwards balancing market prices are on average 30% higher with respect to Day-ahead prices, reaching 40% during solar PV hours as balancing demand is high.
- RES deployment is increasing imbalances which, due to high balancing needs, increases the occurrence of negative prices as negative bidding plants[4] are cleared in 3R[2].

1) Secondary Reserve. 2) Tertiary Reserve. 3) Wholesale Market. 4) Negative bidding plants are usually inflexible plants which cannot decrease production (e.g., CHP or running hydro) or RES plants with zero operational costs.

Sources: Aurora Energy Research, REE

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Currently, renewable plants participating in Ancillary Services are making up to 26% more revenues than the rest of the fleet

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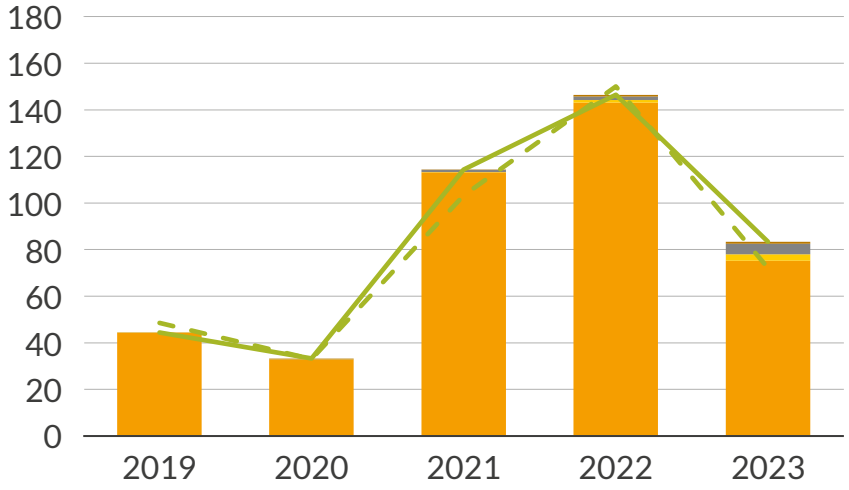
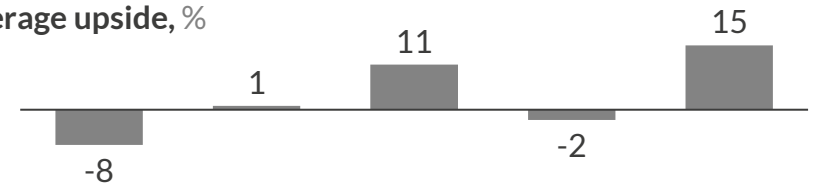
Solar PV plants participating in balancing markets make up to 15% more than the fleet average

Number of participating plants[1] in Ancillary Services

Breakdown of solar PV capture price per market, €/MWh

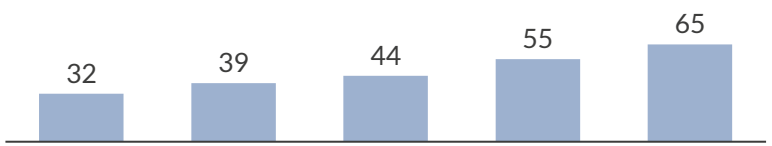


Average upside, %

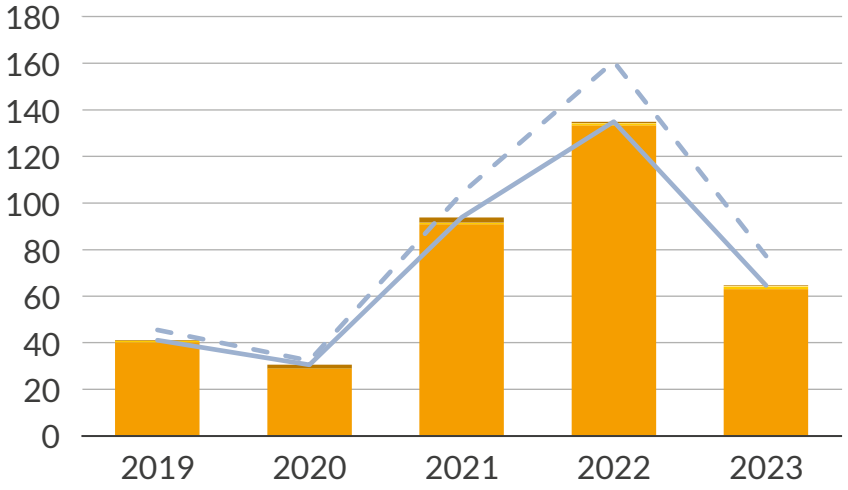


Whilst some wind assets make money from AS[2], most use these markets to mitigate additional losses

