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MANAGING GRID CURTAILMENT RISK IN EUROPE

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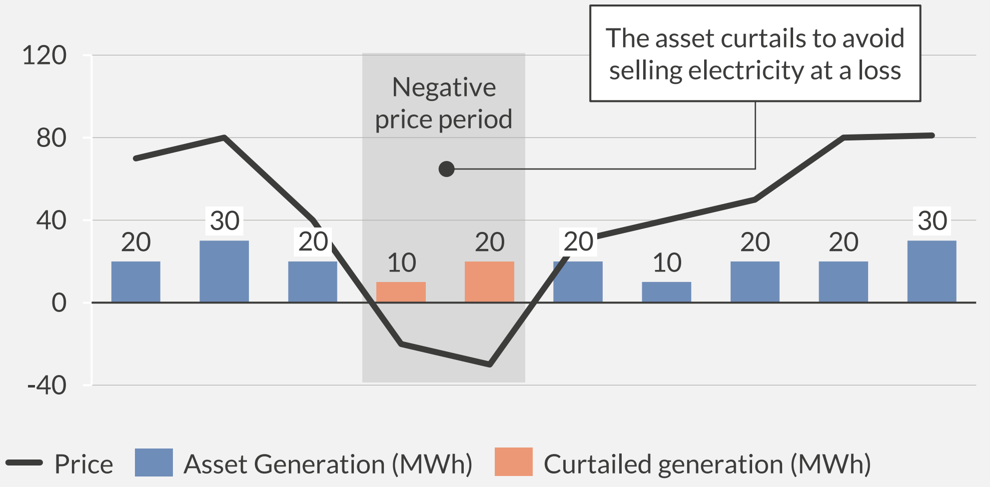
There are two types of "curtailment", and they happen for different reasons

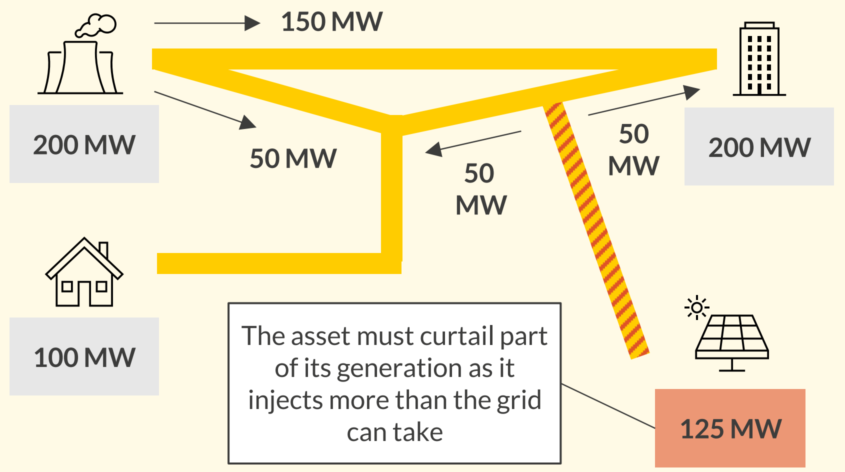
Economic Curtailment

- 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. For renewables this is normally during zero or negative price hours.



Grid Curtailment

- 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, high congestion on the local system
- Compensation for curtailed energy depends on the market rules.



In this presentation I will be focusing on **Grid Curtailment**

Source: Aurora Energy Research

Nearly 30 TWh of generation was lost to grid curtailment in 2023 across 6 countries in Europe, at a cost of close to 9 billion Euros

