

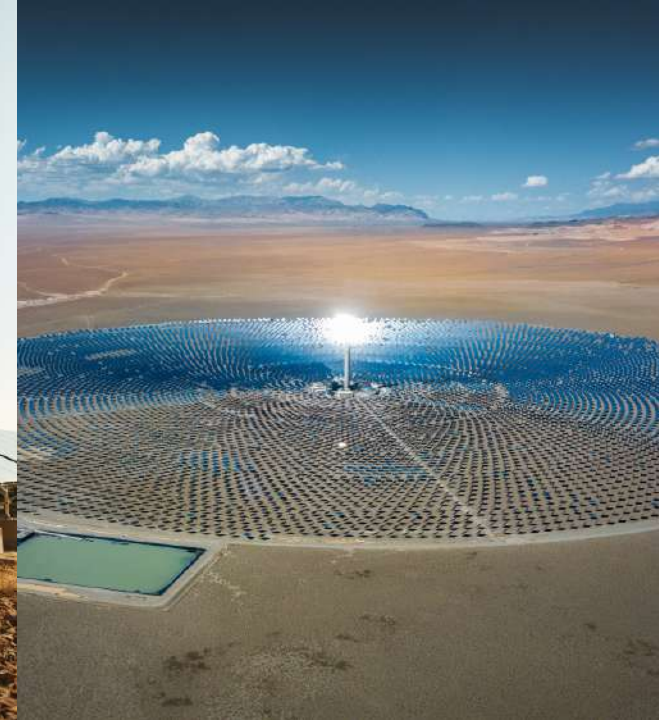


Outlook for RES and storage in the EU Energy Policy

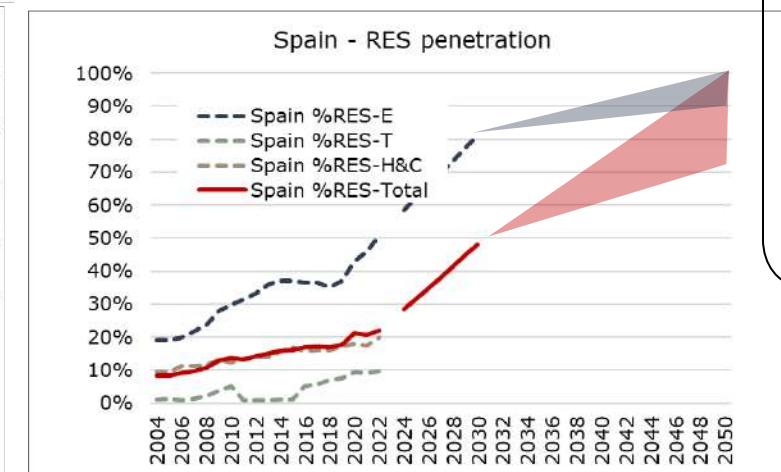
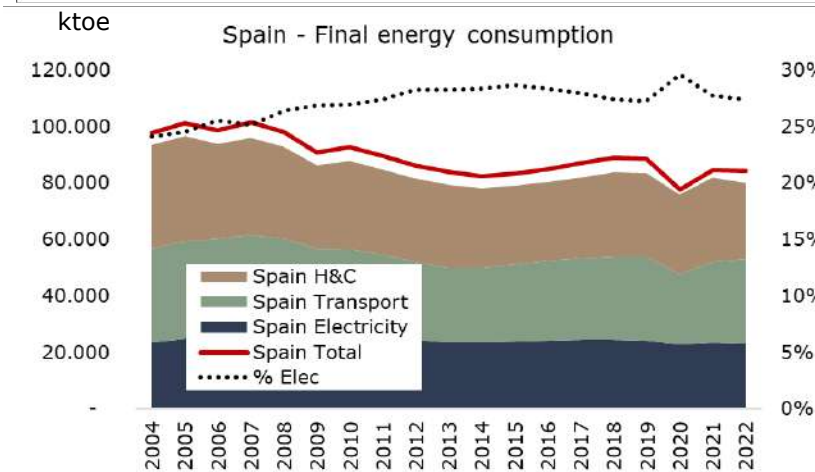
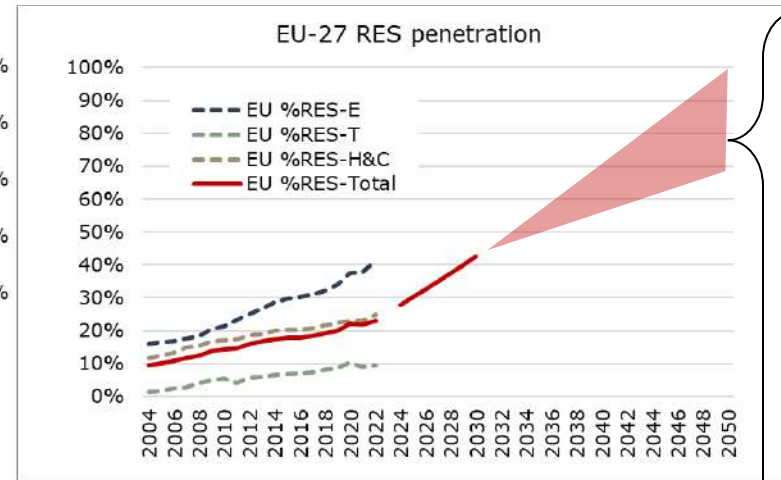
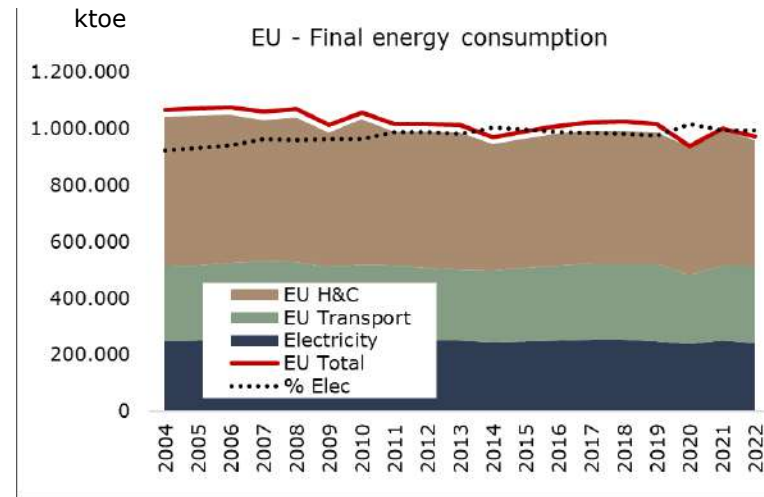
Javier Revuelta

22-10-2025

1. Spain's energy targets
2. Market developments
3. RES for Green Hydrogen
4. Blackout and role of RES
5. Future role of RES



Where are we in the decarbonisation path?



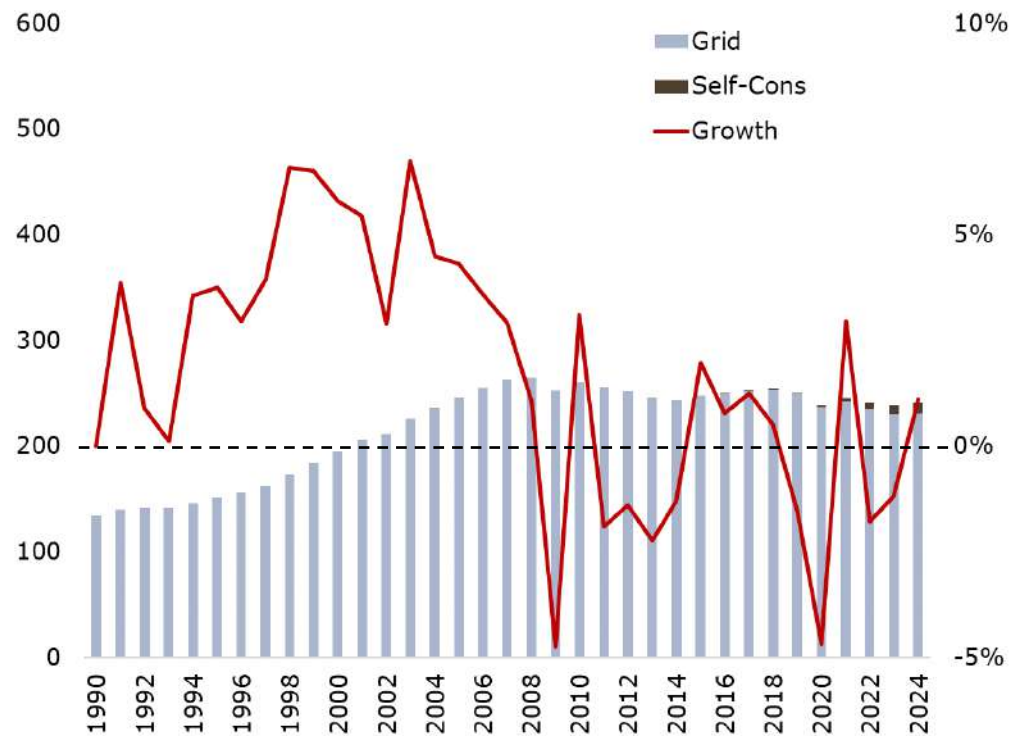
- Decarbonisation ambition
- RES/Nuclear/thermal
- Negative emission technologies (CCS, DAC)
- Supply chain
- Electrification of T and H
- RFNBO, Biofuels
- Storage / curtailments
- Hydrogen
- Interconnections
- Energy efficiency
- Regulation
- ...

Source: historic data from Eurostat. Projected Spanish data for 2030 based on Spanish National Energy and Climate Plan draft of 2023

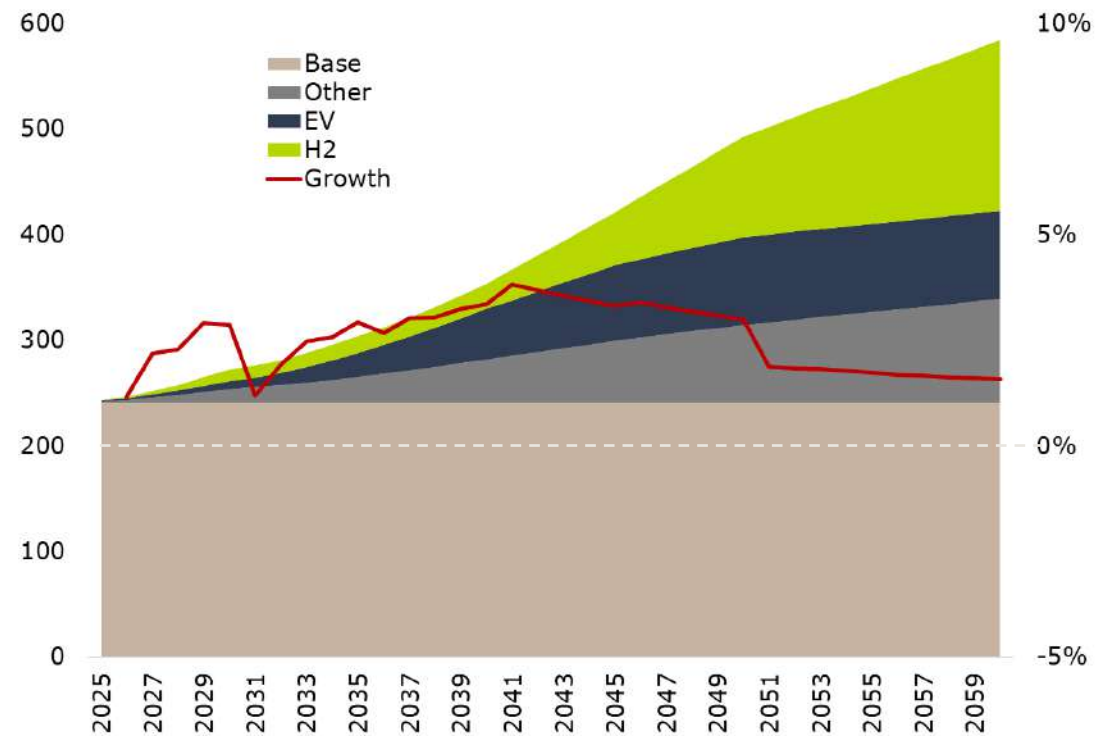
ELECTRICITY DEMAND

System planning is about the long term; annual electricity demand is back to growth and expected to double in the long run from new drivers