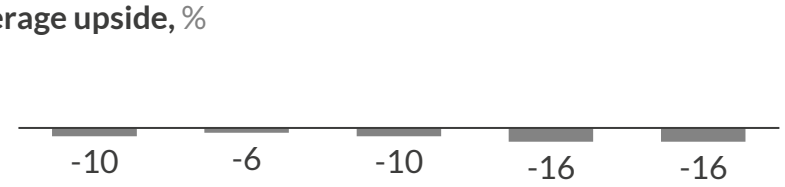
Number of participating plants[1] in Ancillary Services



Breakdown of wind capture price per market, €/MWh



Average upside, %



3R[3] 2R[4] RR[5] Day-ahead Average plant participating in AS[2] Fleet Average upside for plants participating in AS[2]

1) The fleet participating in Ancillary Services had discount to baseloads of 4% and 26% for solar PV and wind respectively during 2023. Wind prices are heavily impacted by their location. 2) Ancillary Services. 3) Tertiary Reserve. 4) Secondary Reserve. 5) Replacement Reserve.

Sources: Aurora Energy Research, REE

- Solar PV plants benefit more from Secondary Reserve than other Ancillary Services, making between 5% and 18% of their revenues in that market in 2023.
- Wind plants participate more in Replacement and Tertiary Reserve reaching 1.7 TWh in 2023, an 87% increase with respect to 2022.
- Wind revenues are highly dependent on location, yet their participation in Ancillary Services constitutes an upside.
- Due to higher revenues, solar PV and wind plants participating in Ancillary Services had a discount to baseload as low as negative 4% while the average fleet faced 18% and 13%, respectively during 2023.

Renewables diversify their generation across all markets to capture higher revenue and hedge against low prices in the Day-ahead Market

Intraday

Generation change

Sell or buy in intraday to rebalance

- Renewables use the different Intraday Markets to rebalance their position due to unforeseen changes in their planned generation, and following participation in Ancillary Services.
- Intraday Markets can also be used to capture periods of high prices, depending on the specific plants' strategy.

Secondary Reserve

Low WM[1] prices are expected, implying high 2R[2] prices[3]

Allocate a proportion of capacity

- As Secondary Reserve capacity prices are inversely correlated with wholesale prices, this market can offer additional revenues during low price hours in the Day-ahead Market.
- Plants **withhold a portion of their capacity to participate in Secondary Reserve** upwards instead of bidding their full capacity in the Day-ahead Market.

Balancing downwards

Generation expected in the WM[1] markets

Plants bid part of their capacity in BM[4] downwards

- Plants bid negatively in downwards Balancing Markets so, if imbalances are high enough, they are called to turn down their generation and are remunerated for doing so.
- Some strategies involve bidding at positive prices to reposition themselves ahead of other Ancillary Services.

Balancing upwards

High imbalances are expected

Plants bid part of their capacity in BM upwards

- When imbalances increase, usually during RES generation hours, upwards prices in Ancillary Services are higher than wholesale prices.
- Renewables turn down some of their generation in the Wholesale Market and bid part of their generation in Ancillary Services.
- RES participating in Ancillary Services during high imbalance periods capture high balancing prices.

1) Wholesale Market. 2) Secondary Reserve. 3) This is caused by CCGTs including start-up costs and reservation costs during high RES generation hours where Wholesale Market prices are usually low. 4) Balancing Market.

Sources: Aurora Energy Research.

