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ENERGY RESEARCH

# Evolution of Grid Curtailment in Spain

Public Report

# Introducing our team

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Sources: Aurora Energy Research

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

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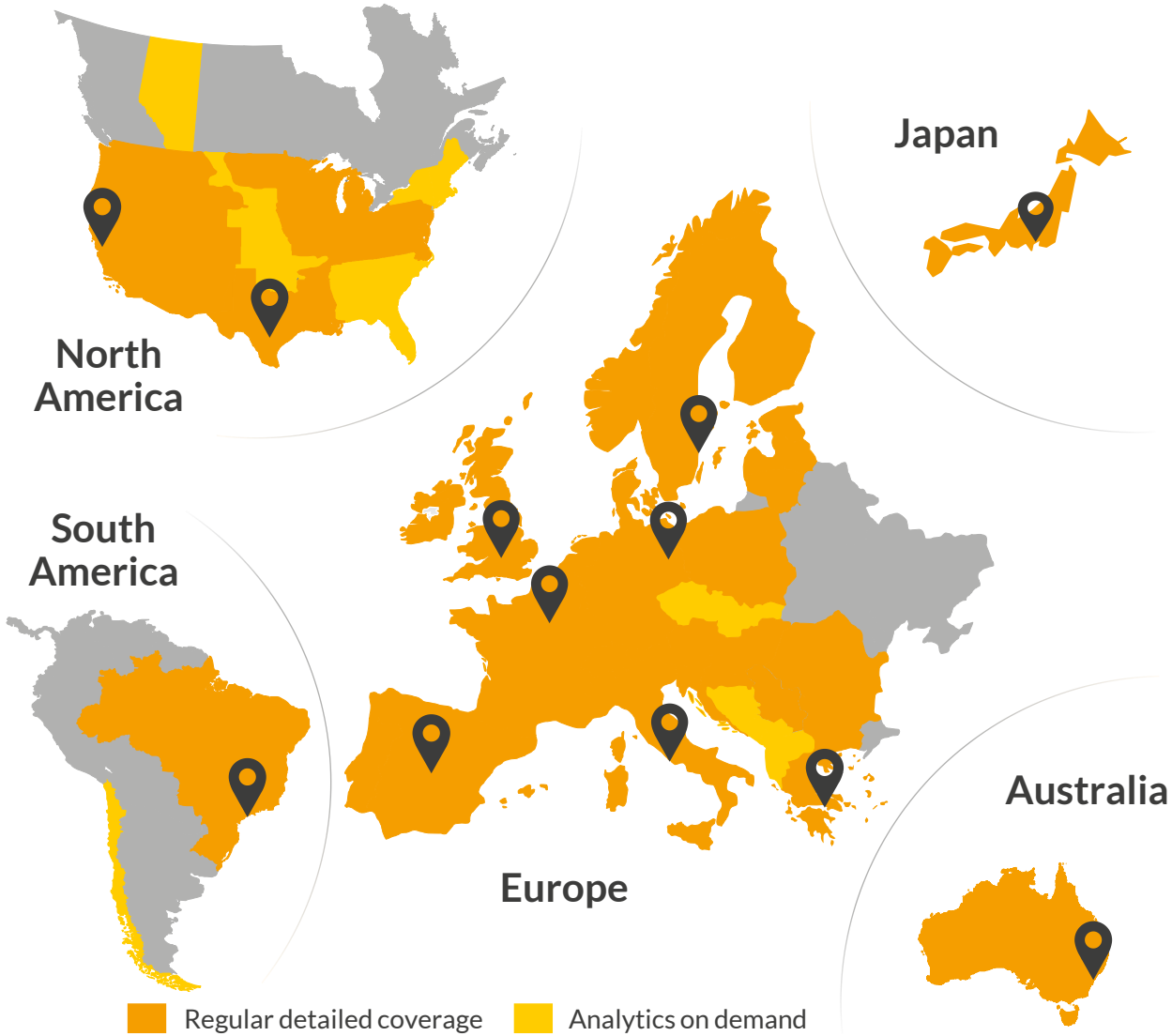


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Source: Aurora Energy Research

# Agenda

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I. Introduction to grid curtailment

II. Specificities about Spanish grid curtailment

III. How to forecast those curtailments?

# There are two types of "curtailment", and they happen for different reasons

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## Economic Curtailment

- Economic curtailment refers to the reduction or restriction of electricity generation from a power plant for economic reasons. It occurs when the cost of generating electricity exceeds the market price.
- The price at which a generator will curtail will depend on its variable costs and the structure of its revenues:
  - Generators with high variable costs will curtail before those with low or zero variable costs;
  - Generators compensated at a fixed Feed-in-Tariff based on generation, will choose to generate even when prices are below their variable costs, as this maximises revenue.
- We expect that solar and wind plants will face similar costs of curtailment, with variations between sites typically larger than those between technologies; however, wind generators tend to have slightly higher variable costs than solar.
- Economic curtailment is typically included in market advisory projections.

## Grid Curtailment

- To ensure the safe operation of the power system, the grid operator can curtail renewable production under defined circumstances.
- Grid curtailment happens when constraints on the local electricity grid prevent further energy to be exported from assets connected close to it.
- Grid curtailment is most prevalent in times of:
  - High (local) RES production
  - Low (local) demand
- Whether curtailed generation is compensated or not depends on the market rules; in Spain, it depends on when it happens – more details on this later.
- Grid curtailment is not typically included in market advisory projections, unless their cost is embedded in the pricing structure (e.g. nodal price projections).