HISTORICAL DEMAND EVOLUTION (TWH)

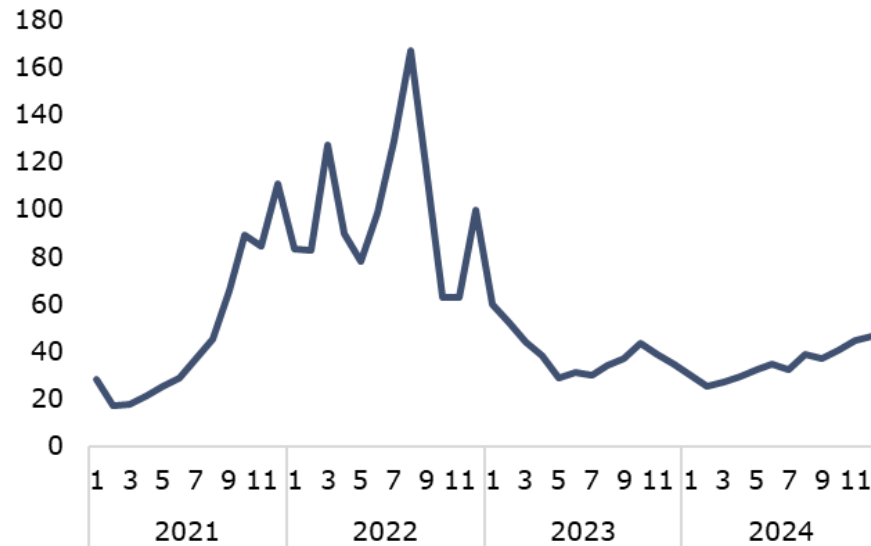


AFRY'S DEMAND PROJECTION (TWH)



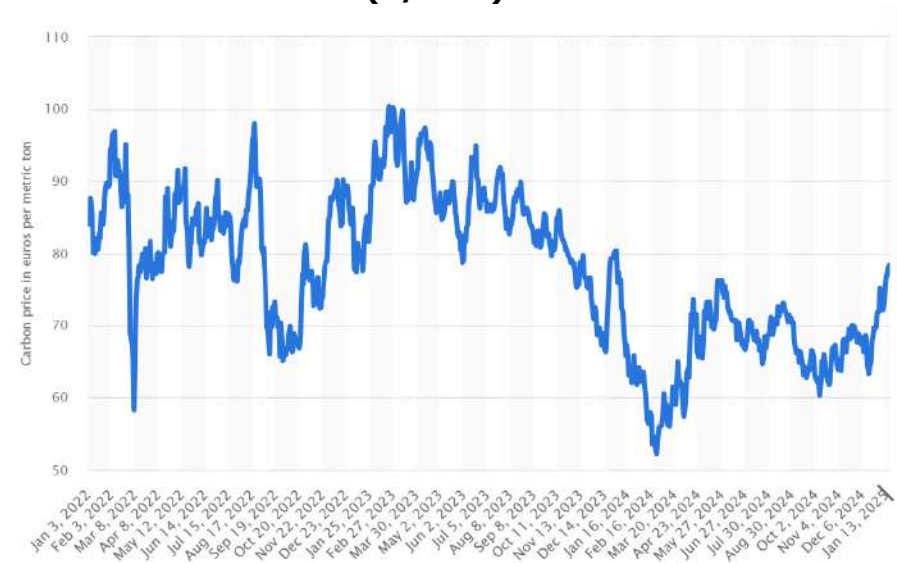
High and volatile gas and CO2 prices driven by the global context, with falling gas price amidst rising LNG supply and slower Chinese economy

AVERAGE MIBGAS PRICES (€/MWH_GAS)



- Russian pipeline gas? American LNG deployment
- Industrial demand recovery
- Temperatures, availability of critical infrastructure
- Economic activity (China), geopolitical conflicts

EU ETS CARBON PRICE (€/TON)



- Decreasing supply of allowances vs. demand reduction
- Speculative component
- Regulatory uncertainty ('cancellations' and 'overlapping policies')
- Different market and price for ETS2 for buildings from 2027/2028

Challenges and drivers for decarbonisation and reduction of energy imports

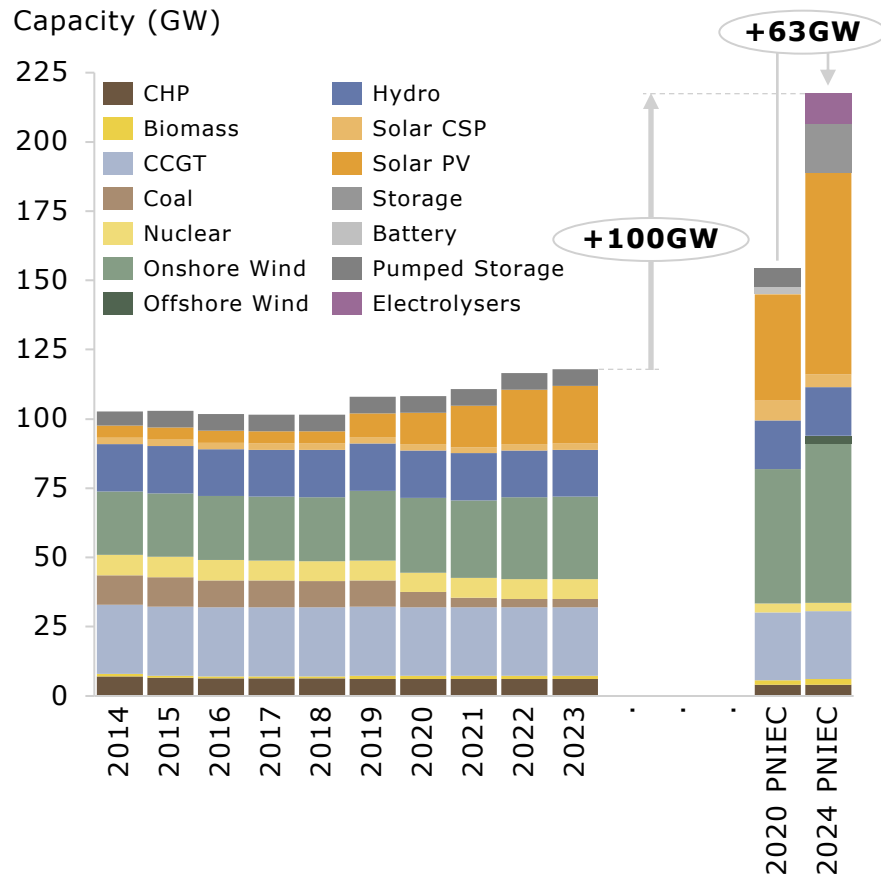
OBJECTIVES AND TECHNOLOGIES

- **RES**: 20% (2020) to 32% -->**42.5-45%** (2030)
- **Electrification** (Transport, H&C)
 - EVs, trains, airplanes?
 - heat pump, electric heat
- **Hydrogen**
 - origin: grey, blue, green, turquoise, pink
 - uses:
 - actual: refineries, fertilizers
 - heavy transport, maritime, aviation
 - industrial heat, steel
 - seasonal energy storage
- **Biofuels**, sustainable fuels
- Nuclear
- Carbon Capture & Storage
- Reforestation
- **Direct Air Capture**

INSTRUMENTS AND CHALLENGES

- **European Trading Scheme**
- **'Fit-for-55%'** → 40% RES-Final energy by 2030
- Forbidding sales of vehicles with ICE
- Incentives, European/National support
- EU budget 2021-2027: Multiannual Financial Framework (1,200b€) and **Next Generation EU** (800b€)
 - Grants and Loans
 - 30% for Climate Change
- Target **Net Zero by 2050**
- **'Winter package'** regulations
- **'Taxonomy'** : Nuclear and Gas
- State Aid Guidelines
- **RePowerEU**: faster energy independence from Russia →45% RES-Final Energy by 2030
- RED III, CABM, ReFuel Aviation, FuelEU Maritime

The new Spanish NECP 2024 brings extremely ambitious targets, more setting a long term path than reasonable figures for year 2030

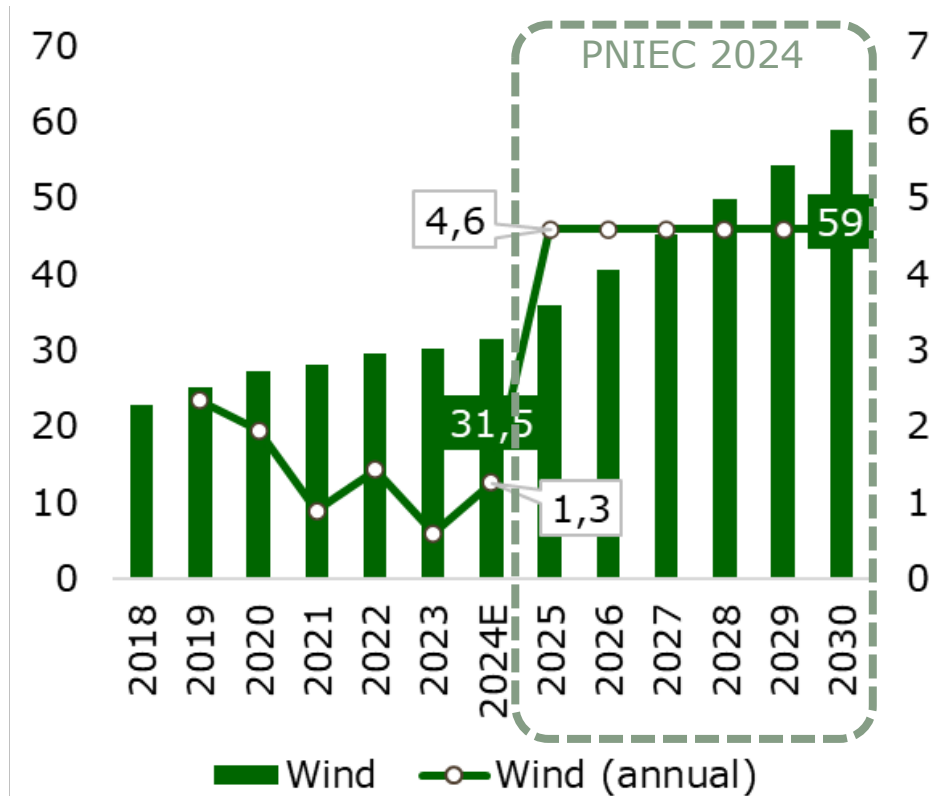


Technology	Dec 2023	NECP 2020	NECP 2024	
Onshore Wind	30	48.5	57.5 (+2.8 offshore)	3.5GW/y
Solar PV	25 (+7 BTM)	38.4	53.8 (+19 BTM)	6GW/y
Solar CSP	2.3	7.3	4.8	0.5W/y
Biomass	1.1	1.7	1.9	0.1GW/y
Nuclear	7.1	3.0	3.0	-4 reactors
CCGT	24.7	24.6	24.6	-
Coal	3.2	0	0	close all
CHP	6.1	4.0	4.1	-375MW/y
Hydro	17.0	17.5	17.5	-
Pumped Storage	6	6.7	22	>2GW/y
Batteries	0.0	2.5		
Interconnection SPA-FRA	2.8	8.0	5.0	+1 project
Electrolysers	0.0	0.0	12	2GW/y