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The potential upside for solar assets is larger than for wind given lower prices; we established two scenarios considering participation in additional markets

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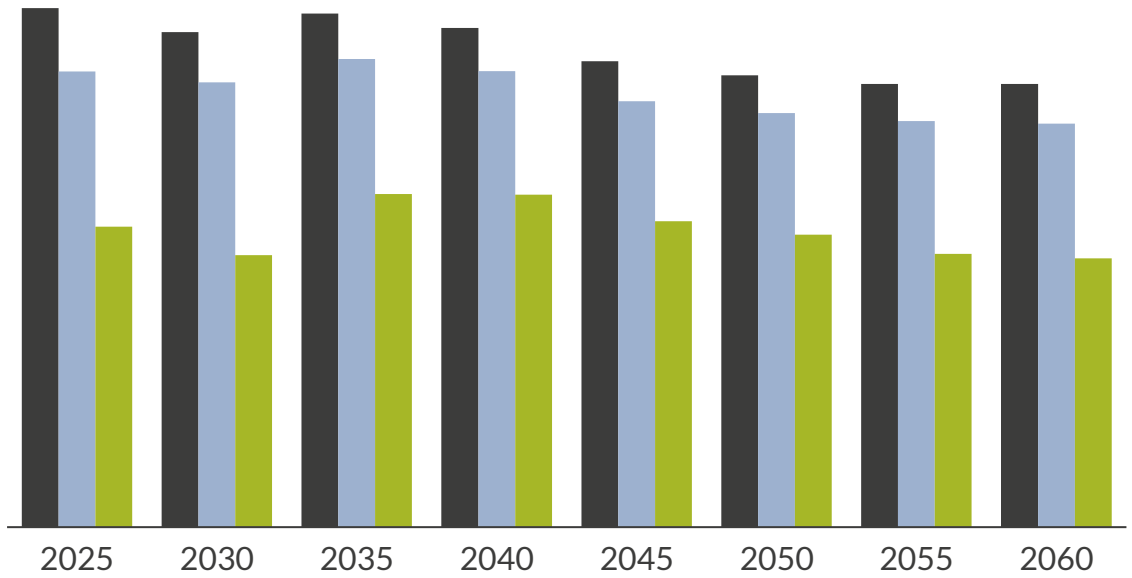
The IRR for solar PV assets is lower than onshore wind given the lower capture prices, despite lower CAPEX values

Baseload and renewable Capture prices[1], €/MWh



Average Discount to Baseload 10-year average[2]

Baseload Onshore wind Solar

We ran two scenarios to calculate the upside for renewables participating in the Intraday Market and Ancillary Services as well as the Day-ahead

Strategy 1

Based on the historical behaviour observed we consider the following capacity allocations in the scheduling phase for upwards actions:

- **Day-ahead Market:** 80%
- **Secondary Reserve (capacity):** 10%
- **Balancing Market:** 10%

For downwards actions, we consider that all the capacity reserved for participation in the Day-ahead Market is available.

We consider fail rates in the Secondary Reserve and Balancing markets, reflecting increasing competition from renewable assets in these markets.

Strategy 2

Given that we expect increased renewables competition in Ancillary Services markets over time, we applied a sensitivity over the capacity reserved in these markets to reflect a more conservative strategy:

- **Day-ahead Market:** 90%
- **Secondary Reserve (capacity):** 5%
- **Balancing Market:** 5%

1) Refers to January PRMF 2024 uncurtailed capture prices. 2) For the 2020s decade, only 2025-2030 are included in the average. 3) Internal rate of return 4) Solar CAPEX: 702 €/kW. Wind CAPEX: 1,297 €/kW. Load factors considered are 22% and 34.7% for solar PV and wind respectively.

Sources: Aurora Energy Research

Higher participation in Ancillary Services, leads capture prices being 4% higher on average, with the biggest upside coming in the 2020s