In this report, we will be focusing on **Grid Curtailment**

Source: Aurora Energy Research

# Congestion management costs and the volume of non-compensated renewable curtailment in Spain has been increasing since early 2022

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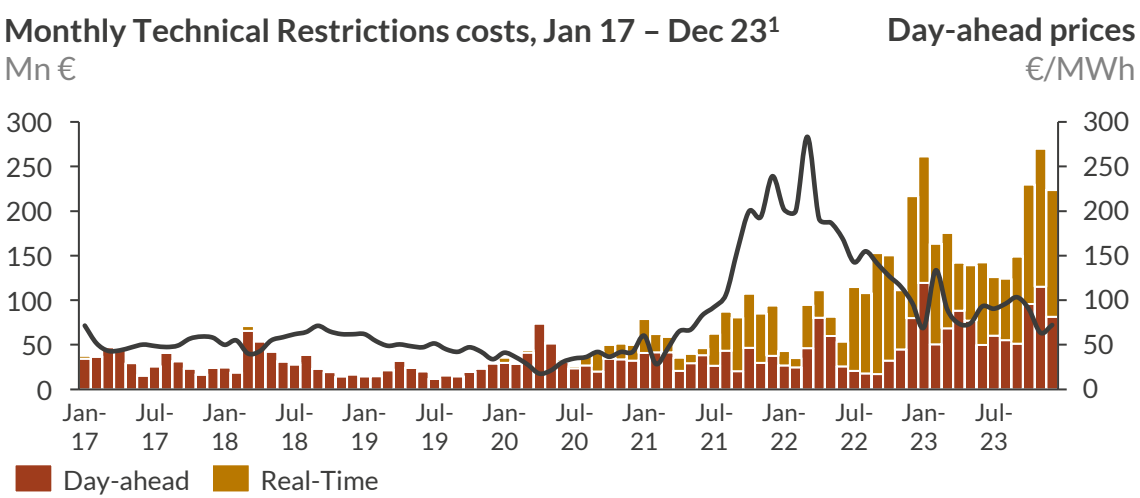
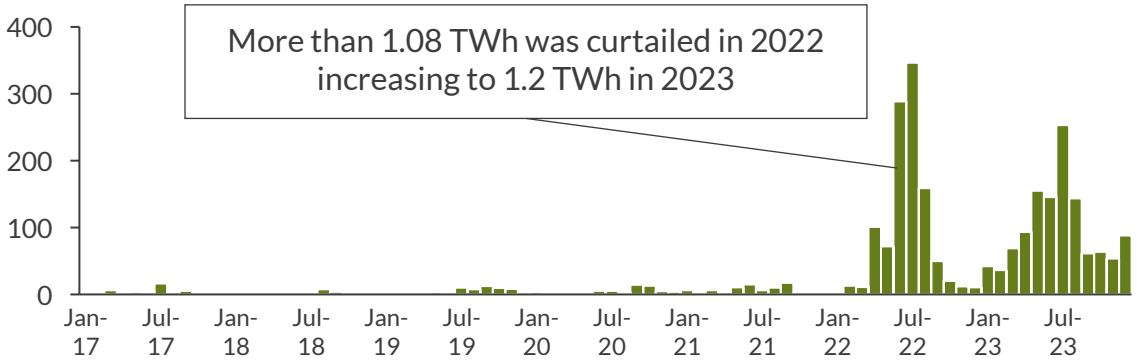
## I Congestion management costs have increased since January 2021 remaining high since

Monthly Technical Restrictions costs, Jan 17 – Dec 23[1]



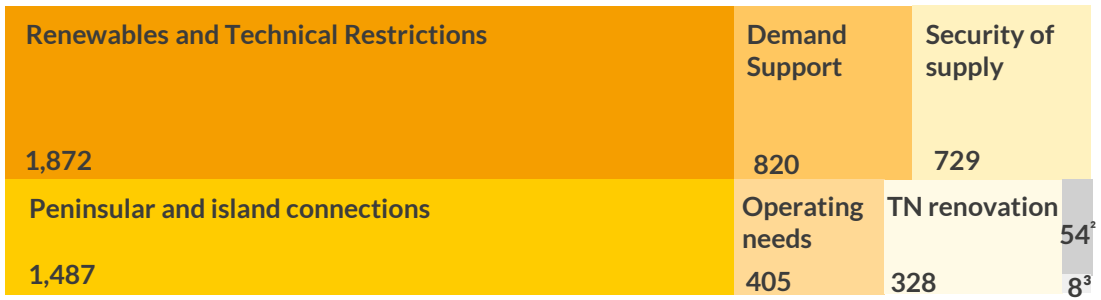

## II Non-compensated curtailment started to become significant as of May 2022 with the first significant solar curtailment

Non-compensated[4] renewables curtailment in Spain[1]




## III REE planned to invest 1.9 €b for grid investment in their last Network Development Plan (2021-26)

REE investments 2021-26, €m




- Technical Restrictions costs increased in the last three years with an average of 390 €m/year between 2017 to 2020 increasing to 800 €m in 2021, 1.3 €b in 2022 and 2.1 b€ in 2023 so far
- 2022 saw the first year with significant non-compensated[4] renewables curtailment accounting for more than 1TWh and 1.2% of the total production of those types of assets
- According to the latest Network Development Plan (21-26), investment in grid investment will only be 1.9 €b while the congestion for the last 3 years (20-23) accounts for 4.2 €b so far

1) Data from the 12th of November to December are preliminary. 2) Generation and Storage. 3) Interconnections. 4) Technical Restrictions day-ahead Phase 1 downward.

Sources: Aurora Energy Research, ESIOS, REE

# The energy transition in Europe is threatened by an increasingly constrained grid, requiring significant infrastructure investment