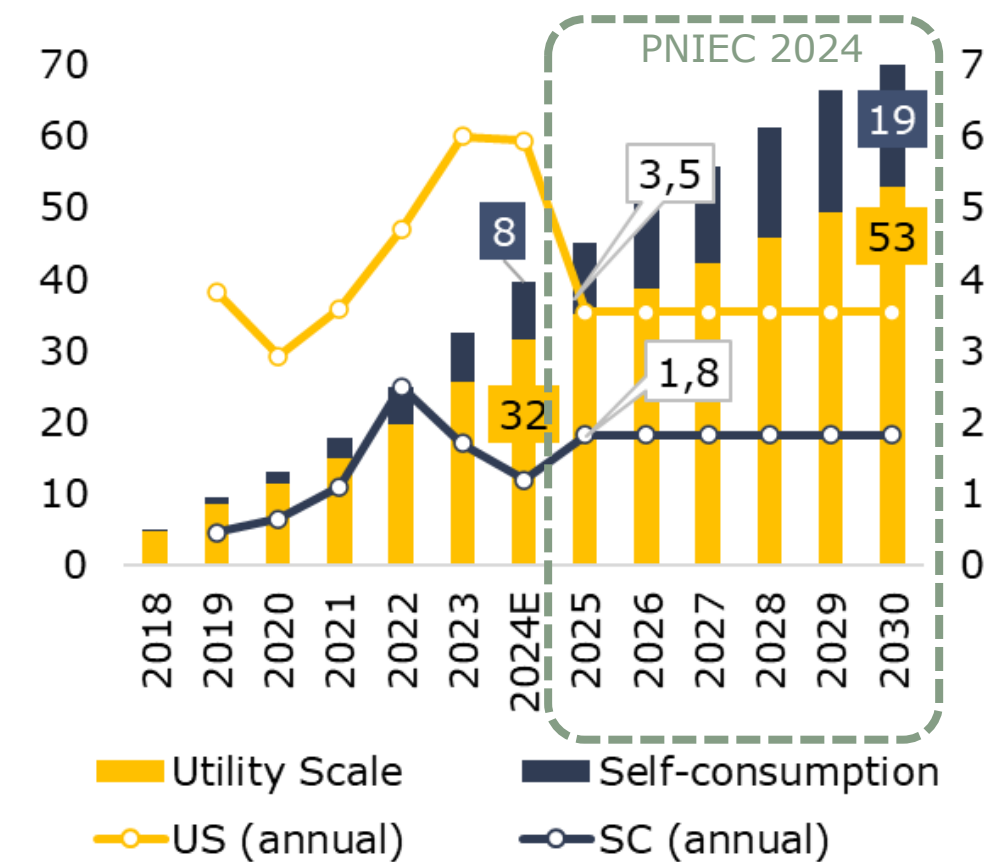
CAPACITY MIX

The PV buildout rate remains strong with large pipelines in RTB. Will new demand and flexibility arrive on time?

INSTALLED CAPACITY WIND (GW, GW/Y)



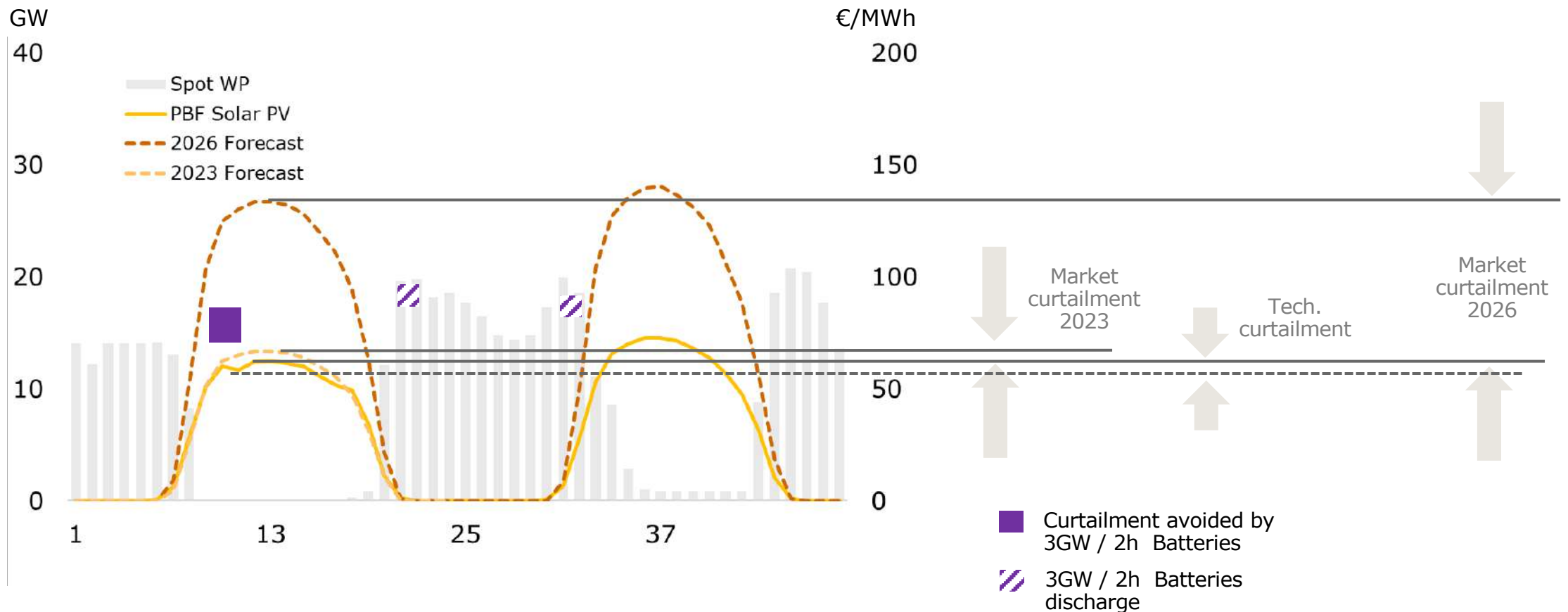
INSTALLED CAPACITY PV (GW, GW/Y)



Source: ESIOS (updated in March 2025) and PNIEC

Market RES curtailments will increase substantially in absence of substantial additional storage

ILLUSTRATIVE MARKET PERFORMANCE ON 14 TO 15 MAY 2026

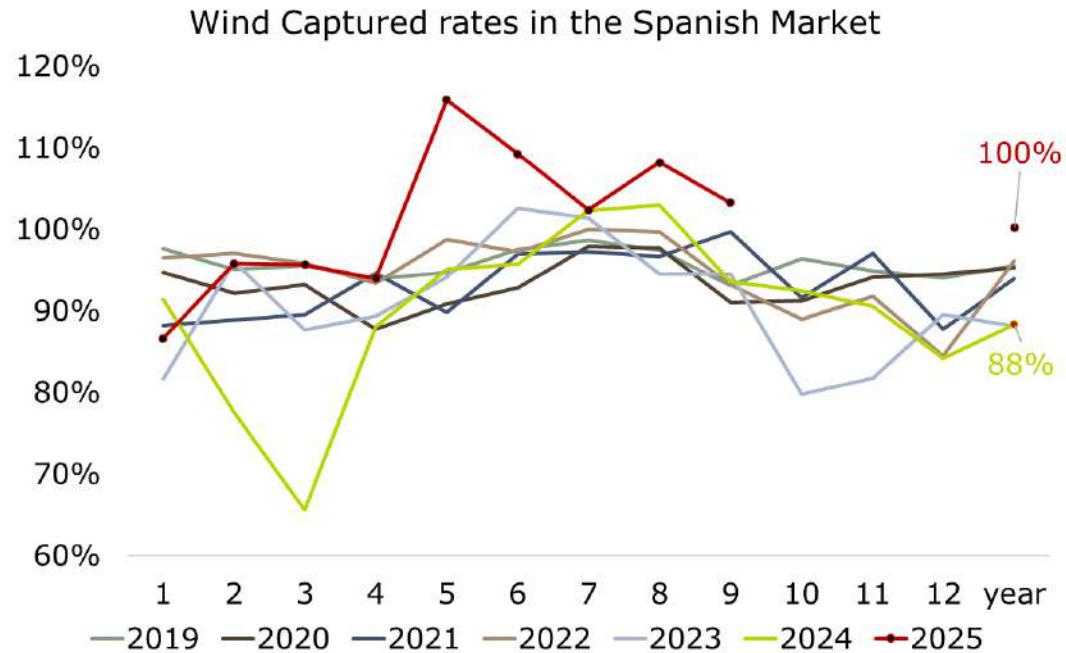


Source: AFRY

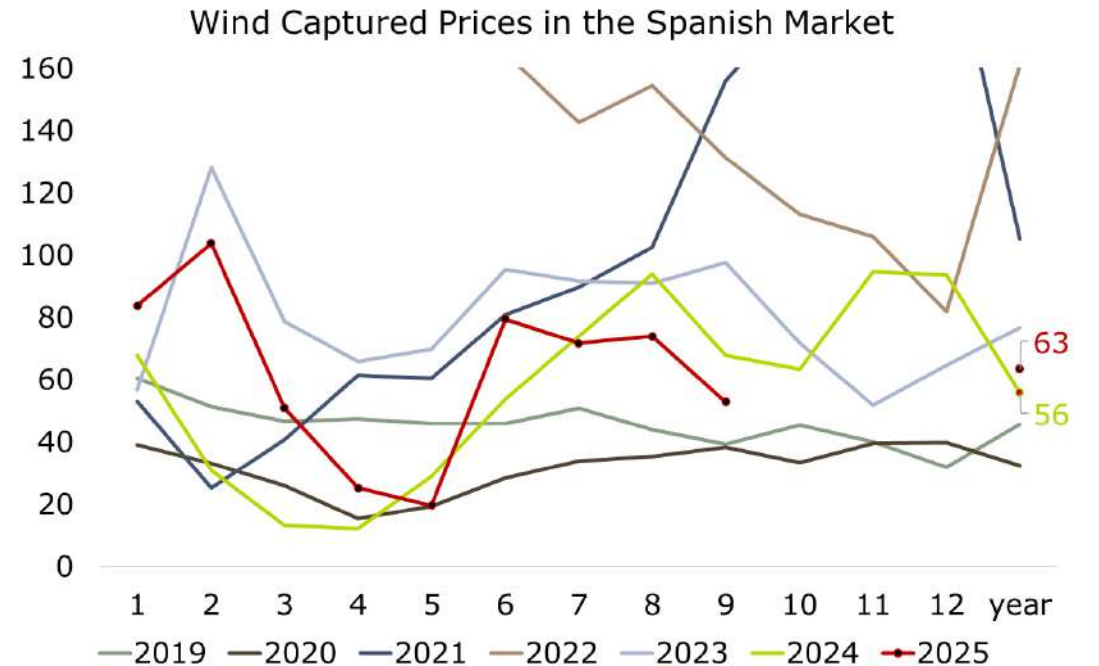
MARKET PRICES

Wind captured rates remain steady as wind power produces less in some low solar hours and captures high non-solar hours

WIND CAPTURED RATES



WIND CAPTURED PRICES (€/MWH)



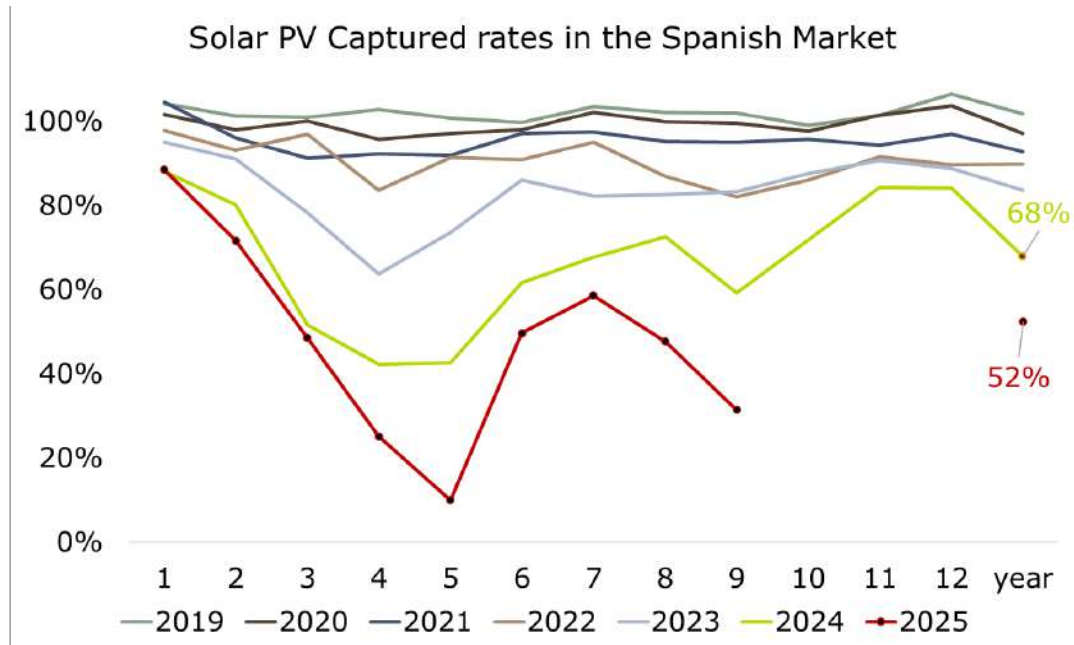
Source: ESIOS and AFRY analysis. Data until 11/09/2025