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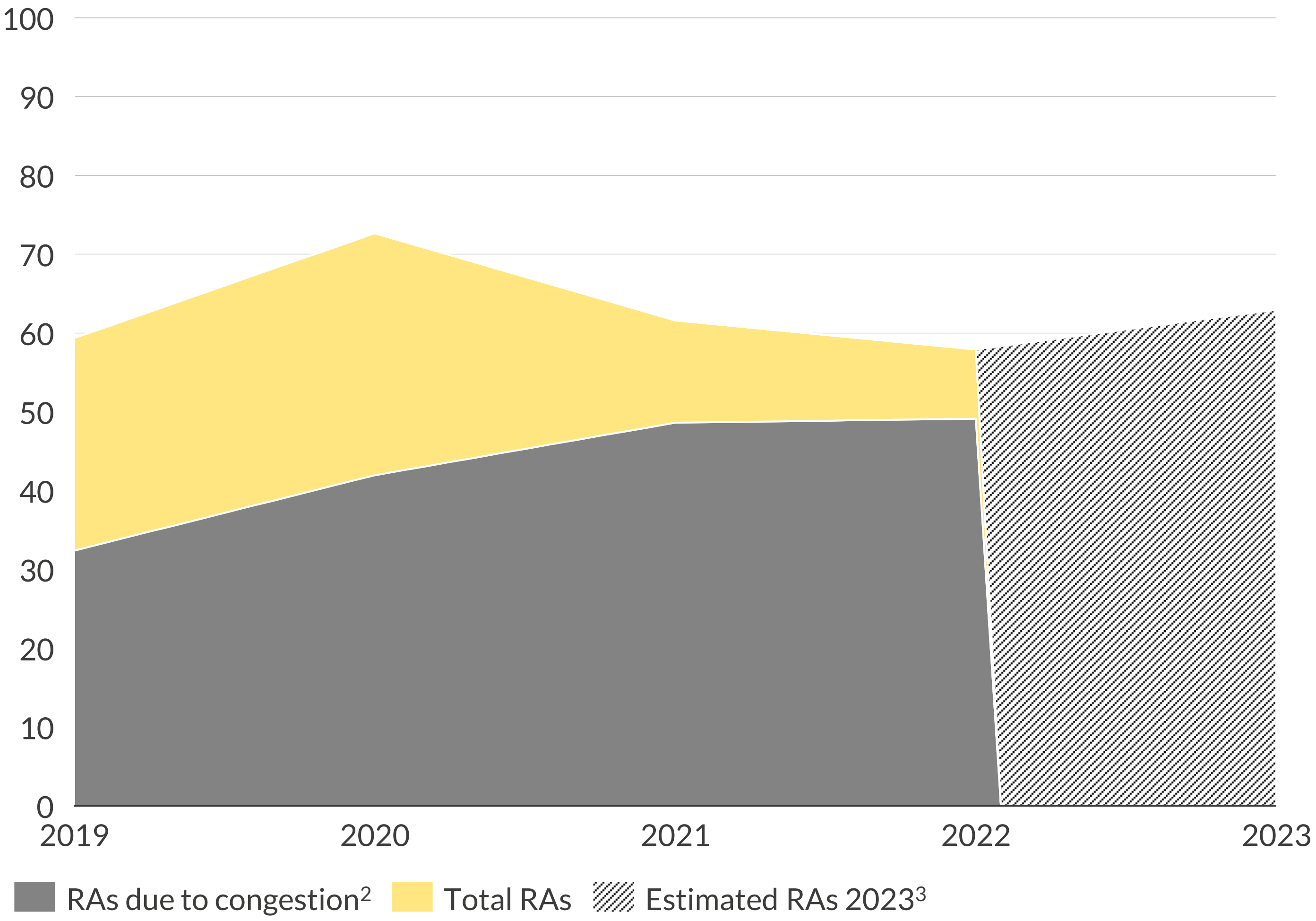
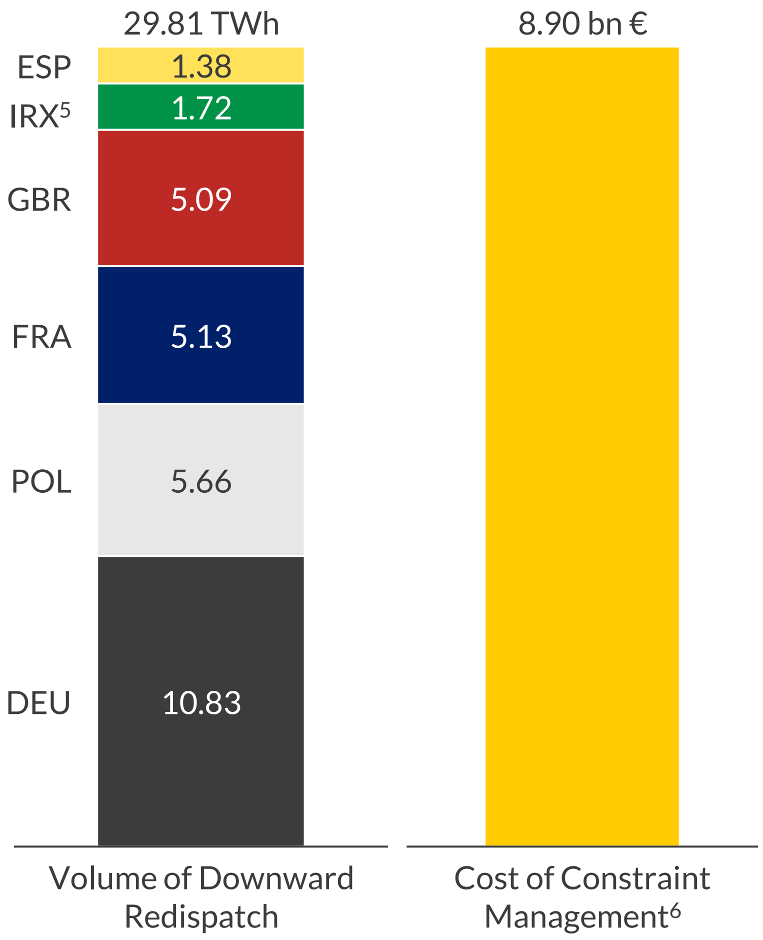
Growth in Remedial Actions (RAs) taken to ease grid congestion across Europe[1] since 2019

TWh



Constraint Management measures in 2023[4]

TWh and bn €



1) Europe in this case includes the EU27, GBR, NOR but excludes MLT and CYP. Data for most countries comes from ACER/CEER MMRs, or where unavailable from national TSOs. ITA excluded as data deemed unrepresentative by ACER and no data provided by Terna. 2) RAs due to congestion calculated from total volumes using ACER figures for congestion. 3) Estimates for 2023 RAs based on data from TSOs in 10 countries with highest congestion in previous years. 4) Based on downward dispatch actions reported by individual TSOs in most congested grids . 5) Only includes RES curtailment. 6) For 6 displayed countries; FRA cost estimated by comparing against DEU and GBR costs per volume.

Sources: Aurora, ACER, BNetzA, EirGrid, ENTSO-E, National Grid ESO, REE, RTE, PSE

The cost of managing grid congestion is largely driven by the growth of renewable generation, and the inability for grid investment to keep pace

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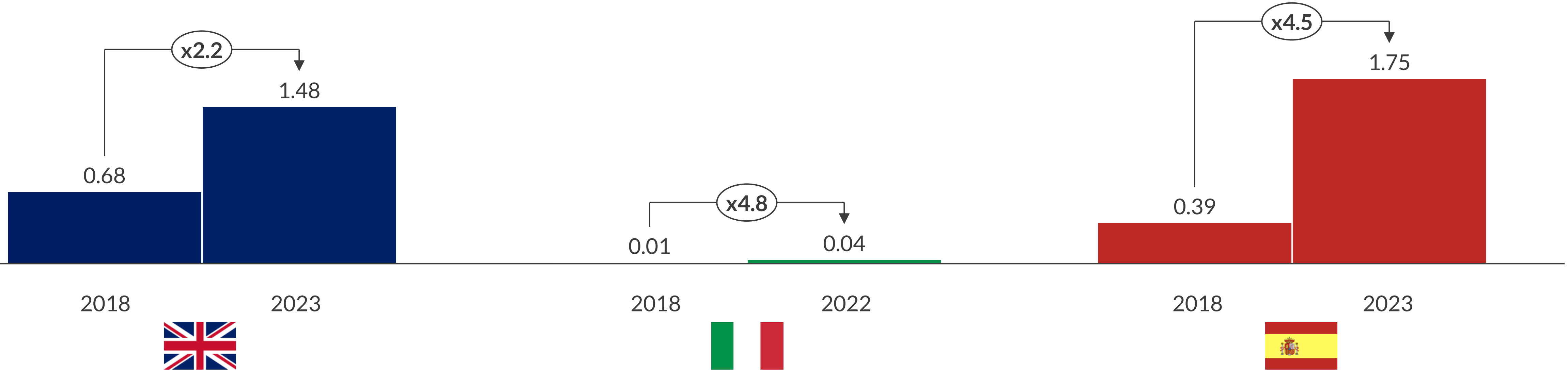
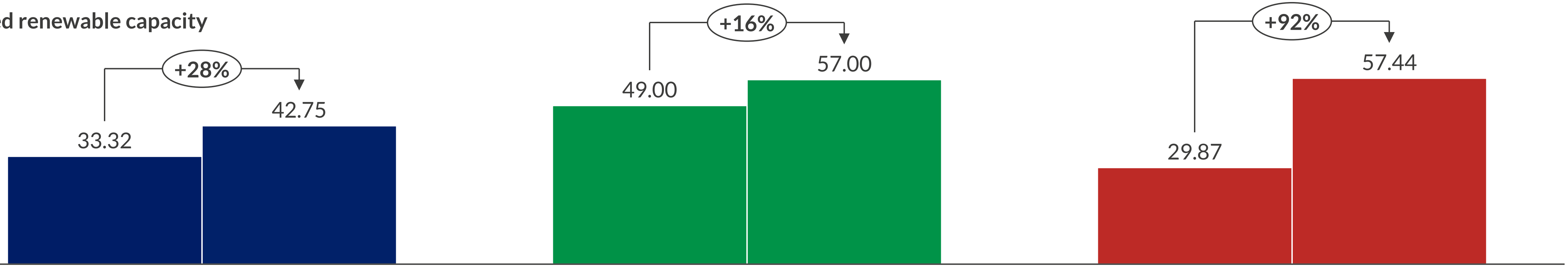
Constraint management costs[1]