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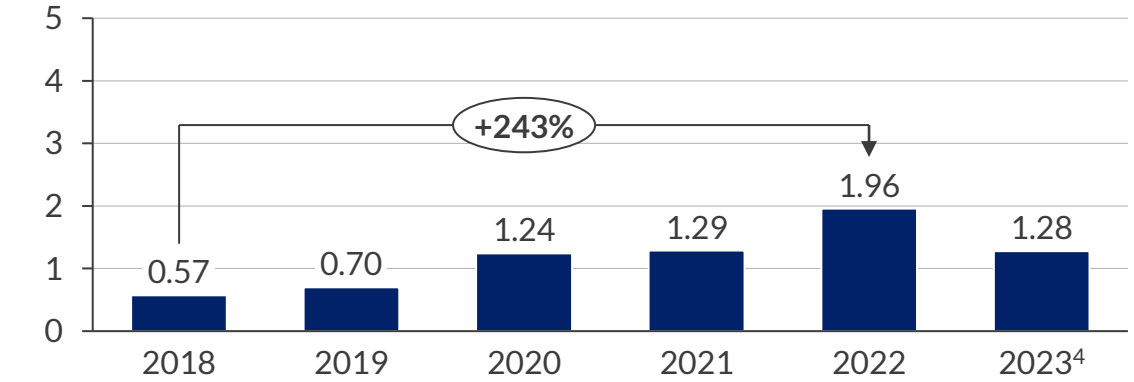
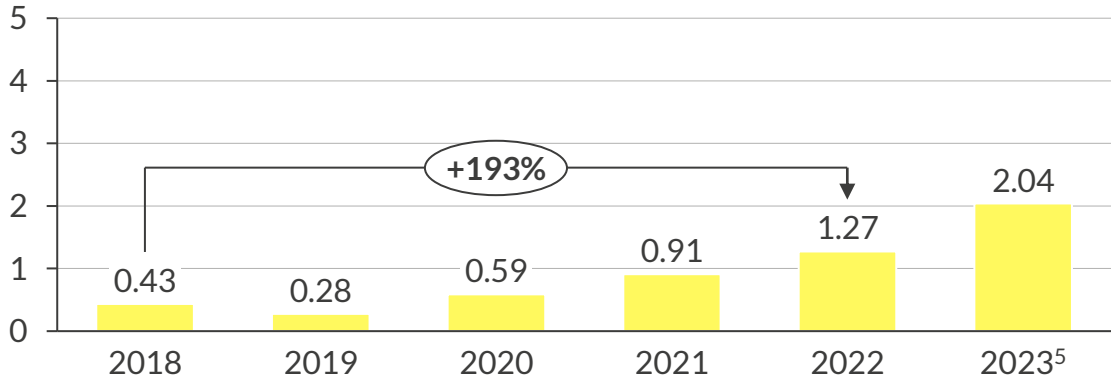
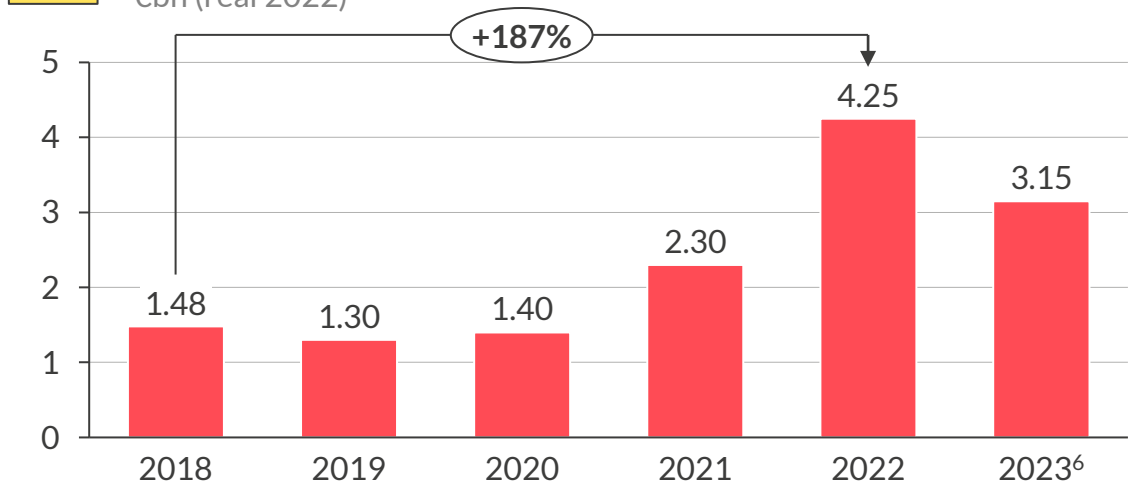
**Annual cost of constraint management[1]**
£bn (real 2022)




**Annual cost of constraint management[2]**
€bn (real 2022)




**Annual cost of constraint management[3]**
€bn (real 2022)




- From 2018 to 2022, the cost to secure the European grid increased by an average of 200% showing a clear need for infrastructure investment in the grid
- While the substantial increase of commodities prices exacerbated 2022 costs, 2023 seems to indicate a consistent increase compared to the pre-2020 situation
- In 2022, the costs of Great Britain, Spain and Germany represented 7.5 £/MWh, 5.4 and 8.7 €/MWh respectively. Despite the increase in power prices in 2022, the cost of securing the grid represents now a significant share of the electricity cost in Europe

1) Covers any actions taken due to limitations on transmission network, whether for thermal, voltage or stability reasons. 2) Covers all the costs from the Technical Restrictions Market in Day-Ahead and Real-Time. 3) Covers Redispatch, Countertrading and cost of the grid reserve. 4) Dec-23 costs are not known and replaced by Nov-23 costs. 5) Nov-23 and Dec-23 costs are preliminary. 6) Q1/Q2 23 costs are known and multiplied by 2 to make it comparable.
Sources: Aurora Energy Research, REE, National Grid, Bnetza

# Network congestion is raising concerns throughout Europe with Great Britain and Germany considering locational market and bidding zone split

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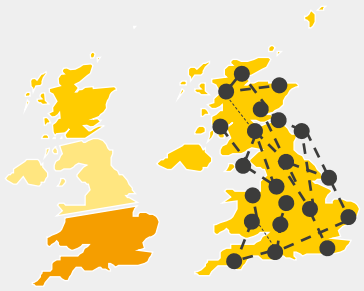
## GB is debating the benefits of zonal versus nodal pricing zones

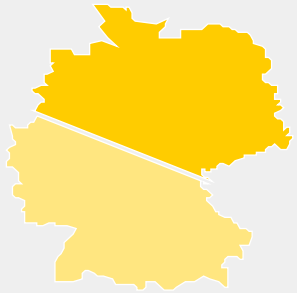
- The Department of Energy Security and Net Zero (DESNZ) called for a consultation with important stakeholders to review current electricity market arrangements (**REMA**).
- The results, published in March 2023 indicate that the government will consider introducing nodal or zonal pricing zones.
- However, respondents were divided as to which market policy is best suited to GB needs. **Both options are going to be evaluated in the coming months.**



*Potential zonal and nodal splits*

## Germany is considering introducing a zonal price split

- The EU Agency **ACER** has given **the TSOs of France, Germany, Italy, the Netherlands and Sweden** until end of 2023 to conduct a bidding zone review
- In Germany, the possible introduction of zonal price zones leads to **political resistance**: While northern Germany, has much cheap wind power, southern Germany is the power-reliant industrial center
- Particularly Bavaria is worried about increasing power prices in the case of a price zone split



*Potential zonal split*

### Nodal Pricing

- Prices and dispatch determined at the nodes for generators
- No European country has nodal pricing systems, However, outside of Europe it is established in the **CAISO, PJM, ERCOT** and **Singaporean** power markets.