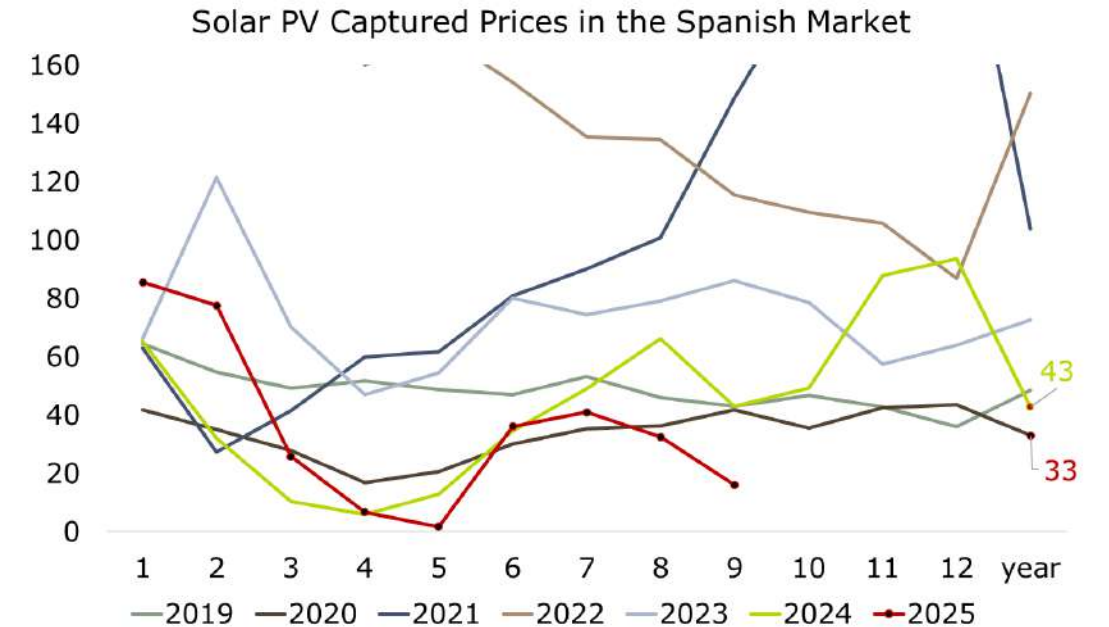
MARKET PRICES

PV captured rates have increased the rate of decrease, with volatile baseload prices driven by volatile gas and frequency of RES market curtailments

SOLAR PV CAPTURED RATES



SOLAR PV CAPTURED PRICES (€/MWH)



Source: ESIOS and AFRY analysis. Data until 11/09/2025

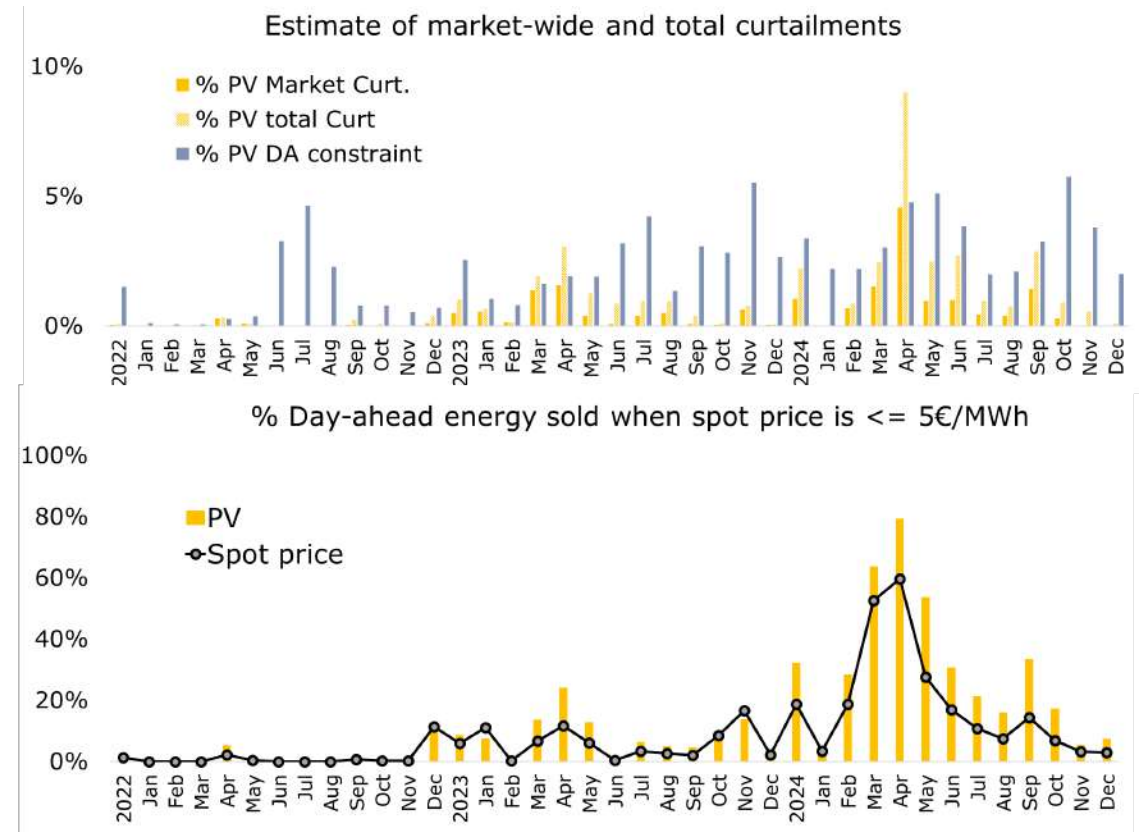


HISTORICAL ANALYSIS

The problem is not 'market or technical curtailments' but captured prices (or PPA clauses on negative and zero prices)

- Hourly prices
- Captured prices
- **Market curtailments**
- **Technical curtailments**

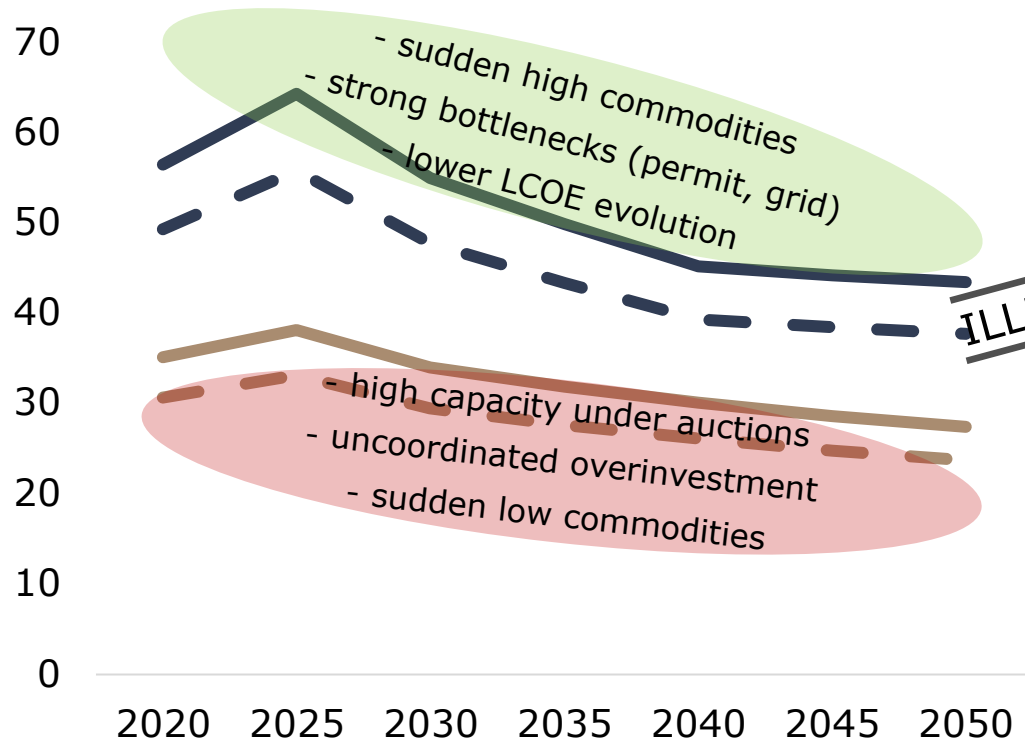
% CURTAILMENTS AND ENERGY PRODUCED WHEN PRICE IS <5€/MWH



Fuente: ESIOS y Análisis AFRY

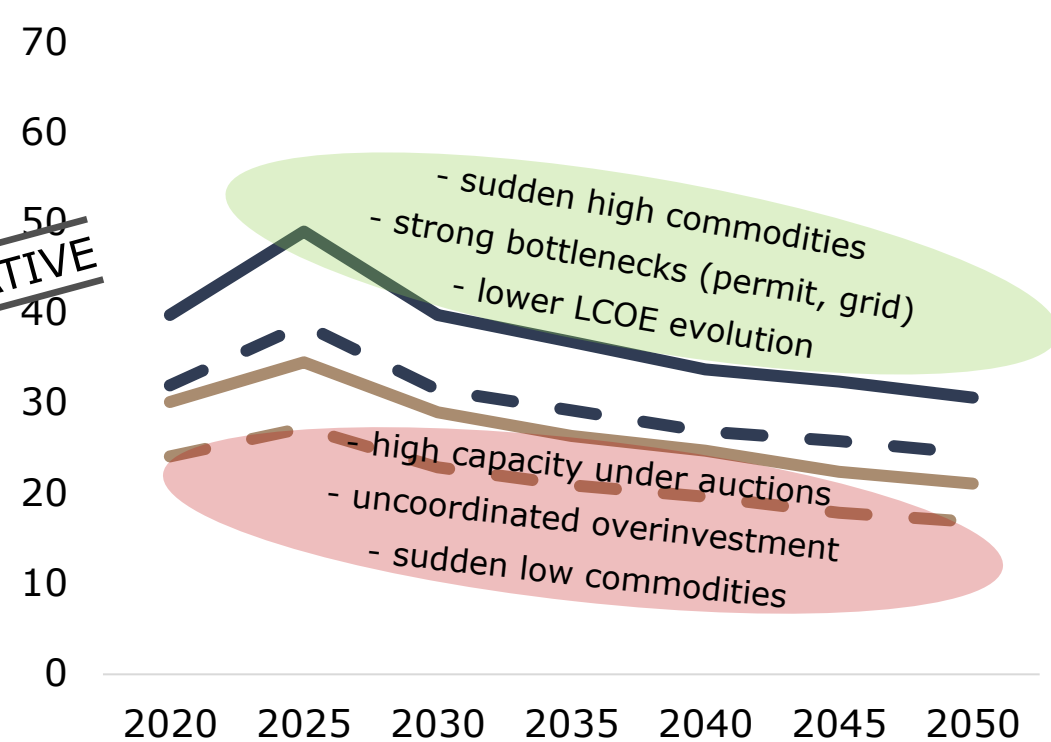
LCOE evolution of renewable technologies will determine revenue requirements... and possibly (but not necessarily) market captured prices

LCOE ESTIMATES FOR ONSHORE WIND* (€/MWH)



- HIGH Capex/Opex & LOW Load Factor
- LOW Capex/Opex & HIGH Load Factor

LCOE ESTIMATES FOR SINGLE TRACKER SOLAR PV* (€/MWH)

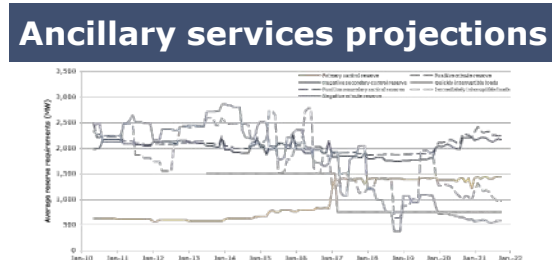
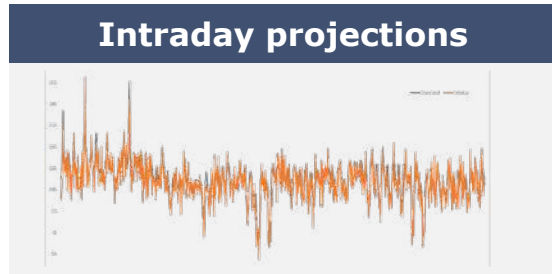
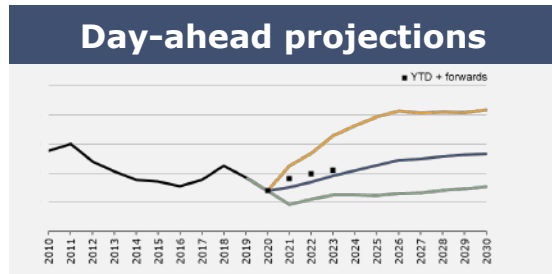


- HIGH Merchant IRRs
- - LOW Feed-in-Tariff IRRs

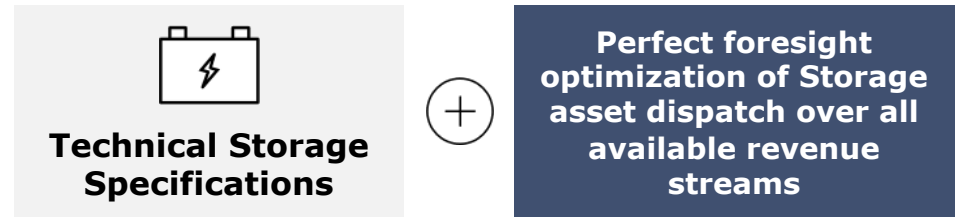
* AFRY's own estimates for a fairly wide range of observed and expected Capex, Opex, and load factors; and own views on projected hurdle rates.