€bn



Installed renewable capacity

GW



1) Constraint management costs in Italy are significantly lower, as zonal prices help price (and solve) structural grid limitations.

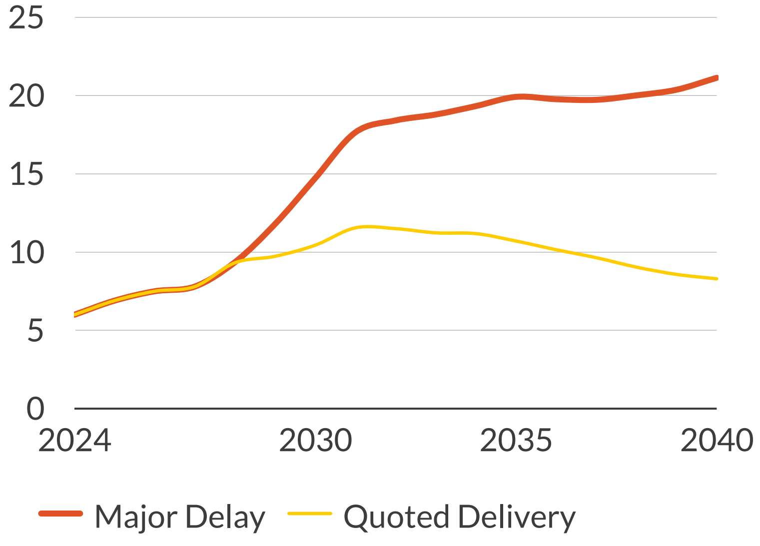
Sources: Aurora Energy Research, National Grid ESO, REE

As the pace of renewable development accelerates in resource-rich areas, congestion problems are expected to grow

Deep Dive

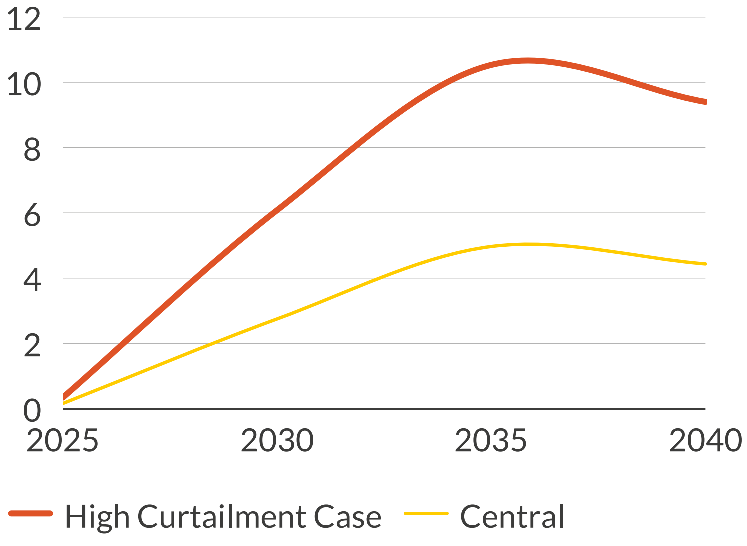
- A new interconnector in 2030, and the ASTI[1] framework helps bring down curtailment over time in the "Quoted Delivery" scenario
- Delays to the planned transmission infrastructure would result in significant renewable curtailment in GB

Curtailment forecast[2]
TWh



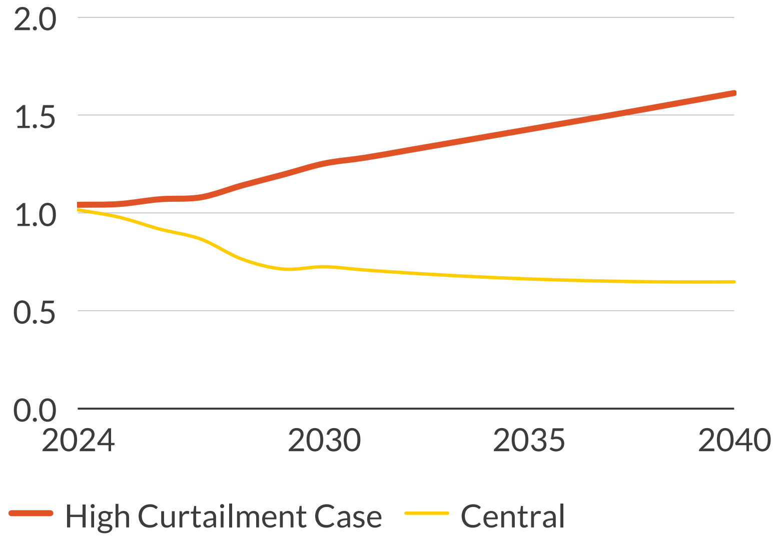
- High load factors in southern zones and the islands attract large solar and wind buildout
- For this new capacity to reach demand centres, significant investment in cross-zonal capacity is required, but geography causes difficulties

Curtailment forecast in key congestion areas[3]
TWh



- Localised development of wind and solar is creating increasing congestion challenges across several areas in Spain
- The retirement of nuclear and increasing local demand (e.g., hydrogen) can help mitigate curtailment growth, but uncertainty remains