### Zonal Pricing

- Generators and retailers settle prices at an aggregate, or marginal, bid in the entire zone.
- Currently, bidding zones in Europe are mostly defined by national borders, the exception being Scandinavia and Italy that have intra-national zonal pricing

Sources: Aurora Energy Research

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# Technical Restrictions is an Ancillary Service in which the TSO solves grid constraints in the Day-Ahead Market and in Real Time

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## I The Technical Restrictions (TR) market solves grid constraints by modifying energy programmes to ensure they are technically feasible

- Definition: "Any circumstance or incidence derived from the electrical system that affects the **security, quality and reliability of supply** and that requires, from a technical perspective, **the modification Day-Ahead, Intraday or Continuous Market Energy programmes"**
- Technical restrictions are solved over two time horizons:
  - Day- Ahead
  - Real Time
- Technical restrictions can arise from:

Voltage control: reactive power is required to re-establish the system's voltage level
*REE might separate Voltage Control from the Technical Restrictions Market[1]. They made a proposal for Voltage Control Market mechanism sandbox in August 2023*

Thermal Constraints: Short-circuit, power line failure or excessive power flow causing an overcurrent flowing

Insufficient reserve capacity[2]

## II The Day-Ahead TR Market is organised in two phases whilst Real Time technical restriction are solved continuously

### Day-Ahead: Phase 1

- The System Operator reviews the energy programme (PDBF) to see if this is technically viable
- The majority of volumes in this phase are in the upwards direction to solve voltage issues in the grid
- In the downwards direction, no offers are required and any market participant can be affected: **this is non-compensated generation curtailment**

### Day-Ahead: Phase 2

- This phase solves the imbalance of generation and demand caused by Phase 1
- Therefore, as the majority of Phase 1 volumes are upwards, volumes in Phase 2 are mainly in the downwards direction

### Real Time

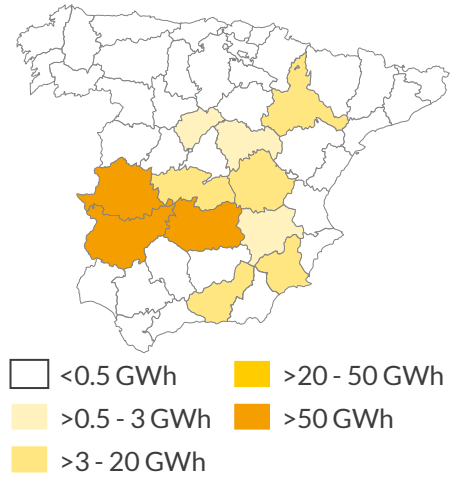
- Technical restrictions are solved continuously in real time
- In the past, Real Time technical restrictions volumes have been significantly lower than Day-Ahead volumes

1) No date are currently defined. 2) For regulation and balancing of the system, for tension control in the Transmission Network and for service recovery.

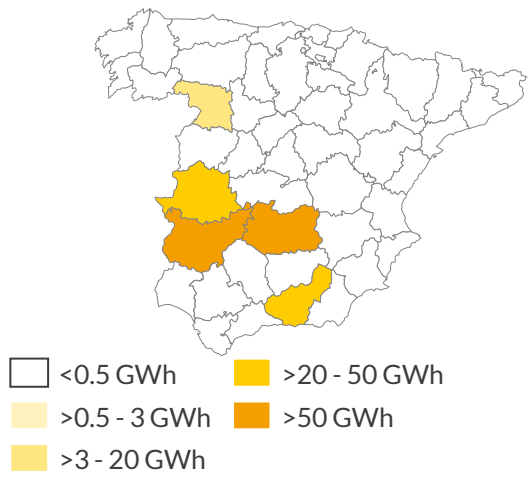
Sources: Aurora Energy Research, REE – Operating Procedure

# Solar thermal capacity saw the largest volume of curtailment in 2022, averaging 9% of total solar thermal generation volumes

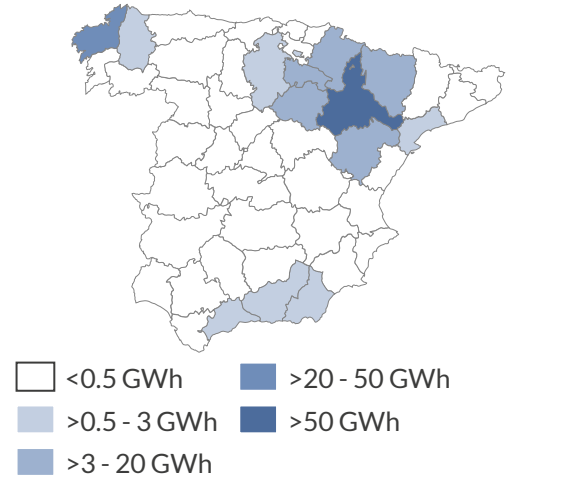
**Phase 1 Day-Ahead downwards volumes: solar PV,** GWh