AFRY's analysis on storage projects includes the project's gross margin optimisation based on co-optimised markets dispatch

PRICE PROJECTIONS



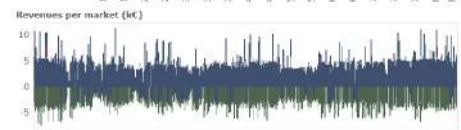
OPTIMIZATION



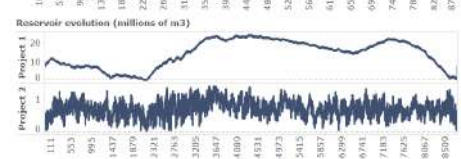
Dispatch per market



Revenues per market

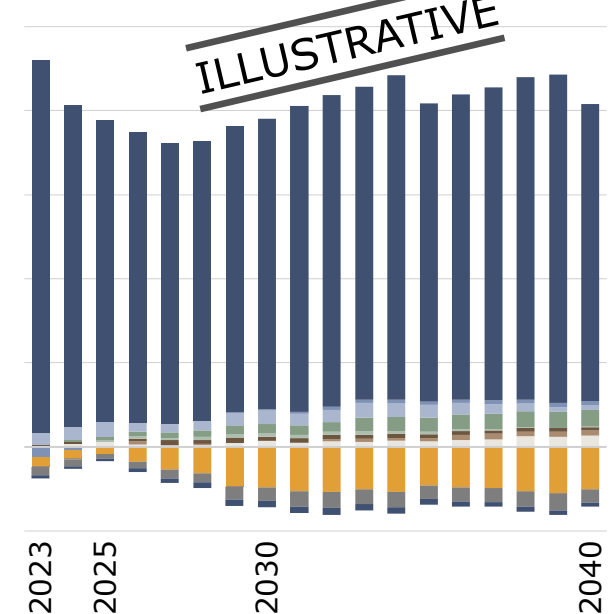


Storage level



OUTPUTS

Gross margin projections in €m or €/kW

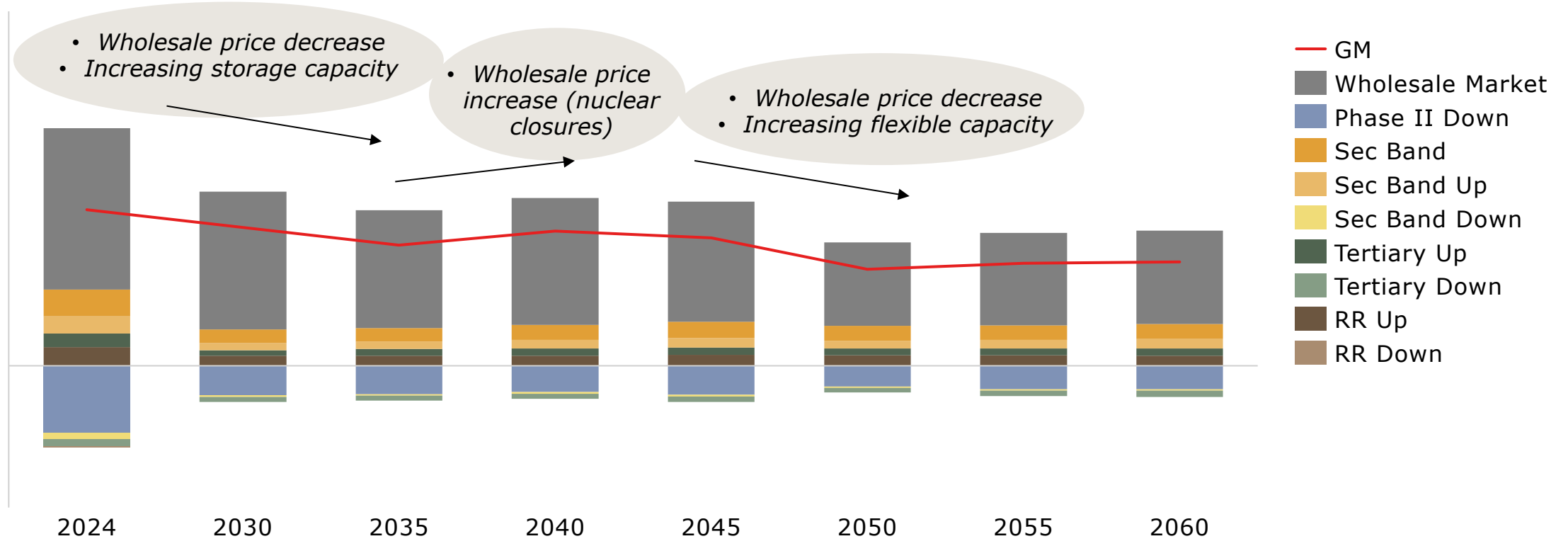


- DA
- Intra
- IntraCont
- PhII
- SBand
- SecAct UP
- SecAct DW
- Ter UP
- Ter DW
- RR UP
- RR DW

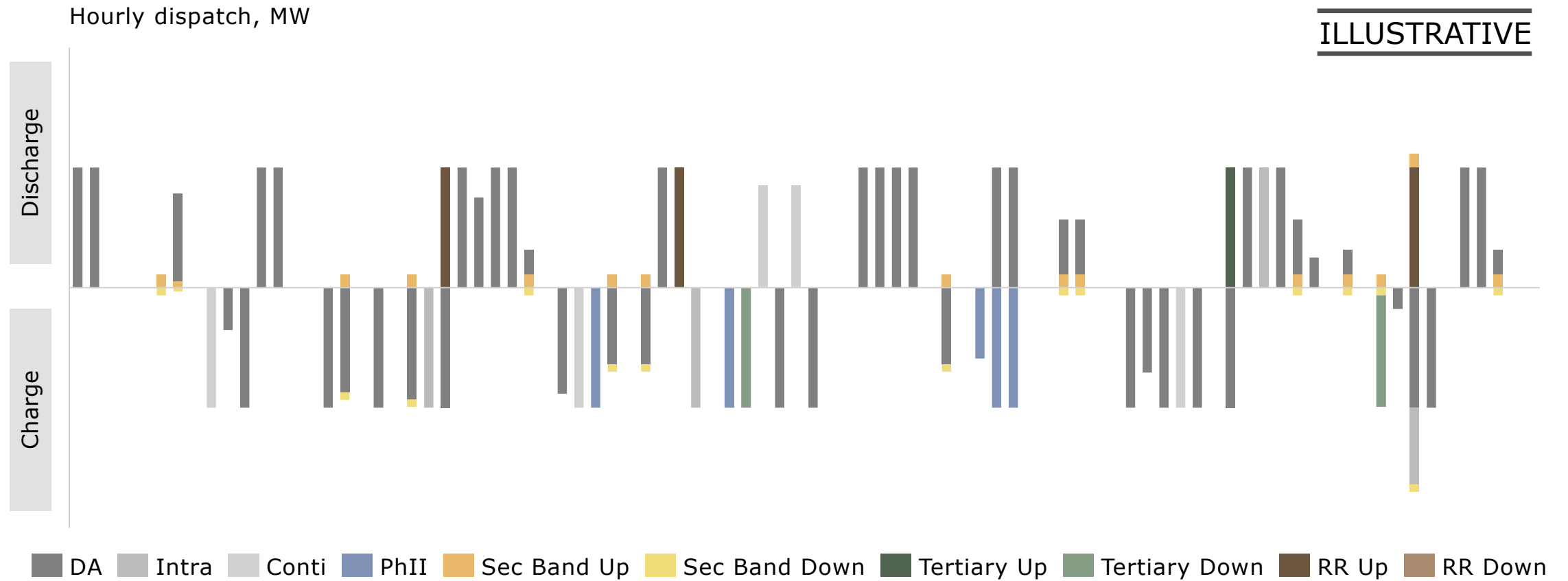
Modelled results show storage gross margins from Day-Ahead market and Ancillary Services will cannibalise as more batteries enter the system

ILLUSTRATIVE

Gross Margin, €/kW, real 2022

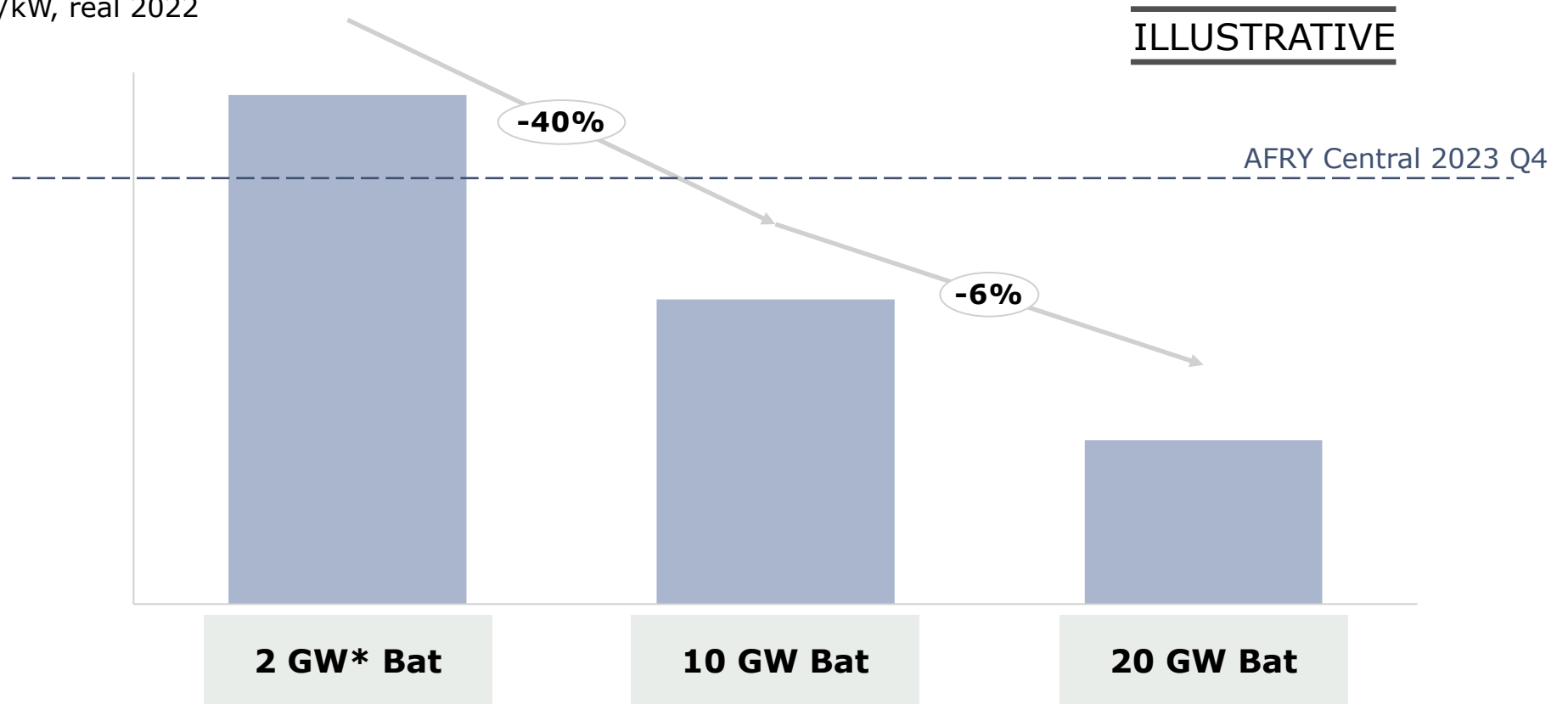


Hourly modelling allows to optimise the dispatch of the battery in the different markets in order to benefit from price arbitrage opportunities



