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Spain Grid Curtailment Forecast

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 until 2030:
  - 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

- 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 contact **Felipe van de Kerkhof**

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1) Nodes are grouped by similar levels of curtailment inside of each province, 85 groups provided.

Source: Aurora Energy Research

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, may choose to generate even when prices are below their variable costs, as this maximises revenue.
  - Additional revenues from GoOs[1] or PPAs may also incentivise renewable plants to generate when prices are below their variable costs.
- 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.

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.

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

1) Guarantees of Origin.

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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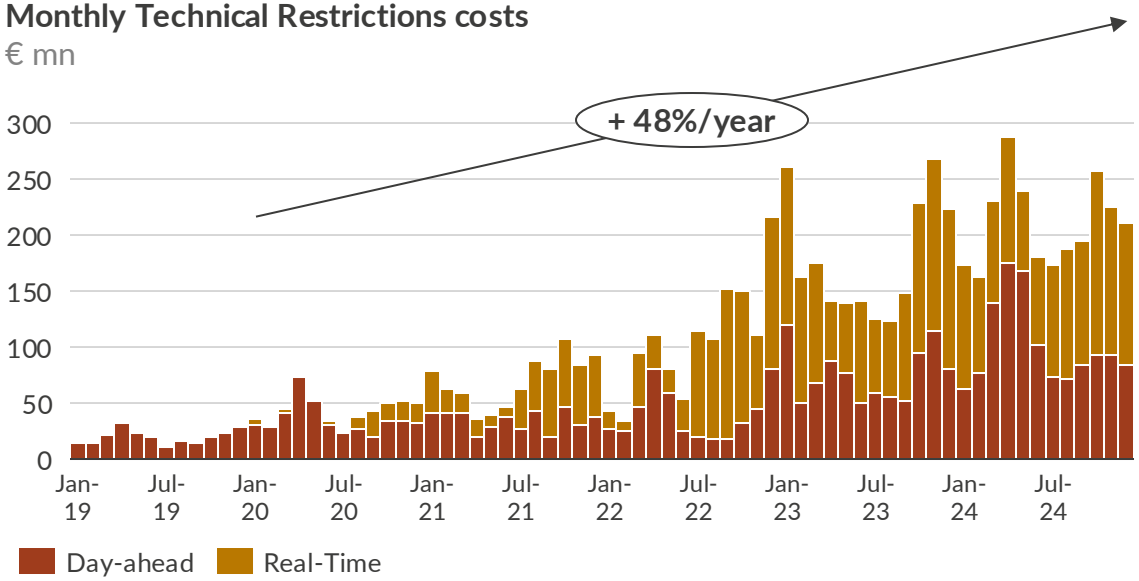
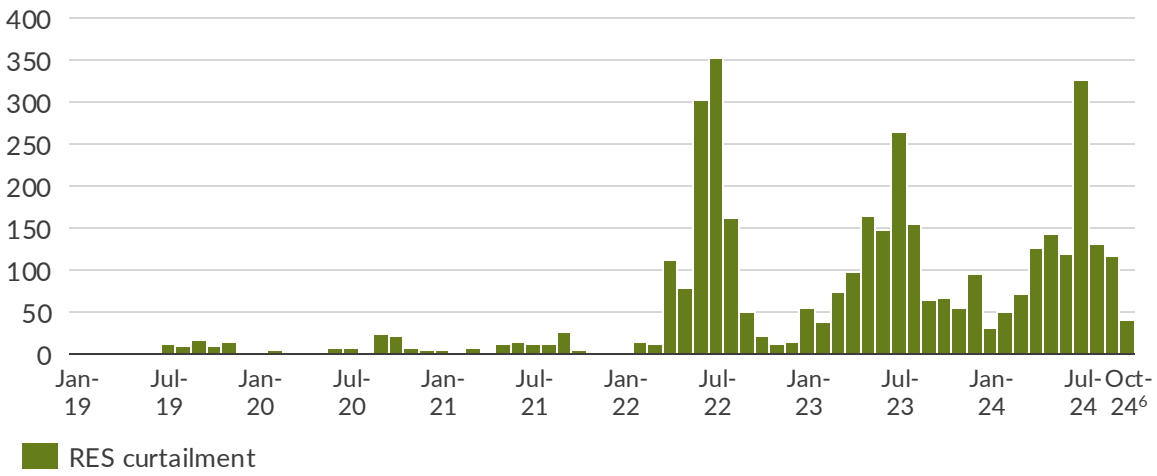
Monthly Technical Restrictions costs