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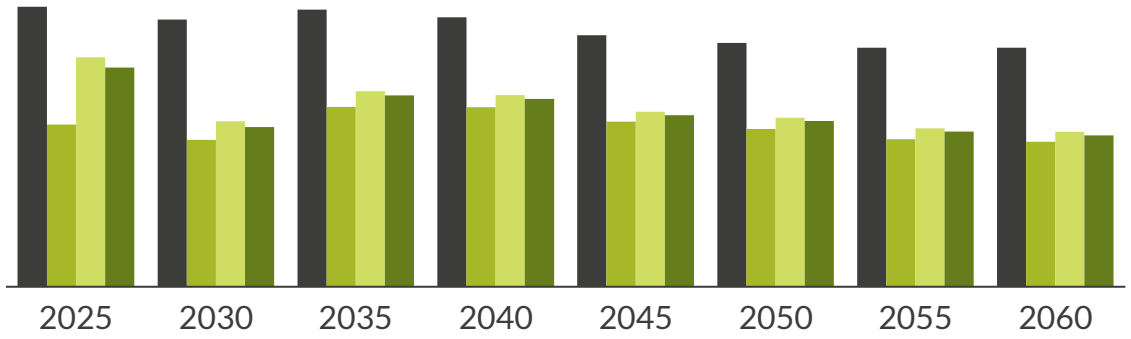
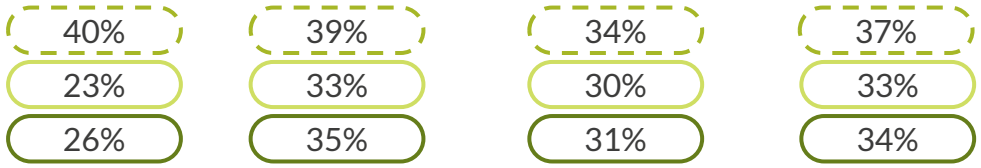
Solar PV plants participating in Ancillary Services are able to mitigate the impact of cannibalisation across the whole timeline

Aurora Central and Solar PV dispatch capture prices[1]
€/MWh (real 2022)



Average discount to baseload, 10-year averages[2]

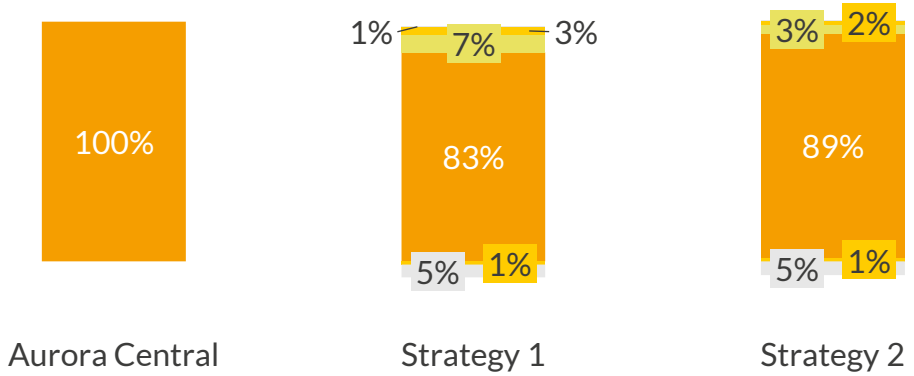


Upside vs Central, %

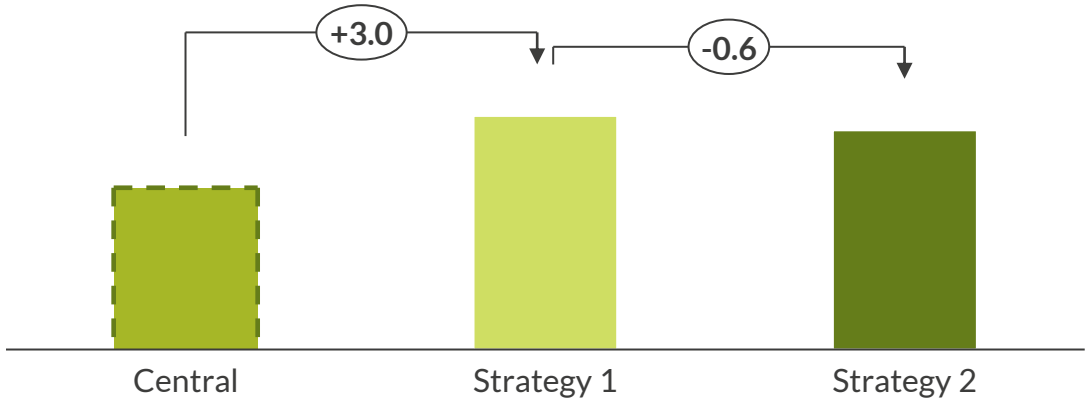
Baseload Central Strategy 1 Strategy 2

Despite total net volumes being lower than Central in the Base case, higher IRRs are achieved in both scenarios compared to Aurora Central