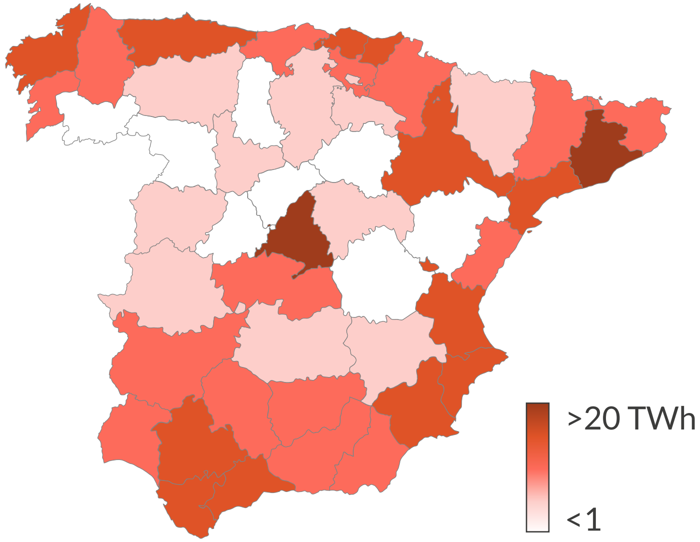
Curtailment forecast in key provinces[4]
TWh



1) Ofgem's Accelerating Strategic Transmission Investment (ASTI) initiative. 2) Rolling average. Curtailment here covers only transmission connected assets and includes all energy sources. 3) Key congestion areas include all market zones except for North zone. High curtailment case considers the occurrence of grid contingencies reducing the grid capacity by 30%. 4) Key provinces with high buildout of variable RES and transmission constraints, includes A Coruna, Badajoz, Caceres, Ciudad Real, Huesca, La Rioja, Navarra, Soria & Zaragoza. Source: Aurora Energy Research

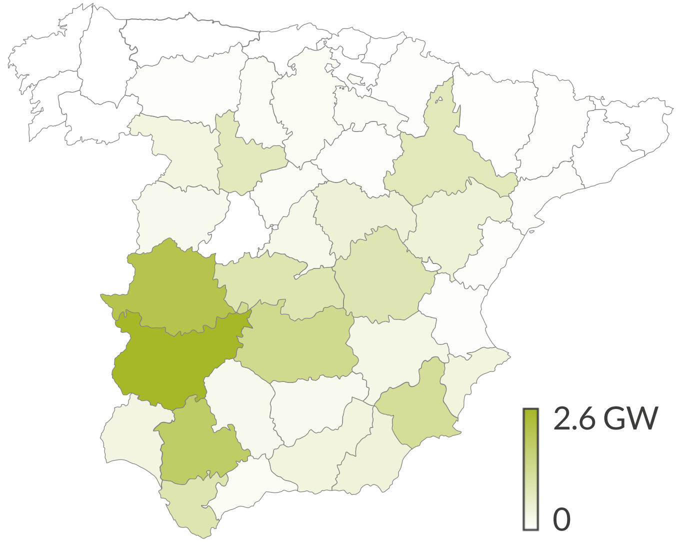
Madrid and Barcelona represent 26% of Spanish demand; the location of renewables away from demand centres puts strain on the grid

Total demand per province in 2023[1]
TWh

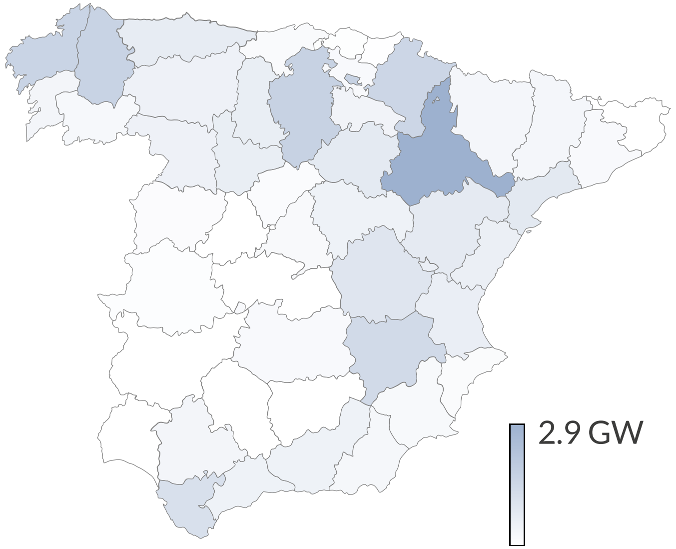


Renewables capacity connected to the grid, as of 31st May 2024
GW

Solar PV ground-mounted



Onshore wind



- Spanish demand is concentrated in Madrid, Barcelona and the Spanish coast
- The inland provinces have relatively low demand levels, but attract significant renewable investment

- Solar PV capacity is concentrated in the south of Spain, where load factors are the highest
- Badajoz is the province with the highest solar PV capacity

- Onshore wind capacity follows Spanish wind corridors, with strong concentrations in Aragón (North-East) and Galicia (North-west)
- Zaragoza is by far the province with the highest capacity, cumulating 11.3% of the peninsular total

Uncompensated curtailment in the Technical Restrictions Market poses a key risk to investment in renewables in Spain…