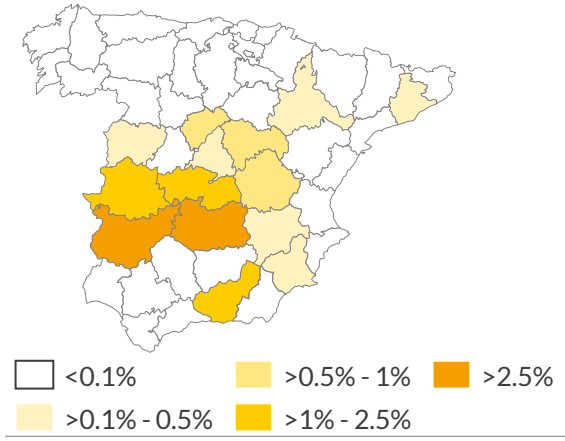

**Phase 1 Day-Ahead downwards volumes: solar thermal,** GWh



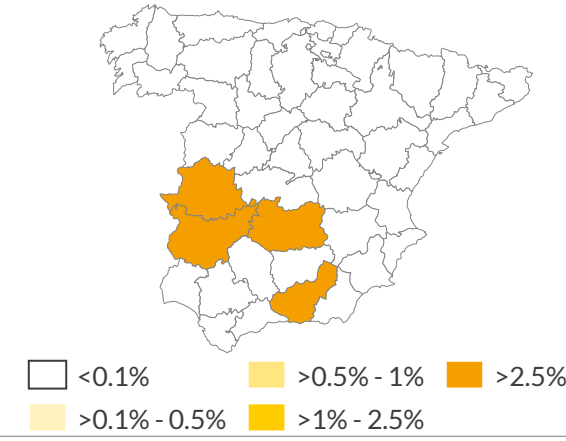

**Phase 1 Day-Ahead downwards volumes: wind,** GWh



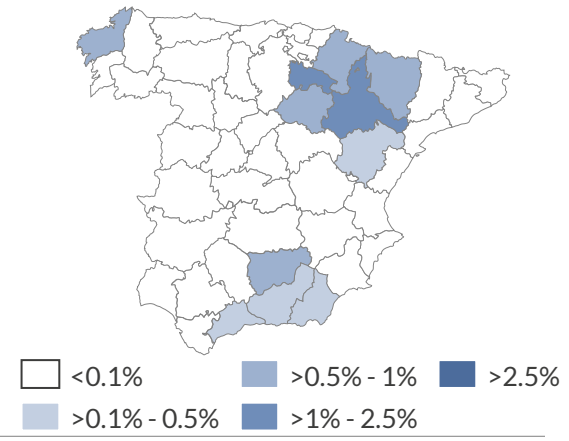

**Phase 1 solar PV curtailment over total solar PV generation,** %




**Phase 1 solar thermal curtailment over total solar thermal generation,** %




**Phase 1 onshore wind curtailment over total onshore wind generation,** %

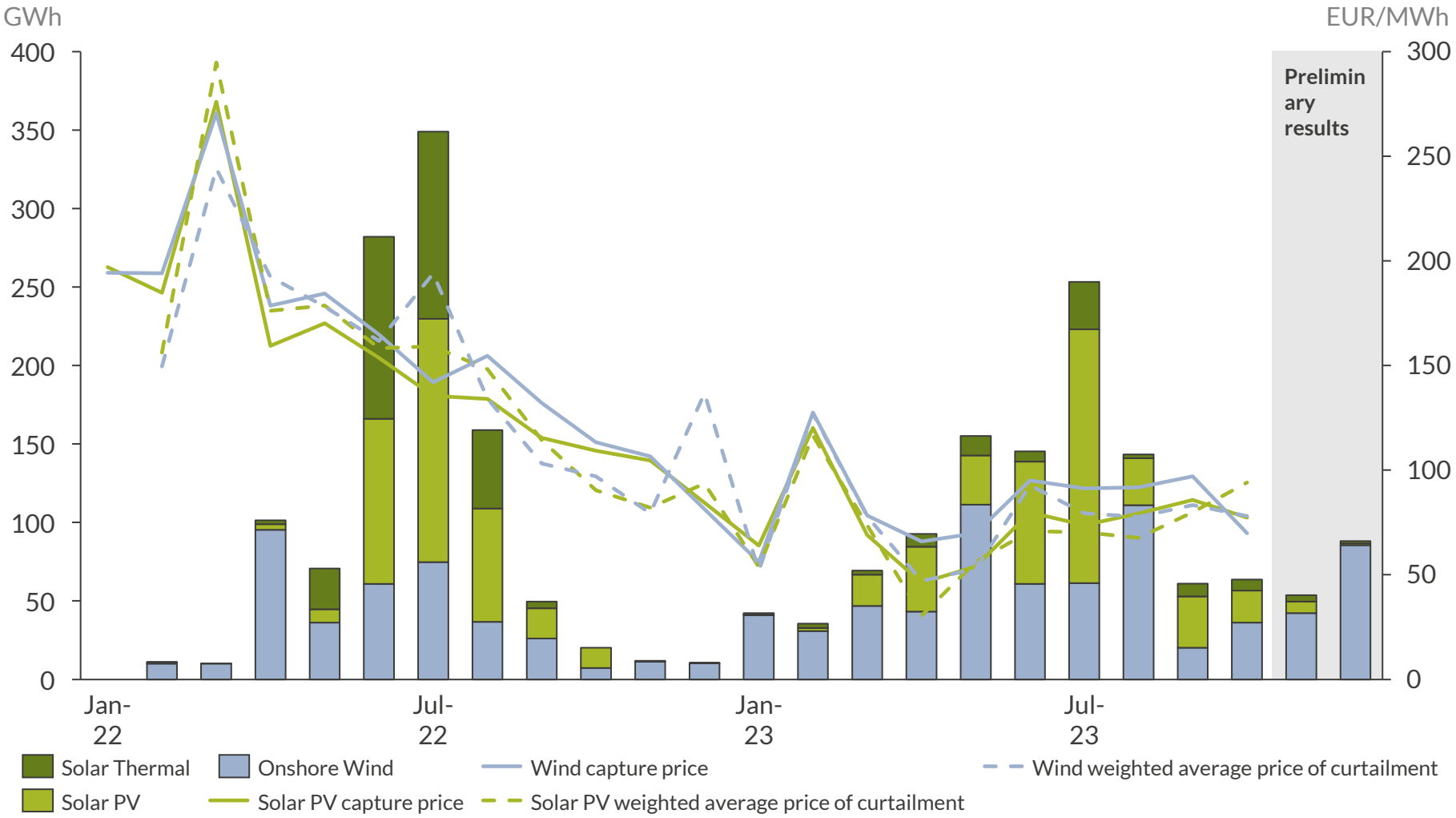



- Solar PV curtailment occurs most heavily in Badajoz, Cáceres and Ciudad Real, averaging 86 GWh in 2022.
- Solar thermal curtailment represents a high percentage of generation in all provinces except Zamora, averaging 9% in Cáceres, Badajoz and Granada, and making up 25% of generation in Ciudad Real.
- Wind is the least curtailed of the three technologies, averaging 6 GWh across all curtailed provinces and reaching a maximum of 1.6% of total generation in the most curtailed province, Zaragoza.
- Solar thermal power plants have been the most impacted as measured by curtailment over the total generation, with Ciudad Real reaching 18% over the period analysed.

Sources: Aurora Energy Research, REE

# Seasonality can be observed with nearly no curtailment when solar generation is low and demand high

**Non-compensated renewables curtailment[1] in Spain**




**Wholesale and capture prices**




1) Curtailment from Technical Restrictions day-ahead Phase 1 downwards. 2) Data from Jan-22 to May-23.

Sources: Aurora Energy Research, REE

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- Clear seasonal patterns can be observed with curtailment reduced by more than 90% between the summer and winter periods.
- The reduction of curtailment in winter can be explained by higher demand and lower renewable energy generation.
- Peak curtailment happened in July 2022 with 349 GWh, composed of 74GWh, 155GWh and 120GWh of onshore wind, solar PV and solar thermal, respectively.
- The weighted average price of curtailment does not fall below capture prices, meaning that curtailment does not only happen when prices are heavily cannibalised.