Average volumes 2025-2055
GWh



2025 COD IRR for solar PV, % (pre-tax real 2022)



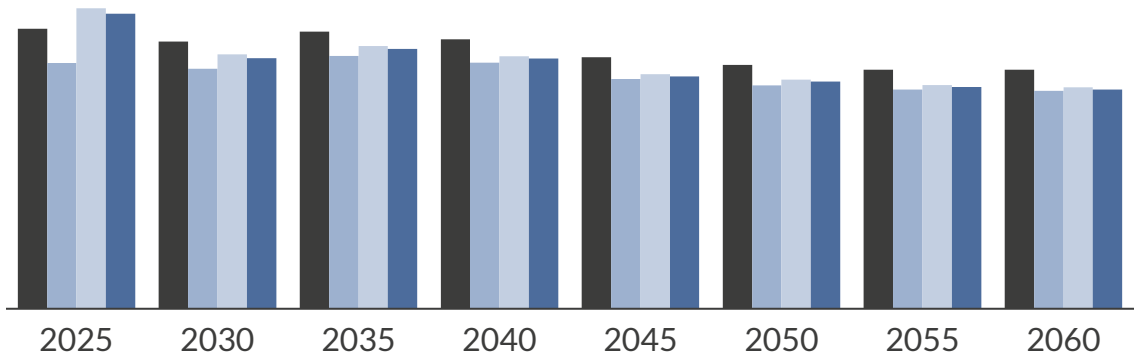
1) Uncurtailed capture prices 2) For the 2020s decade, only 2025-2030 are included in the average.

Sources: Aurora Energy Research

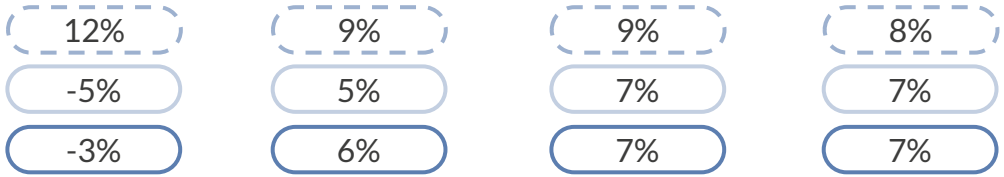
Upside from wind plants participating in Ancillary Services is 1.8 €/MWh lower than solar PV plants on average

After 2040, the Base case upside is diminished to less 2% on average for the rest of the timeline.

Aurora Central and Wind dispatch capture prices[1]
€/MWh (real 2022)



Average discount to baseload, 10-year averages[2]