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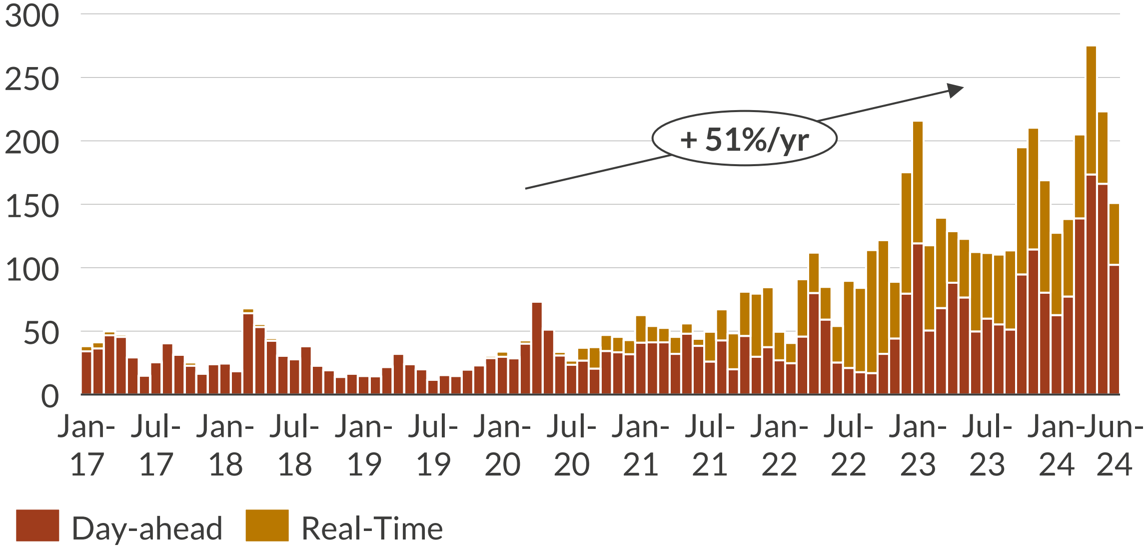
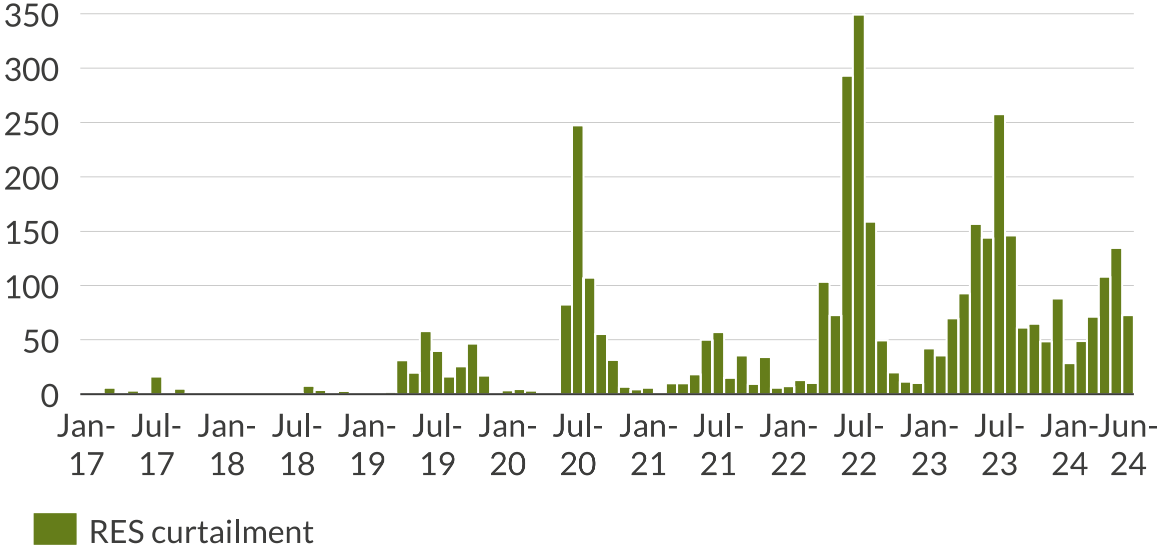
Monthly Technical Restrictions costs since Jan 2017
€ mn



Non-compensated[1] renewables curtailment in Spain
GWh



- Technical Restrictions is an Ancillary Service in Spain through which the TSO solves grid constraints in the Day-Ahead Market and in Real Time.
- The Day-Ahead Technical Restrictions Market is organised in two phases (Phase 1 and Phase 2) whilst Real Time technical restrictions are solved continuously.
- From 2020 to 2023, Technical Restrictions costs have increased at an average rate of 51 % per year, reaching 1.1 € bn in 2022 and 1.7 € bn in 2023. In 2024 first semester, Technical Restrictions have cost 1.1 € bn, a 36% increase compared to the same period in 2023.

- Downward actions in the Day-Ahead Phase 1 is not compensated; in other words, generation curtailment that happens in the Day-Ahead Phase 1 constitutes a risk for investors.
- 2022 was the first year with significant non-compensated[4] renewables curtailment, accounting for more than 1.3 TWh and representing 1.2% of the total renewables production.
- Non compensated renewables curtailment has been a feature of the Spanish market since 2022, despite mechanisms designed to lower curtailment like SRAP (Sistema de Reducción Automática de Potencia).

1) Technical Restrictions day-ahead Phase 1 downward. This data is published by Red Eléctrica with a 3 months delay.

Sources: Aurora Energy Research, ESIOS, REE

Renewables curtailment peaks in summer when transmission lines capacities are low and solar production is high