€ mn



Non-compensated[4] renewables[5] curtailment in Spain

GWh



REE planned investments, 2021-26 Network Development Plan

€ mn

Renewables and Technical Restrictions	Demand Support	Security of supply	International interconnections
1,872	820	729	1,260

Peninsular and island connections	Operating needs	TN[1] renovation	54[2]	Additional modifications 2024
1,487	405	328	8[3]	489

- From 2020 to 2024, Technical Restrictions costs have increased at an average rate of 48% per year, reaching 2.5€ bn in 2024.
- 2022 was the first year with significant non-compensated[4] renewables[5] curtailment, accounting for more than 1.1 TWh (1.0% of total renewables production).
- The previous Network Development Plan budgeted 5.7 € bn to strengthen the national transmission network and 1.26 € bn for international connections. In April 24, an amendment increasing the investment by 489 € mn was approved.
- Currently, REE is reviewing proposals for the 2025-2030 Plan and must prepare an 'Initial Development Proposal,' which is expected to be published at the beginning of 2025.

1) Transmission network. 2) Generation and Storage. 3) Interconnections. 4) Technical Restrictions day-ahead Phase 1 downward. 5) This includes solar PV, solar CSP, wind, biomass, other RES, hydro and pumped storage. 6) Includes data until Oct-8 2024 (REE publishes this data with 3 months delay).
Sources: Aurora Energy Research, ESIOS, REE

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

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]

The Day-Ahead TR Market is organised in two phases whilst Real Time technical restrictions 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) Estimated to be live by Q1 2026. 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

In 2023, phase 1 curtailment of solar and wind increased by 52% relative to 2022

Phase 1 Day-Ahead curtailment volumes in 2023

GWh

Phase 1 Day-Ahead curtailment volumes, as a fraction of total generation in 2023

%

1) Aurora's team was able to identify the location of 87.8% of the peninsular Technical Restriction Phase 1 downwards volumes for solar and wind in 2023, due to data availability. 2) Percentages over total curtailment identified in a province. 3) This is mainly due to projects participating in the SRAP mechanism. More information can be found in section II.3 of this report.
Sources: Aurora Energy Research, REE

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2023 curtailment trends

- Solar PV curtailment increased 22% compared to 2022. Cáceres was the most heavily curtailed, with 2.6% of its solar PV generation being curtailed during Phase 1.
- Onshore wind curtailment increased drastically, reaching 695 GWh in 2023, a 79% year-on-year increase mainly driven by increases in Soria, Huesca, La Coruña, La Rioja and Albacete.

Understanding grid topology is essential; curtailment in one area can be alleviated or exacerbated by elements of the grid in neighbouring areas

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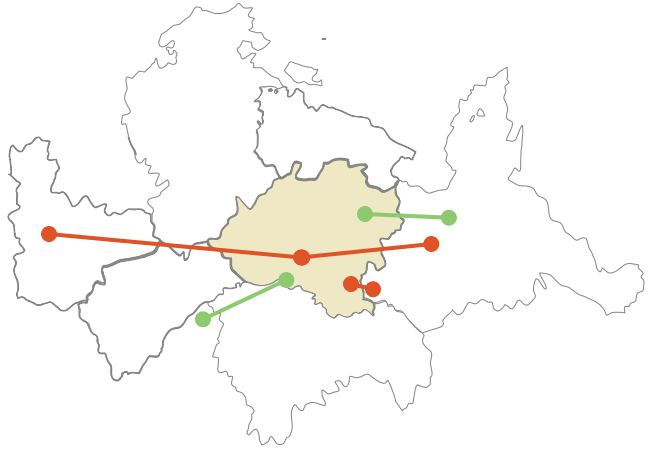
Peninsular high-voltage[1] transmission network topology

- Grid curtailment occurs on a nodal level and is mainly driven by:
  1. Transmission constraints: lines have insufficient capacity to transport electricity from generation sites to demand centres
  2. Grid stability requirements: maintaining grid frequency and voltage within the limits set by the System Operators

New methodology

- Aurora models the **power flows** following the closure of the Day-Ahead market, and the corresponding redispatch of energy volumes.
- Grid connections can differ from geographical borders. As an example, Soria is connected electrically to demand centres in Valladolid and Madrid, despite not sharing a physical border.

Example – Soria[1]



1) Voltage superior or equal to 220 kV

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

Aurora's power flow model curtails plants to solve for grid congestion according to the Operating Procedure defined by the System Operator

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REE[1] defines the redispatch methodology in Operating Procedure 3.2. Aurora replicates this methodology in its model.