The deployment of batteries in the system leads to cannibalisation of revenues from day-ahead and ancillary services

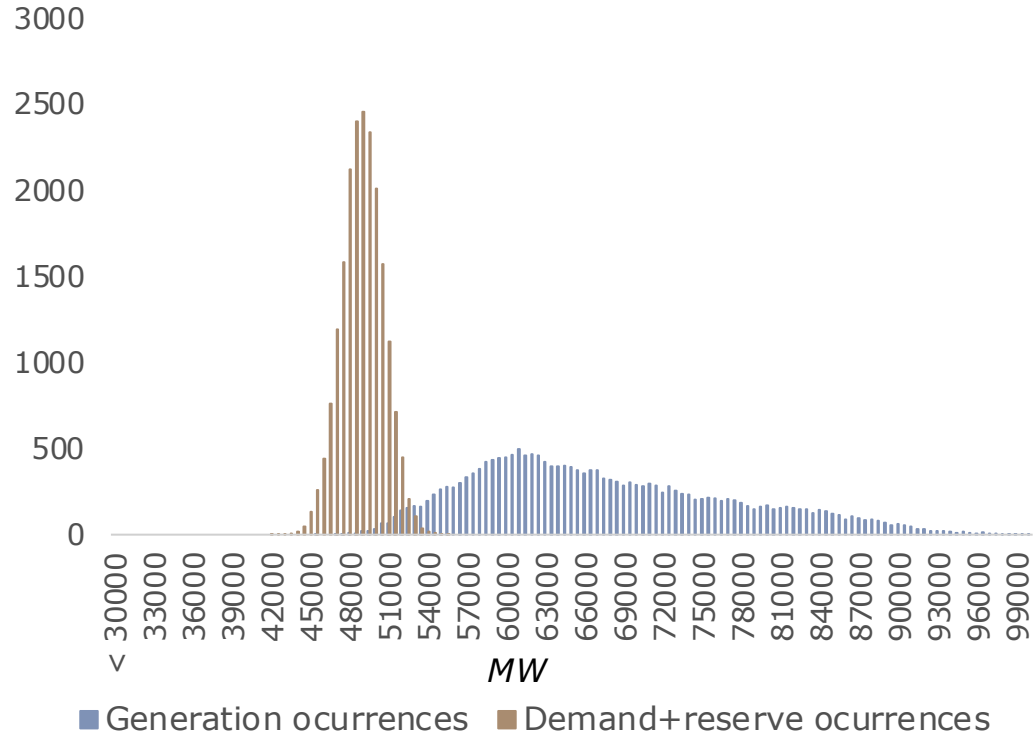
Gross Margin 2030, €/kW, real 2022



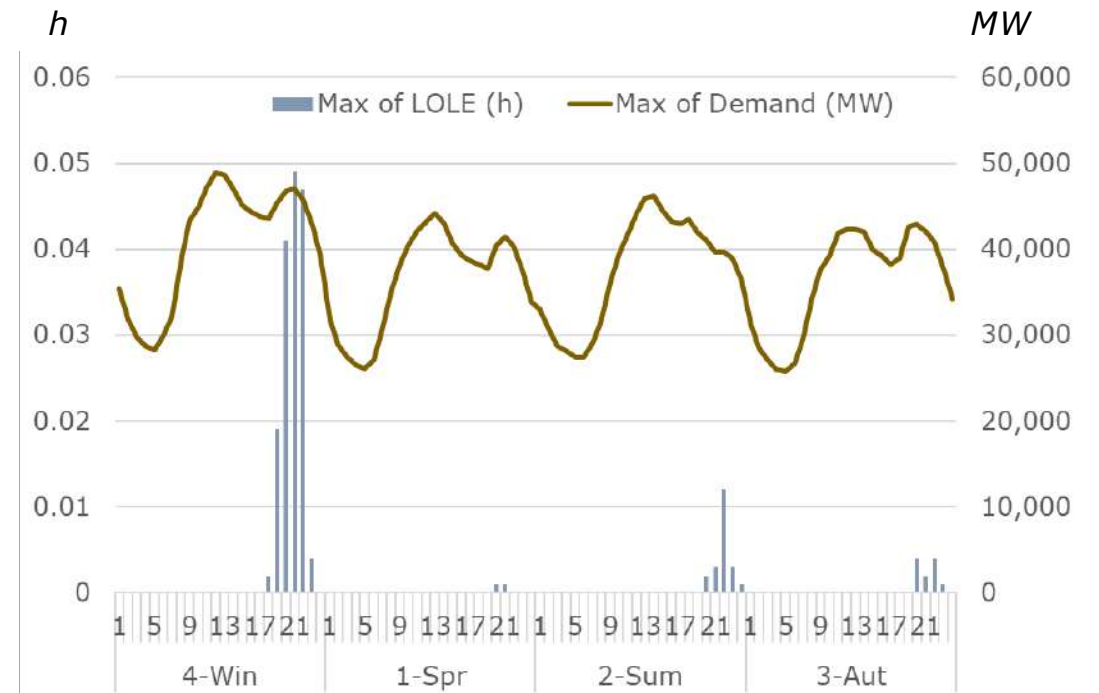
*Battery capacity over existing (negligible) capacity

Critical demand is expected to remain in winter after sunset, and drives the need for system backup capacity

GENERATION AND DEMAND PROBABILITY FUNCTIONS (SAMPLE CRITICAL HOUR IN 2030)



HOURLY DISTRIBUTION OF LOLE (SAMPLE 2030)



The Iberian power market will need reliable capacity after the sunset, mostly in Winter

In 2023&2024, regulatory bodies published reliability standards which follow the 2021 Capacity Market mechanism draft order

Capacity Market mechanism: overview

Regulation



- European Regulation 2019/943
- Reliability standard for Spain, LOLE: 1.5 (2024)
- Derating factors and auctioned capacity to be published.

Remuneration design

- Bids submitted in €/MW/year; remuneration is pay-as-bid.



A1

The **main auctions** for new capacity at a 5-year horizon. Designed to cover firm capacity needs and promoting investment in new storage.

A2

The **adjustment auctions** for existing capacity at a 1-year horizon. Designed to solve eventual capacity adequacy problems.

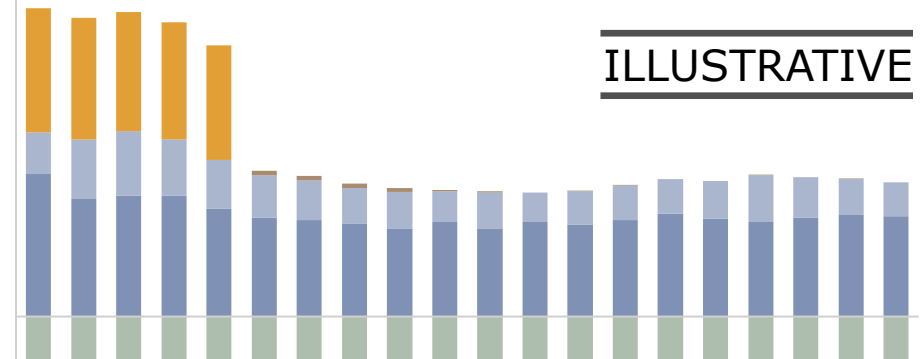
Key barriers



- Lower volume attracted vs. NECP (design based on SoS analysis, and not to promote flexibility or integration of RES).
- The specific design parameters may benefit some technologies.

4-hour battery capacity mechanism, €/kw real 2022

Larger duration batteries are expected to show more competitive results in a capacity mechanism since they could benefit from favorable derating factor values.



ILLUSTRATIVE

- Fixed OPEX
- Gross margin DA
- Gross margin AS
- Annual capacity payment
- 5-year capacity payment

The Capacity Market under development and Capex grants ('PERTE') will be key to bring (most) storage capacity. But how much is that?

ERAA AND NRAA

The screenshot shows the entsoe website's download page for the ERAA 2023. It features a grid of six download links for different parts of the report, each with a PDF icon and a file size. The links are: ERAA 2023: Executive Report (PDF, 4.9 MB), Annex 1: Input Data & Assumptions (PDF, 2 MB), Annex 2: Methodology (PDF, 2.7 MB), Annex 3: Detailed Results (PDF, 3.3 MB), Annex 4: Country Comments (PDF, 240 KB), and Annex 5: Definitions and Glossary (PDF, 114 KB). Below this grid is a larger image of the cover of the 'Análisis nacional de cobertura del Sistema Eléctrico Peninsular Español' report, dated October 2023, published by red eléctrica.

<https://www.entsoe.eu/outlooks/eraa/2023/eraa-downloads/>

https://www.ree.es/sites/default/files/01_ACTIVIDADES/D ocumentos/informe_os_nov23.pdf

STILL MANY UNCERTAINTIES...

- Assumptions of ERAA and NRAA 2024?
- Additional capacity required for RS=1,5h/y
 - LOLE>RS only in 2027 & 2028
 - Presumably 1.5-1.8GW firm capacity for 2027&2028
- Derating factors of all technologies?
- Available funds for Capex grants
- Any other new 'flexibility market' under consideration?
- AFRY Multiclient study proposals to complement the CM
 - Proposal A: Long and Short duration storage (2 buckets or 'scaling factors')
 - Proposal B: Two round CM (Socio Economic Welfare vs. Security of Supply)

The Capacity Market under development and Capex grants ('PERTE') will be key to bring (most) storage capacity. But how much is that?

ERAA AND NRAA

<https://www.entsoe.eu/outlooks/eraa/2023/eraa-downloads/>

https://www.ree.es/sites/default/files/01_ACTIVIDADES/DOCUMENTOS/informe_os_nov23.pdf

STILL MANY UNCLEAR

- Assumptions of capacity
- Additional capacity
- Derating factors
- Available funding
- Any other new
- AFRY Multicliente
- Proposal A: or 'scaling factor'
- Proposal B: Security of

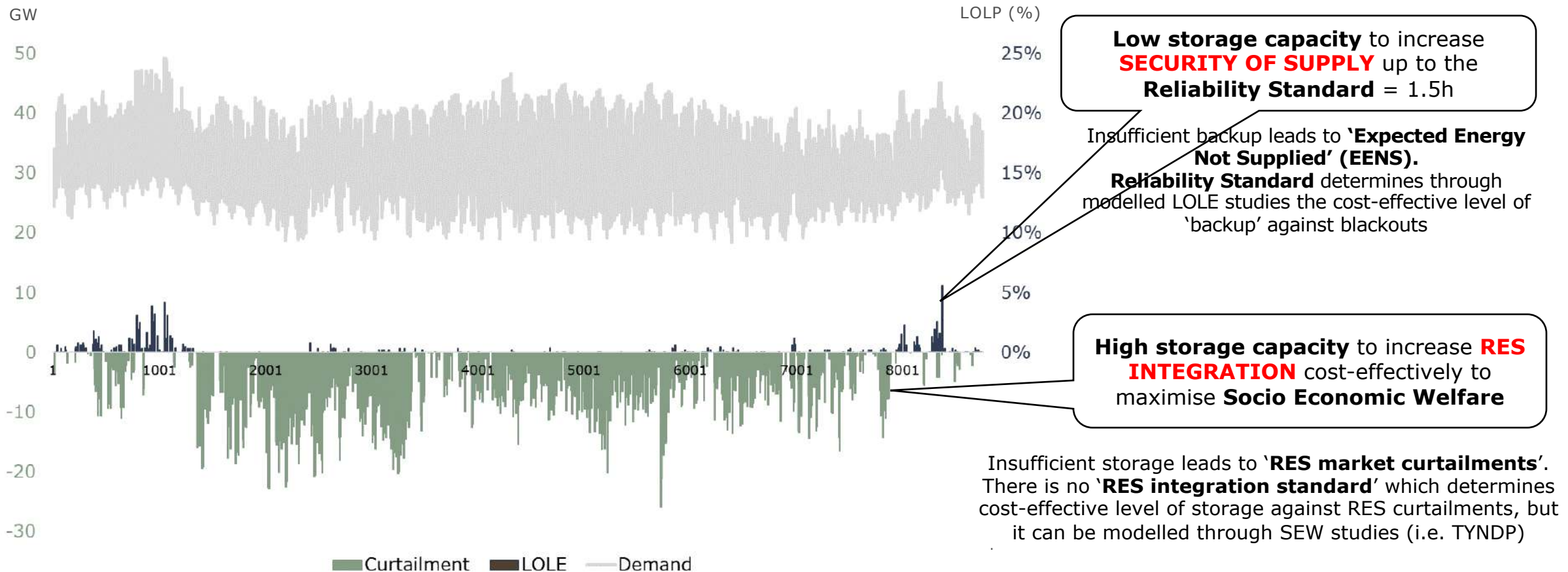


https://afry.com/sites/default/files/2023-03/afry_energy_storage_development_key_message_final.pdf

n?
CM
tickets
e vs.