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**Get in touch with: humberto.medrano@auroraer.com**

# Agenda

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I. Introduction to grid curtailment

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III. How to forecast those curtailments?

# Analysing grid congestion and curtailment requires a spatial understanding of demand, production capacity and power flows

**Grid constraints occur when grid capacity is insufficient to transport power from generation to demand centres**

To develop a better understanding of grid congestion and curtailment it is necessary to develop a detailed spatial understanding of:

A Location of demand centres

B Location of conventional power production

C Location of renewables production

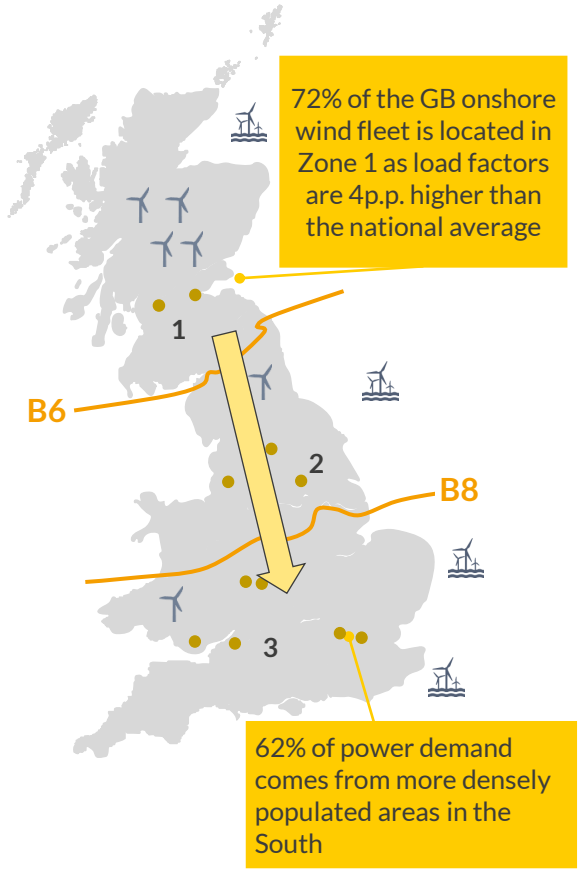
D Province net positions (demand – total production)

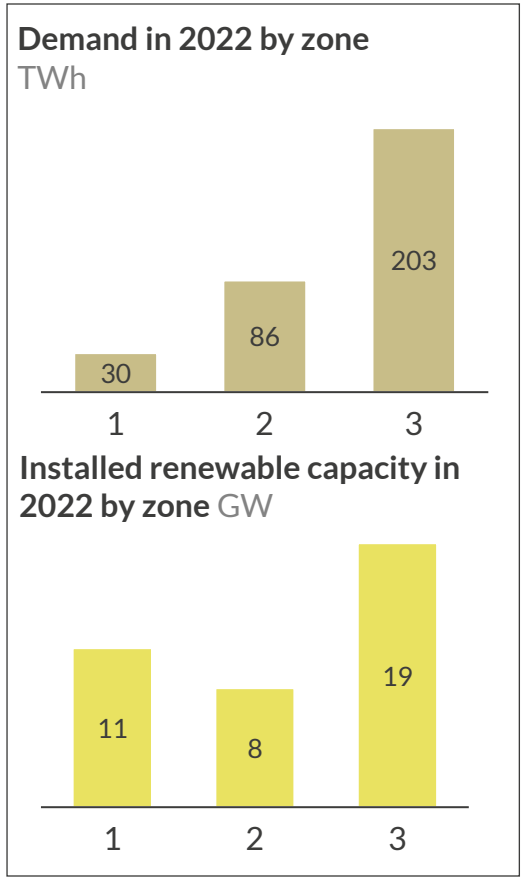
E Grid connection between provinces

The analysis will help us get a better grasp of grid congestion and curtailment. Nonetheless, curtailment might also be the result of:

- Intra-province bottlenecks
- DSO/TSO lack of infrastructure
- Other reasons, such as redispatch caused by voltage control actions[1]

**GB example: demand is focused in the South of England, whilst wind capacity is focused in Scotland, leading to North-South flows and congestion particularly at the B6/B8 boundaries**



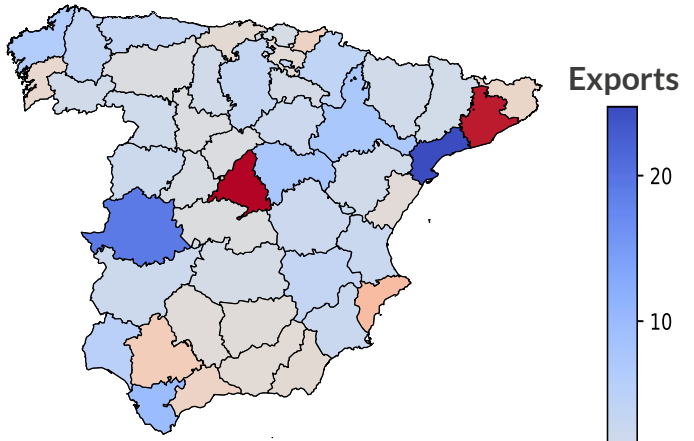

Key demand centres | Onshore wind | Offshore wind | Main direction of flows

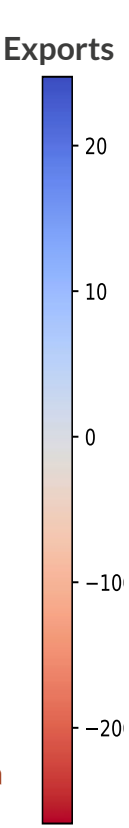
1) Currently, curtailment (TR DA Phase 1 Downwards) is only used for thermal constraints in Spain.