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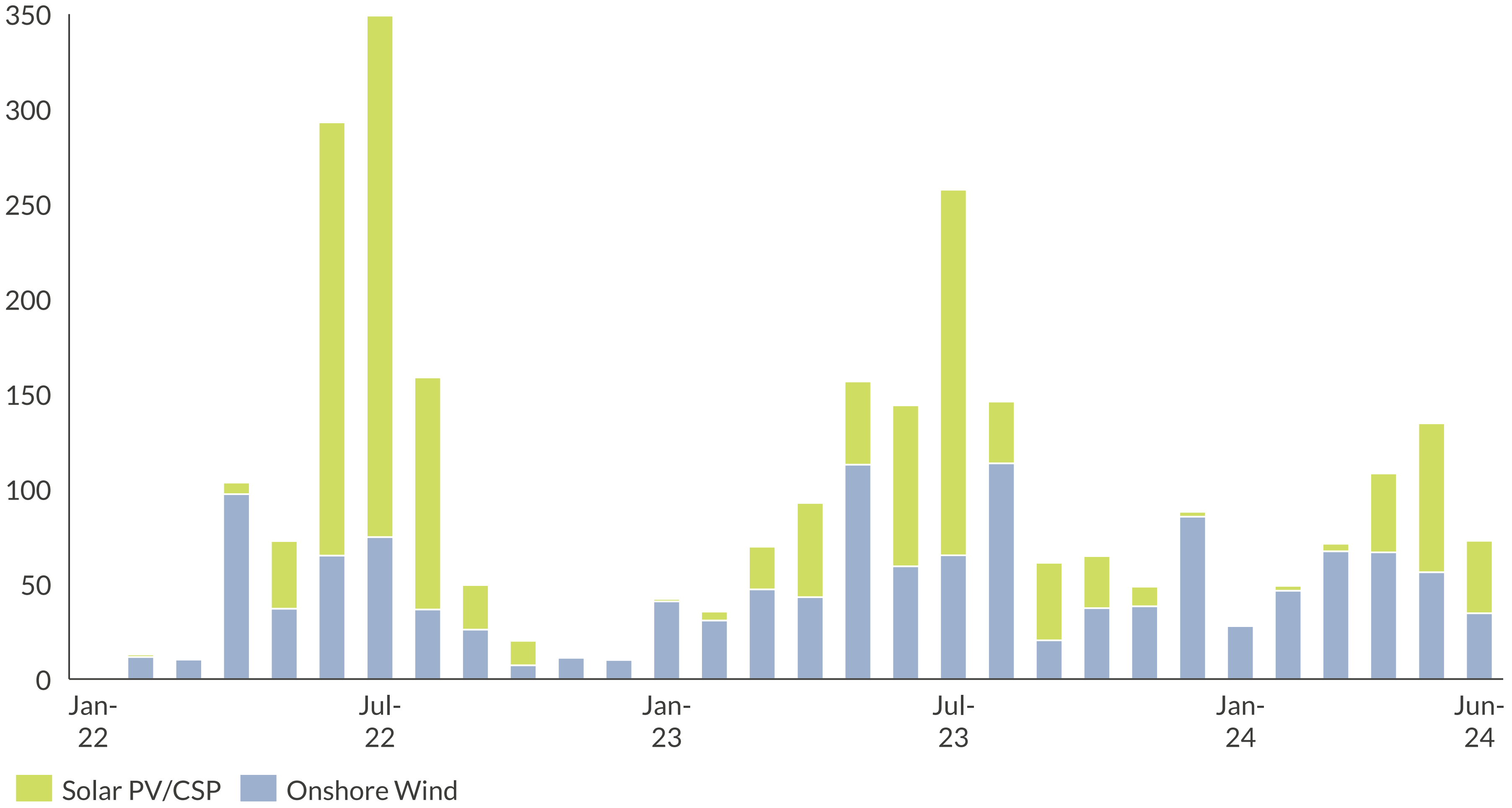
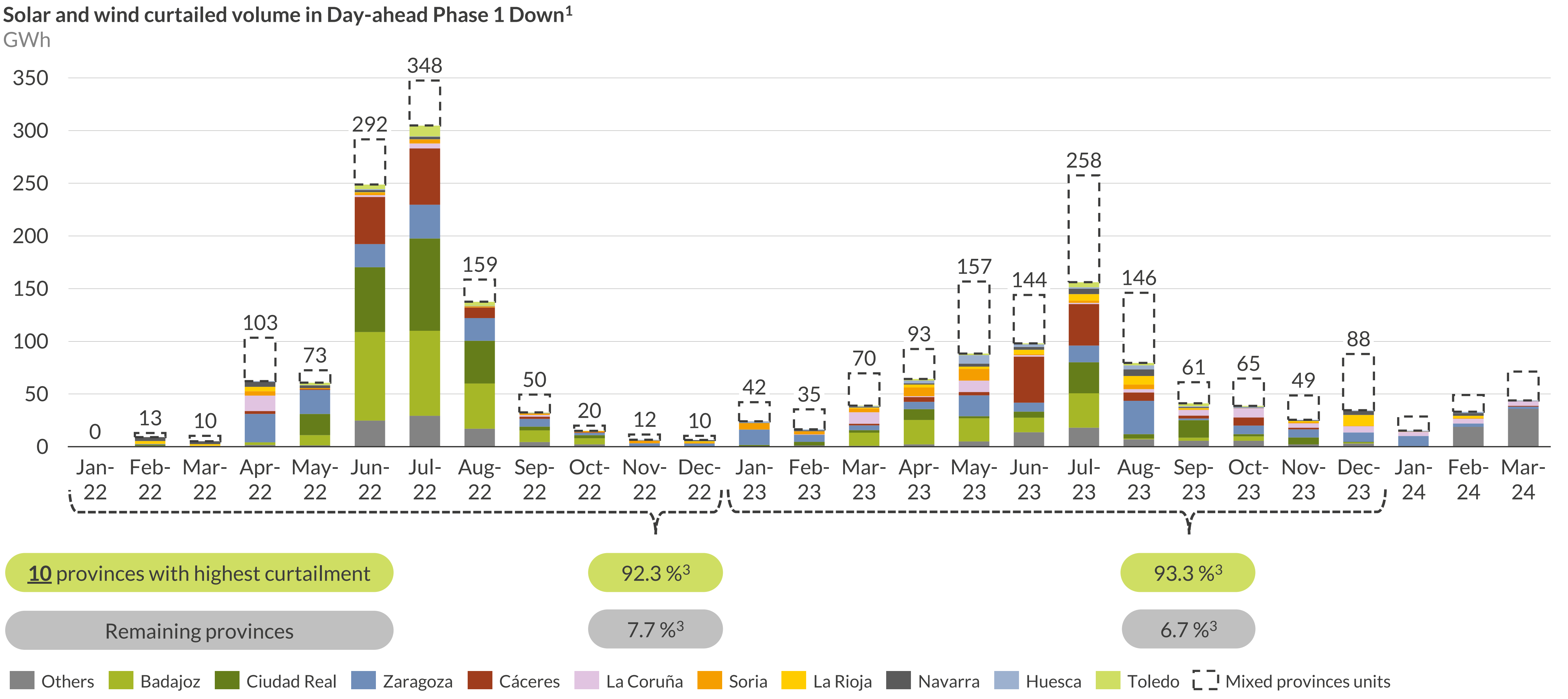
Day–ahead non-compensated renewables curtailment[1] in Spain in 2022-2024
GWh



- Curtailment typically occurs in hours of low prices, and when renewables production is at its highest.
- During winter, stronger demand and lower renewable power generation reduces the curtailment risk.
- Curtailment for Solar CPS decreased in 2023 with the introduction of the SRAP mechanism, although overall RES curtailment volumes increased from 1,089 GWh in 2022 to 1,207 GWh in 2023.
- Non compensated renewables curtailment volume in 2024 amounts to 464.3 GWh for the Jan—Jun 24 period², a 14% decrease compared to the same period in 2023.