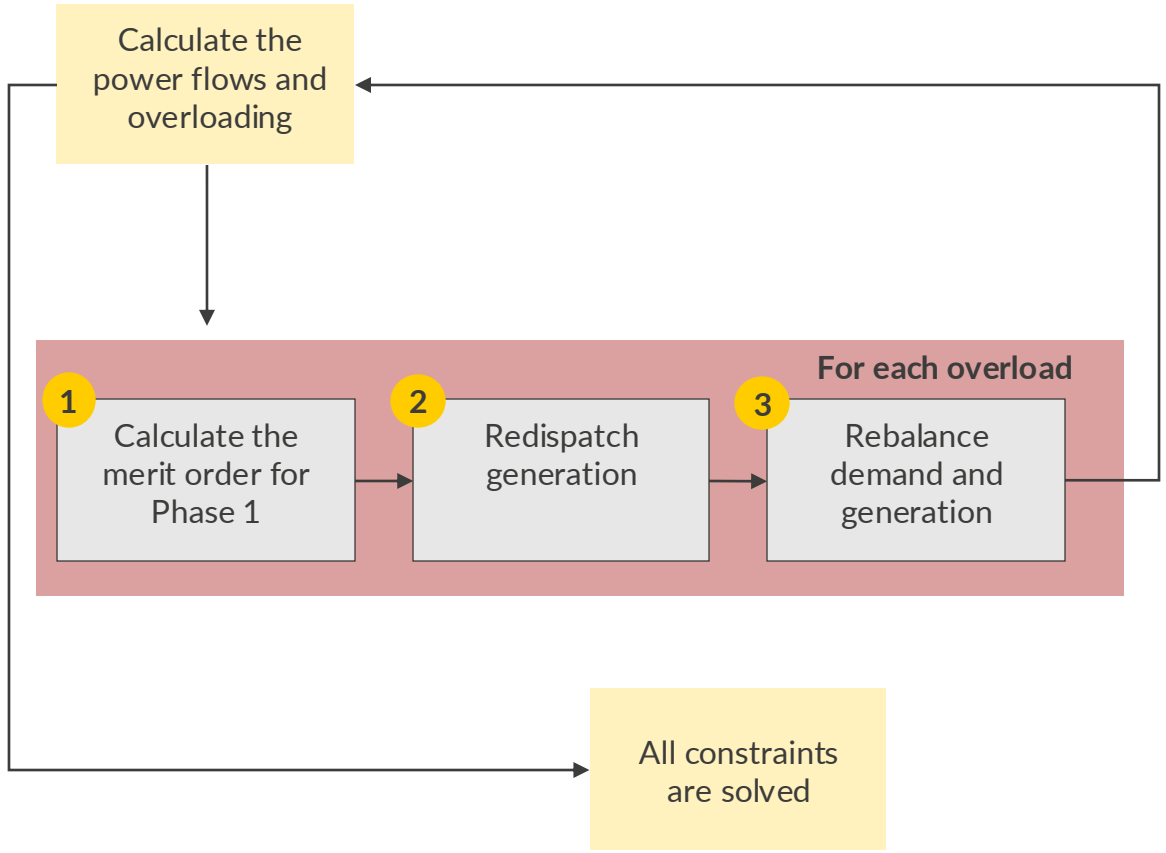
1. Constraints are first solved by turning up plants in the Phase 1 Technical Restrictions Market[2]. If a constraint cannot be resolved by increasing generation[3], plants will be curtailed to resolve the constraint.
2. Plants are selected in order of the contribution factor to the overloaded line. If multiple plants are connected to the same node (and so have the same contribution factor) then they will be turned down according to the priority of dispatch per technology defined by REE.
3. Phase 2 of the Technical Restrictions Market rebalances demand and generation after constraints are resolved. Plants that participate in Phase 1 cannot participate in Phase 2.

Thermal plants are curtailed first whilst renewables are curtailed last; flexible assets are curtailed ahead of non-flexible ones

Technologies are curtailed according to the following order:

1. All technology types, except renewables and high efficiency cogeneration[4]
2. High efficiency cogeneration plants[4]
3. Dispatchable renewables[5]
4. Non-dispatchable renewables

Illustrative example of the methodology used to solve grid constraints in Aurora's Power Flow model



1) Red Eléctrica España: Spanish System Operator (SO). 2) The SO can modify the output of a plants' full capacity or turn a plant up by a fraction if needed. 3) In the case of storage, "turning up" can refer to reducing consumption. 4) As defined in Article 2 of Royal Decree 616/2007. 5) Mainly refers to Solar Concentrated Power (CSP) and Biomass.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