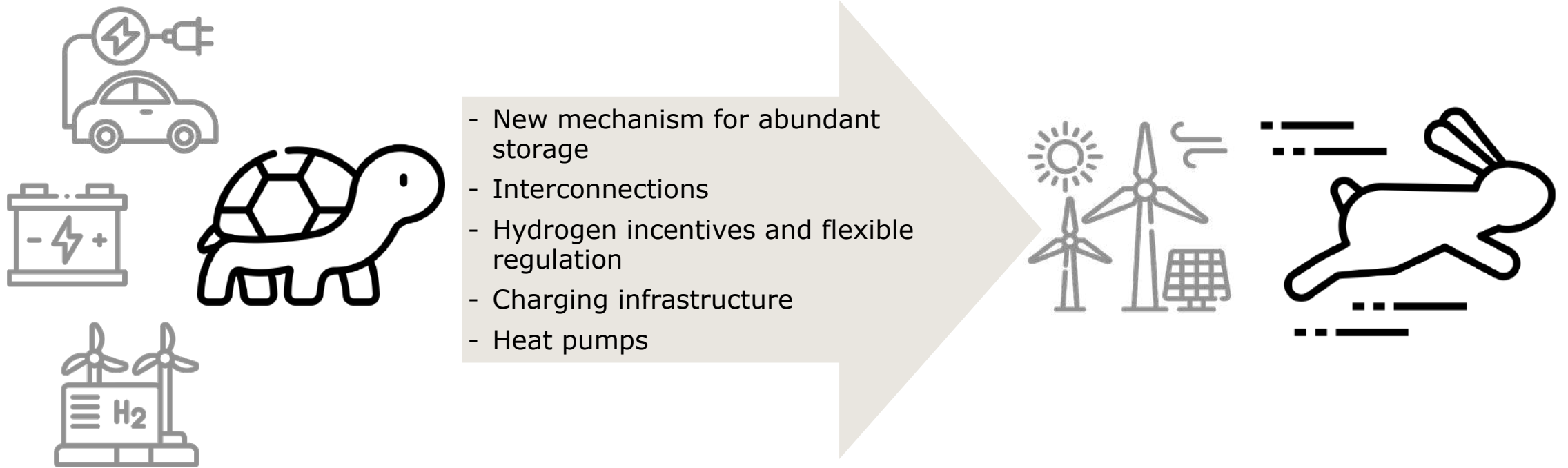
Should the market and the Regulator size storage for Security of Supply or for efficient RES integration?

HOURLY LOSS OF LOAD EXPECTATION (% LOLP) VS RES CURTAILMENTS (GW)



CONCLUSIONS

Speed up the tortoise or slow down the rabbit to keep economic equilibrium?



Storage is a key instrument to enable further RES integration, at the very beginning of a strong deployment. But it will likely not come alone...

01



SPANISH MARKET APPROACHING TIPPING POINT FOR MERCHANT RES

- relevant curtailments threaten merchant RES (and auctions)
- Storage is the key enabler to keep rising RES integration and provide future backup

02



MERCHANT STORAGE UNLIKELY (but not impossible)

- Capex reductions? First mover? Technical Constraints?
- Cannibalisation of arbitrage and Ancillary Services

03



REQUIRED REGULATORY INCENTIVES

- Capacity Market, Flexibility markets?
- Capex grants

04

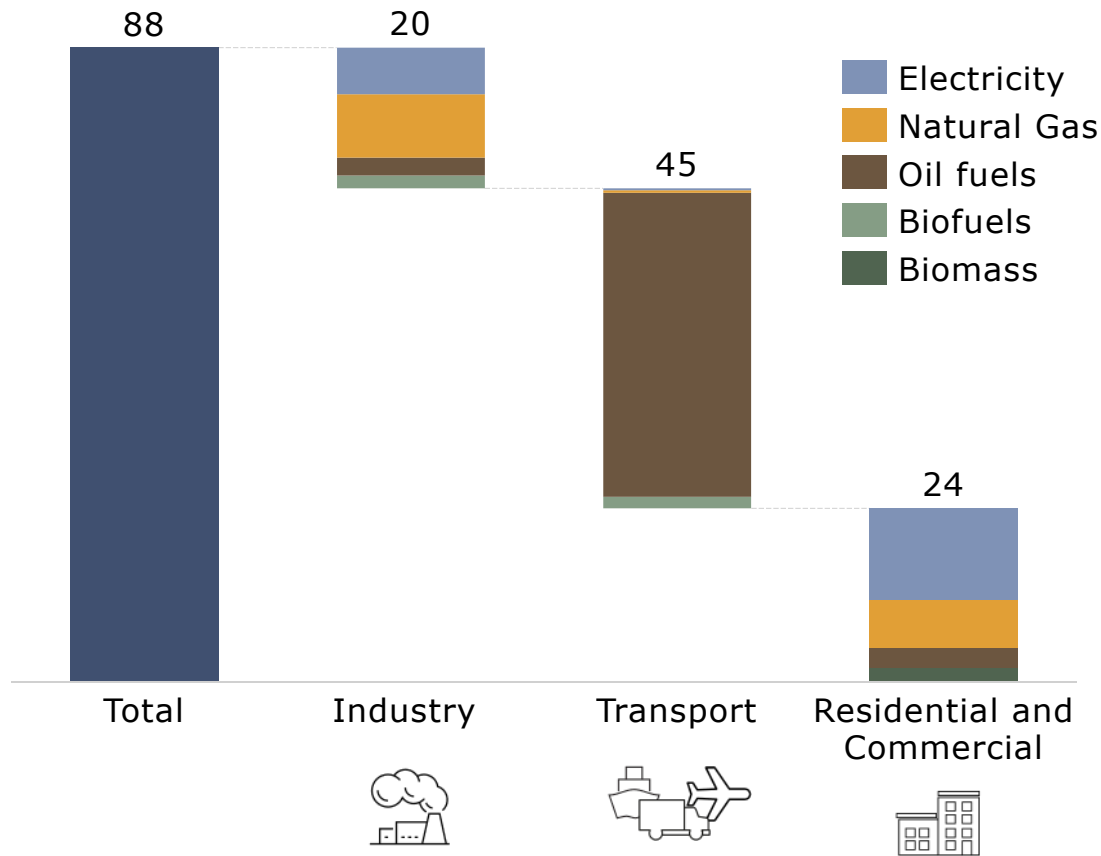


VALUE BEYOND SECURITY OF SUPPLY?

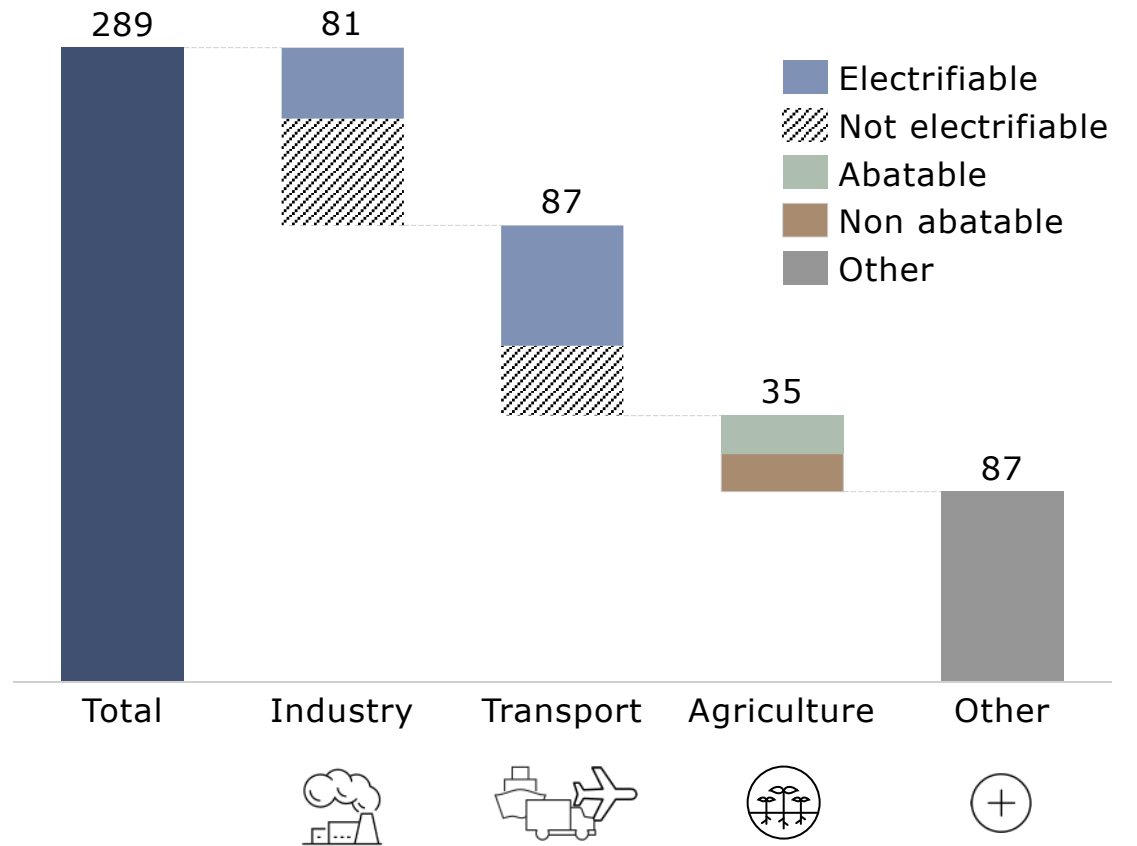
- Efficient RES integration, positive SEW
- PSH: local materials, longer life, low import dependency
- Requires new European and National regulation

Renewable molecules will play a key role for the decarbonisation due to non-electrifiable applications which represent over 30% of Spain's emissions

FINAL ENERGY CONSUMPTION, 2021 [MTOE]



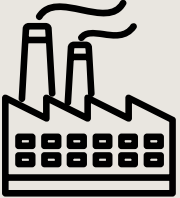
FINAL EMISSIONS, 2021 [MT CO2EQ]



Source: AFRY Analysis; Spanish Ministry for the Ecological Transition and the Demographic challenge (2023): National Greenhouse Gas Inventory Report

In Europe hydrogen's role is in applications where there are few options to achieve decarbonisation


Industrial sector



- Existing industrial feedstock for refineries, ammonia and other chemicals production
- New process uses in steel manufacturing
- Replacement of fossil fuels for process high temperature heat

No alternatives for deep decarbonisation of industry


Mobility sector



- Heavy trucks and long-haul freight
- Public transport in busses and trains
- Maritime and shipping (H₂ and ammonia)
- Aviation (synfuels and direct H₂ use)

Electrification may be possible but not with current technology

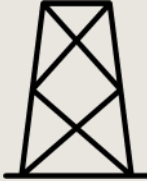
Heat sector



- Space heating for buildings with hydrogen boilers to replace gas and other fossil fuels
- Hybrid heat pumps

Electrification possible with heat pumps but not 100%

Power sector



- Energy storage and Power-to-X
- Direct H₂ use in CCGTs
- Enabler of more intermittent RES
- Fuel cells

No alternatives for seasonal storage of energy



In a decarbonised Spanish economy, what is the hydrogen demand? and when should it be deployed?