1) Curtailment from Technical Restrictions day-ahead Phase 1 downwards. 2) Data from Jan-24 are preliminary. 3) The weighted average price of curtailment represents the volume weighted average baseload price at which technologies were curtailed.
Sources: Aurora Energy Research, REE

Ten provinces experienced 93% of all identified non-compensated curtailment for solar and wind in 2022 and 2023

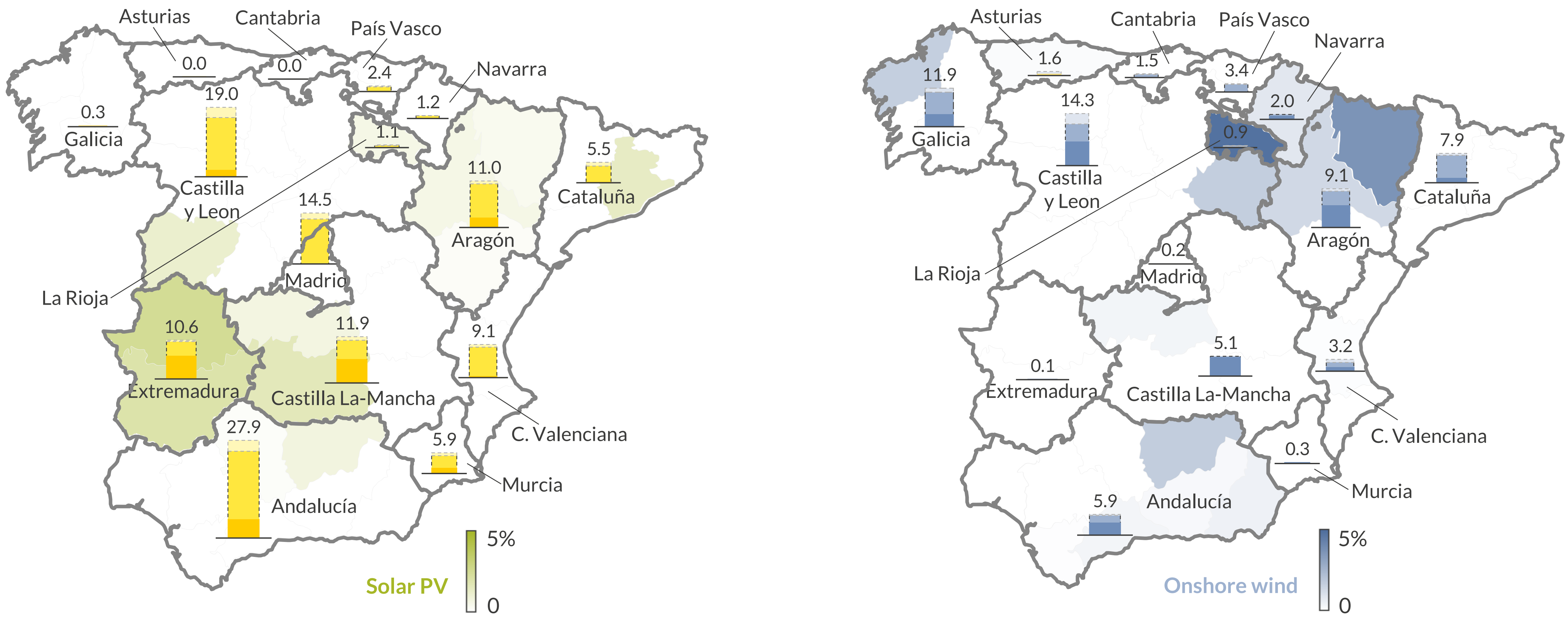


1). Data is published by Red Eléctrica 90 days after curtailment events; 2) Aurora's team was able to identify the location of 68% of the national Technical Restriction Phase 1 downwards volumes for solar and wind, as Ambiguous programming units pertain to multiple provinces; 3) Percentages over total curtailment identified in a province, which is 68% of total curtailment

Sources: Aurora Energy Research, REE

With RES development continuing in areas with relatively high curtailment rates, the risk of curtailment increases over time…

Shading: **Phase 1 Day-Ahead curtailment volumes, as a fraction of total generation** (%)
Bars: **Installed capacity and capacity in the pipeline** (GW)



Solar | Wind | Operational | Approved[3] | Submitted application[4]

… but the downside can be quantified to help reduce uncertainty and enable the delivery of renewables projects

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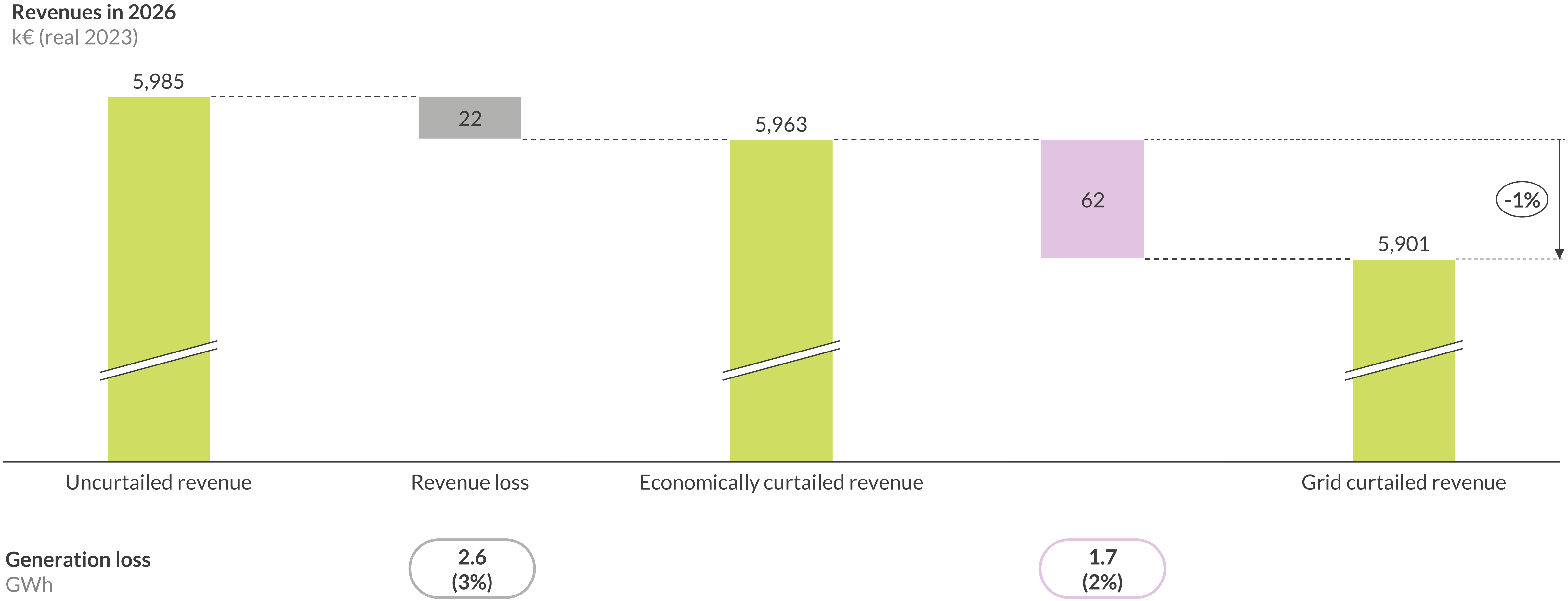
A 50MW wind asset in Soria would see 1671 MWh of lost generation (or 2% of the total generation in 2026), amounting to a total loss of 62k € in revenues due to curtailment in the Technical Restrictions Market (TRM)