Source: Aurora Energy Research

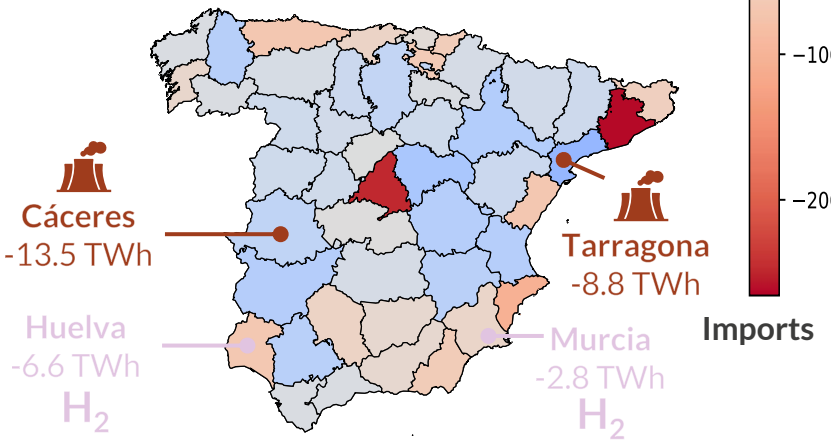
# By 2030, extreme net positions of some provinces swing, as baseload capacities phase-out and intermittent supply develops

**Yearly provincial net positions[1] in 2022**
TWh/year

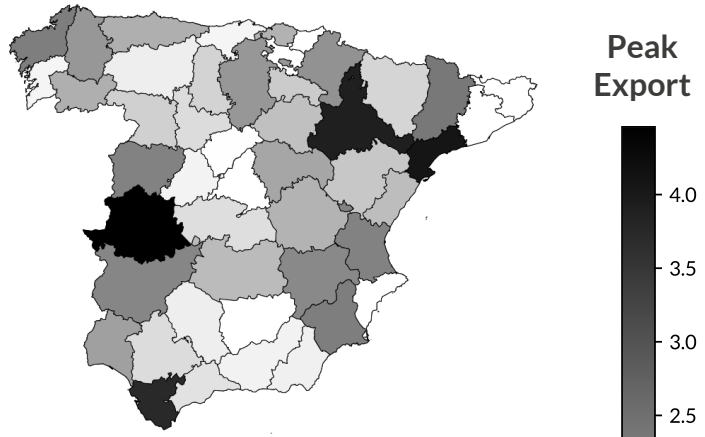





**Yearly provincial net positions[1] in 2030**
TWh/year

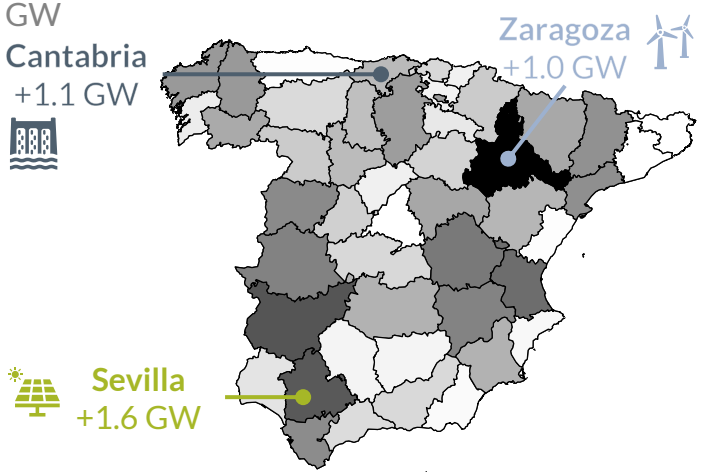



**Maximum hourly positive net position 2022**
GW






**Maximum hourly positive net position 2030**
GW




1) According to Aurora's October 2023 Central scenario.

Sources: Aurora Energy Research, REE.

- By 2030, the peninsular power supply will decentralise, as renewable generation deployment mirrors nuclear capacity phase-out.
- The peak net position of Sevilla will increase by 1.5 GW over the next seven years, as solar PV build-out concentrates in the south, turning Sevilla from a net importer today into a net exporter in 2030.
- Cadiz and Asturias see their yearly net position turning negative due to a decrease in CCGT generation from 32TWh in 2023 to 11TWh in 2030[1].
- By 2030, production profiles of pumped storage in Cantabria and onshore wind plants in Zaragoza increase the maximum net position in these provinces by + 1.1 GW and +1.0 GW, respectively.

# With nearly 350 GWh curtailed during the last 2 years, Badajoz is an interesting province to analyse

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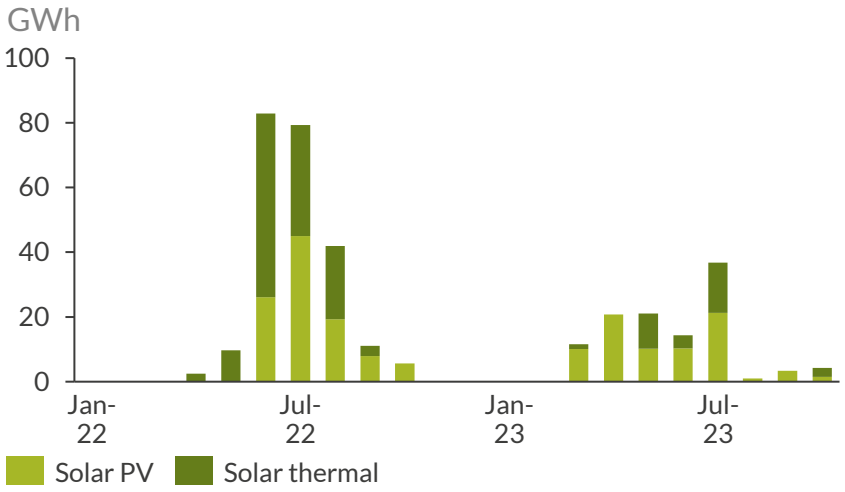
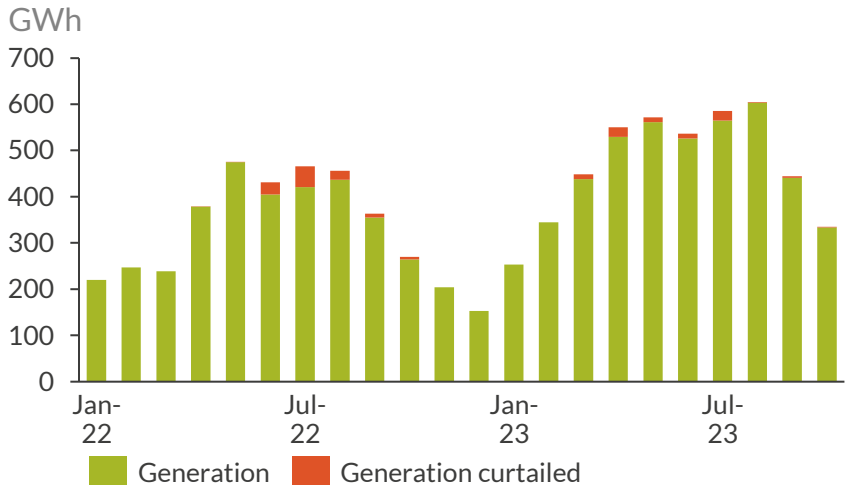
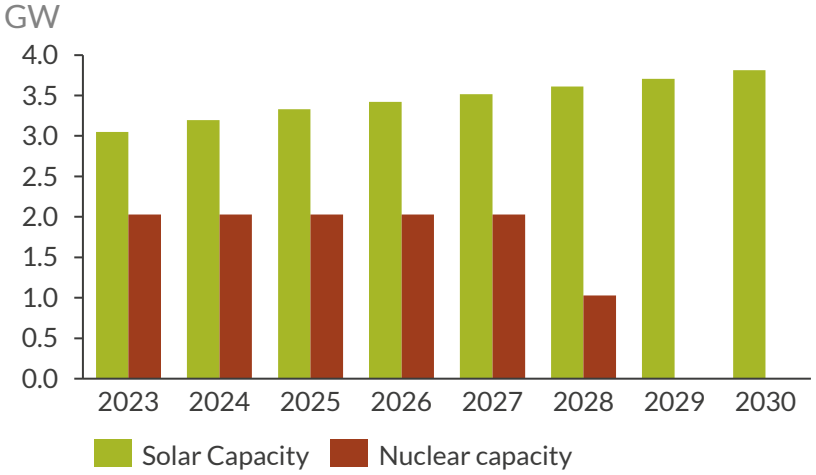
### Historical curtailment in Badajoz