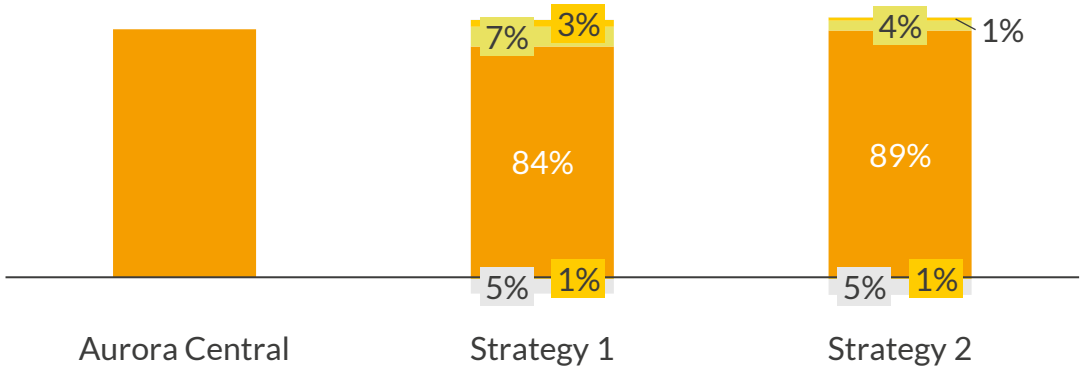


Upside vs Central, %

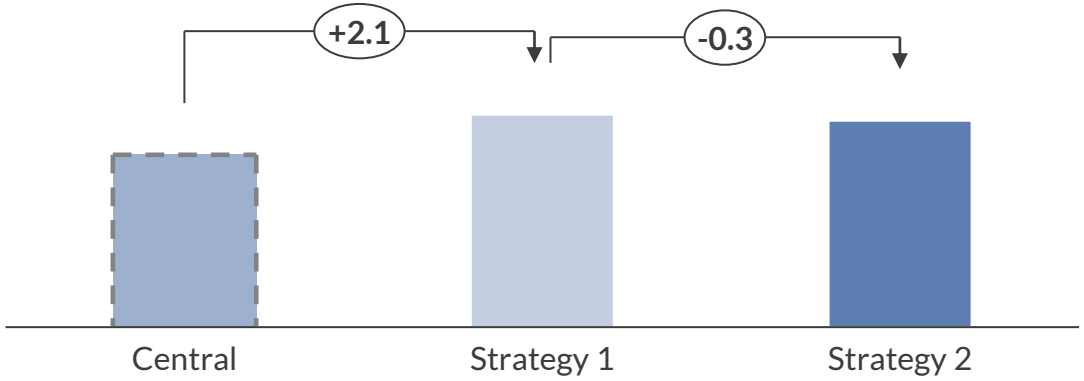
Baseload Central Strategy 1 Strategy 2

Despite total net volumes being lower than Central in the Base case, higher IRRs are achieved in both scenarios compared to Aurora Central

Average volumes 2025-2050
GWh



2025 COD IRR for wind, % (pre-tax real 2022)



Day-ahead Intraday Balancing Market Secondary Reserve energy

1) Uncurtailed capture prices 2) For the 2020s decade, only 2024-2030 are included in the average.

Sources: Aurora Energy Research

Agenda

AURORA

I. Introduction

II. Available markets for renewable assets

III. Historical analysis of the renewables revenue stack

IV. Aurora's renewable assets dispatch forecast

V. Key takeaways

Key takeaways

1. In the upcoming years, as firm capacity retires and rapid renewable deployment continues, Ancillary Services volumes are expected to increase. Intermittent renewables are increasingly participating in these markets as they look to diversify their revenue streams.

2. As Secondary Reserve capacity prices tend to be inversely correlated with Wholesale Market prices in the short-term, participation in Ancillary Services markets can be particularly effective for solar assets, given the increased cannibalisation risk compared to wind in Spain, and their more predictable generation profile.

3. Solar plants already participating in Ancillary Services and the Intraday Market saw an upside of 25% in revenues in 2023 primarily driven by participation in the Secondary Reserve Market. However, as more assets participate in this market and prices decrease, we expect increased competition to decrease the upside.

4. Considering a strategy of reserving 20% of solar capacity for upwards actions in Ancillary services leads to an average upside of 12% across the project lifetime, reaching a maximum of 35% on average during the 2020s. This leads to a 3% increase in IRR compared to solely participating in the Wholesale Market.

5. A more conservative scenario considering only 10% of capacity for upwards actions results in an average upside during its lifetime of 9% for solar assets, representing an increase of 2.4% in the IRR compared to solely participating in the Wholesale Market.

Sources: Aurora Energy Research

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 – Reports in Nov-23 and Jun-24**

Historical data Dashboard

Available in Q1 2024

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 until 2030:
  - Demand per province
  - Capacity stack per province
- The following deliverables will be given for the 9 most risky provinces:
  - Grid curtailment [%] per province
  - Grid curtailment [GWh] per province
  - Weighted average price of curtailment [€/MWh]
- Sensitivities
  - Based on the biggest risks in the market, some sensitivities are developed (No nuclear phase-out, Low Hydrogen, Battery impact, …)
- **Biannually updated – Next update in June-24**

Upcoming Grid Modelling

Available in Q4 2024

Grid Modelling integration

(Q4 2024)

- Develop a Spanish grid model to forecast upcoming grid congestions in the system towards 2030
- Integrate the upcoming network evolution from the latest National Network Development plan

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Source: Aurora Energy Research


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