Sources: Aurora Energy Research

Key mitigations are grid expansion and demand growth, but siting decisions, co-location and revenue diversification can help manage curtailment risk

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Market and Policy

Demand

- Placing demand near renewable-rich areas reduces curtailment risks
- New demand technologies, like data centers and hydrogen, are particularly effective in curtailment mitigation due to their locational flexibility

Expansion of grid capacity

- The primary solution to grid constraints is to expand the grid capacity
- Governments are in the process of accelerating the deployment of grid

Developers

Siting

- Grid constraints are highly location-specific
- Alternate sites can alleviate constraints but might have lower load factors

Co-location

- Co-location enables renewables to shift their generation to less constrained times
- The battery may be able to participate in other ancillary markets

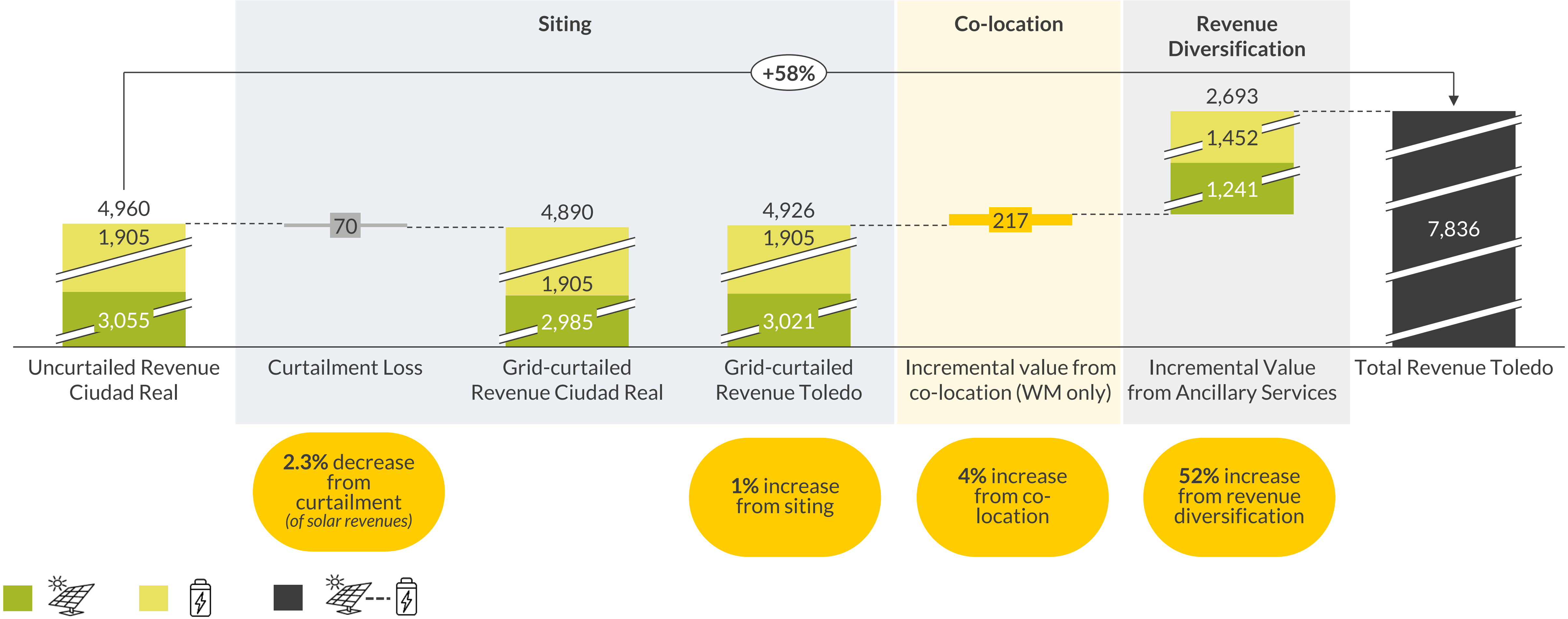
Incremental Revenue Streams

- Diversifying revenue away from the wholesale market can help mitigate the impact of curtailment
- Participation in ancillary services like secondary reserve or balancing markets in the downward direction can offset losses

Sources: Aurora Energy Research

A business model that considers siting, co-location[1] and a revenue diversification strategy can increase revenues by over 50%[2]

Revenues in 2026, 50 MW[3] Solar and 25 MW[4] Battery
k€ (real 2023)



1) AC Connected. 2) RES revenue diversification results in an increase of around 40% in 2026. However, we expect these additional revenues to be "cannibalised" as more RES assets participates in Ancillary Services. Between 2025 and 2060 we expect an average upside of around 8-15%. 3) Peak solar capacity; inverter capacity 45 MW with a 98.6 efficiency. 4) Battery and Inverter's capacity, with a 0.86 Round Trip Efficiency

Key Takeaways

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1. With 30 TWh of generation lost to grid curtailment in 2023, this is becoming a significant issue in Europe; in many countries the problem is likely to get worse before it gets better

2. In Spain, despite historically high levels of grid investment, the issue stems from renewable development away from demand zones; the development pipeline suggests this problem is likely to continue

3. Curtailment in Spain is not always compensated; uncompensated curtailment increased from 1,089 GWh in 2022 to 1,207 GWh in 2023

4. Curtailment is heavily concentrated, with ten provinces representing 93% of non-compensated curtailment; curtailment is also heavily concentrated in summer

5. As developers face a high degree of uncertainty from grid congestion, quantification of the downside and identification of mitigants and opportunities can help manage risk and deliver projects

6. Diversifying revenues away from the wholesale market can have a large impact on the business case of solar, and it is critical for batteries; developing financing structures that consider a more diversified set of revenues will be critical to the energy transition

Sources: Aurora Energy Research

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Details and disclaimer

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