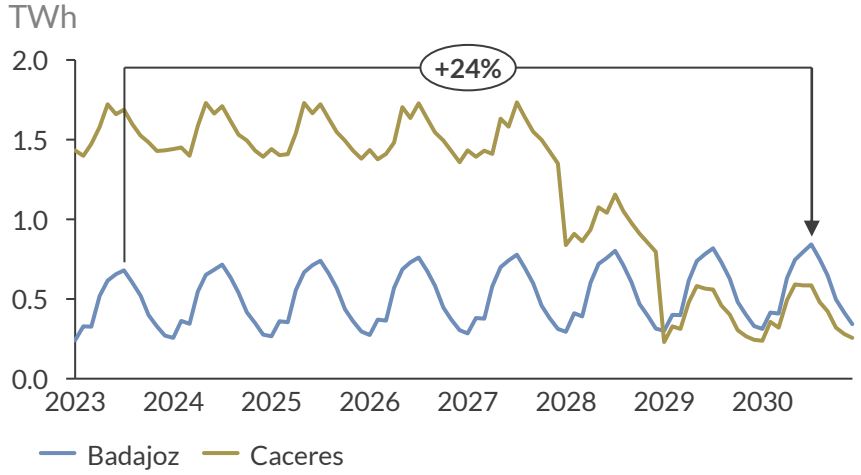

### Volumes curtailed of Solar PV in Badajoz




### Installed capacity in Badajoz




### Forecasted monthly net positions




- With already 3 GW of solar capacity installed in Badajoz, we expect to have another 800MW installed by 2030.
- Badajoz's neighbouring province, Cáceres, will undergo nuclear phase-out as of 2028 reducing the generation in the province by 14 TWh in two years.
- The volumes of solar PV curtailed accounted for nearly 15mn€ in 2022 and 5mn€ in 2023.
- With our estimate of incoming capacity and demand in the provinces, Aurora builds a net position towards 2030 which will serve as a basis for the grid curtailment forecast.

Sources: Aurora Energy Research, REE.

# The evolution of grid curtailment will depend on the evolution of demand, thermal generation retirements and network development

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| | Risk | Impact on curtailment |
|---|---|---|
| **Thermal power plants**  | **Nuclear phase-out** | Nuclear phase-out will reduce drastically the loading of lines close to the power plants which will reduce the need for curtailment in the province/region. |
| | **Reduction of fossil fuel generation** | Due to renewables penetration, the number of hours of fossil fuel generation is decreasing leaving more room for renewables locally decreasing curtailment. |
| **Low-carbon investment**  | **Renewables investment** | The increase of renewables locally will increase the amount of curtailment in high renewables generation period. |
| | **Battery investment** | Batteries will reduce curtailment as they will charge when renewables are abundant. |
| **Demand**  | **Electrical vehicles** | Smartness of electrical vehicles will allow them to charge when the renewables are abundant reducing the need for curtailment. |
| | **Electrolysers (green hydrogen)** | Electrolysers will increase significantly the electricity demand in certain provinces while reducing the need for curtailment. |
| **Grid investment**  | **Grid investment delays** | Lack of grid investment or delays will increase the need for curtailment to accommodate for weak grid infrastructure. |

Source : Aurora Energy Research

# Key takeaways

1. Over 1 TWh of renewables were curtailed without being compensated each year in 2022 and 2023. The situation, showing an upward trend in 2023, reveals that these losses accounted for over 1% of the total renewable output annually, with figures in some provinces soaring beyond 10%.

2. The Technical Restrictions market is used by REE to solve thermal constraints, voltage control and insufficient reserves. It is a locational pay-as-bid market separated into Day-Ahead Phase 1, Day-Ahead Phase 2 and Real Time actions. Curtailment resulting from the Day-Ahead Phase 1 stage is uncompensated and results in a physical limitation to generate.

3. Grid curtailment is disproportionately affecting renewable energy projects, with solar photovoltaic (PV) systems bearing the brunt in a few provinces such as Caceres and Badajoz. These regions, marked by their relatively low demand but rapidly increasing solar capacity, are particularly vulnerable. On the other hand, onshore wind farms face greater challenges in areas like Zaragoza and A Coruña, noted for their significant onshore wind capacity.

4. Future curtailment will be determined by the interplay between the deployment of renewables, the increase in power demand from electrolysers and electric vehicles, and improvements to the grid. The planification of those elements will be key to prevent massive curtailment to happen in the peninsula

1) Technical Restrictions day ahead Phase 1 downward.

Source: Aurora Energy Research

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

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## 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 in the 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

Source: Aurora Energy Research


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