THE EUROPEAN CONTEXT – RENEWABLE ENERGY DIRECTIVES & DELEGATED ACTS

EU regulation distinguishes two hydrogen types: renewable and low-carbon and both should meet a 70% GHG emission savings

HYDROGEN CLASSIFICATION

	GHG emissions savings	Energy content source
 Renewable or RFNBO hydrogen	Minimum 70%	Renewable energy sources non-biological origin
 Low-carbon hydrogen¹	Minimum 70%	Non-renewable energy sources

HYDROGEN DELEGATED ACTS

Additionality DA



- Sets the conditions for procuring “**fully renewable**” **electricity** which can be used to produce **renewable hydrogen**
- This electricity has 0 emissions helping to meet the 70% GHG savings

GHG Methodology DA⁽²⁾



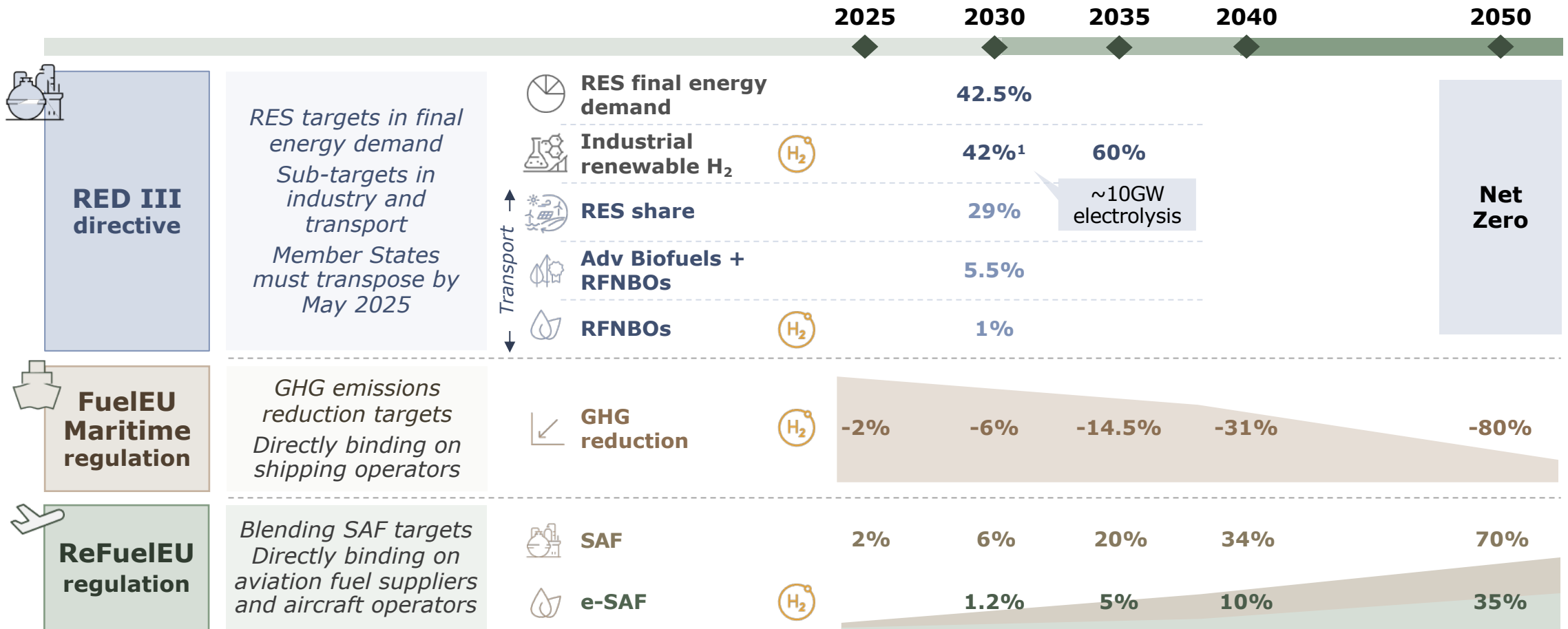
- Defines the minimum threshold of **70% GHG emissions savings**
- Provides the methodology for attributing emissions to the electricity taken from the grid that not qualifies as “fully renewable”
- Power can be taken from the grid provided that the 70% limit is respected

Notes: (1) According to the provisional deal reached in December 2023 by co-legislators in the Hydrogen and gas markets decarbonisation package
 (2) The Delegated act on life-cycle GHG emissions savings methodology for low-carbon fuels is still pending (expected for Q4-2024)



HYDROGEN DEMAND DRIVERS

Renewable H₂ demand in the EU is driven by favourable regulations - RED III has to be transposed, but FuelEU and ReFuelEU in force are motivating offtake



Source: AFRY

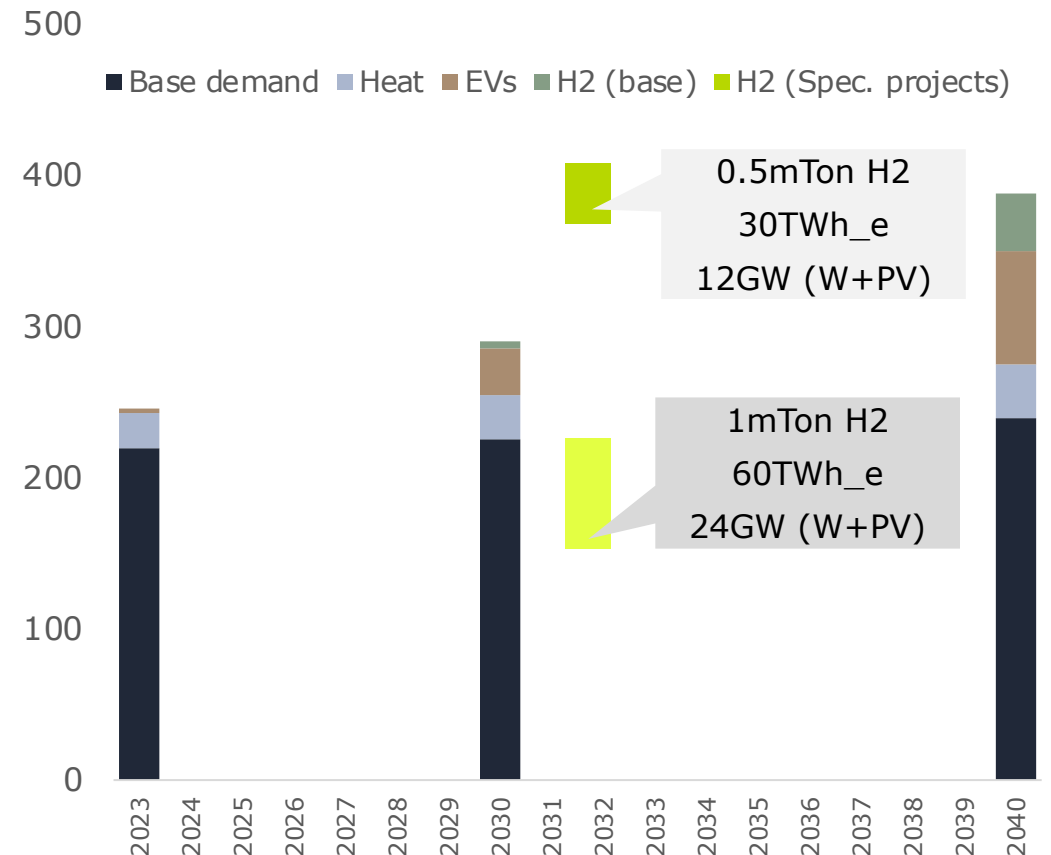
Notes: (1) 34% if fossil-based H₂ is <23%

The power system should adapt to potential new large demands such as specific hydrogen plans

HYDROGEN DEMAND

- Current (grey) H2 demand in Spain is **0.5mTon** or **20TWh** for refineries and fertilisers
 - 4GW Electrolysis
 - @4000h → 0.3mTon, 11TWh_H2 → 40% of H2 demand
 - @8000h → 0.5mTon, 22TWh_H2 → 80% of H2 demand
 - 8GW Electrolysis
 - @4000h → 0.6mTon, 22TWh_H2 → >100% of H2 demand
 - @8000h → 1.1mTon, 45TWh_H2 → 200% of H2 demand
 - Electrolyser efficiency ~70% → 2mTon of H2 target requires +120TWh/y of electricity, which is +50% of today's!
- High potential of new H2 demand but can the system cope with it?
 - SAF, e-fuels, methanol, ammonia, industry
 - Which regulation on additionality and temporal correlation?
 - Grids? RES permitting? System Operation?
 - Incentives? Supply chain?

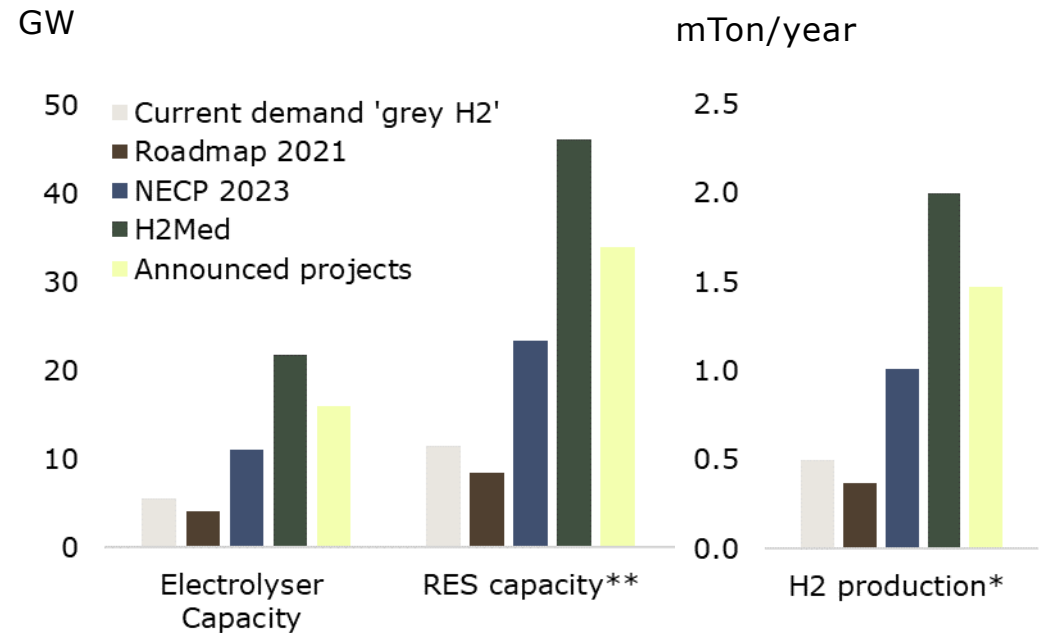
SPANISH ELECTRICITY DEMAND (TWH)



Very ambitious hydrogen plans and investment appetite, but can all elements work out?

- Today demand (grey H2) mostly as a feedstock for
 - Refineries
 - Fertiliser industry (ammonia, methanol)
 - Other industry
- Hydrogen roadmap (2021) aimed at replacing 25% of industrial hydrogen demand with 4GW of electrolyser
- Ambitious European target in 'RePowerEU' (20mTon/y of green hydrogen, 50/50% domestic/imported)
 - H2Med export capacity to France of 2mTon/y
- Spanish NECP 2023: 11GW of electrolyser capacity
- High number of announced potential projects worth >16GW
- Supply chain and economic uncertainties
 - Grants / Regulation of additionality and temporal correlation
 - New demands: transport, SAF, e-fuels, steel, chemicals, food, ceramics, pulp & paper

SCENARIOS OF HYDROGEN PRODUCTION REQUIREMENTS (2030)



*assumption of 70% efficiency, 60% load factor for electrolysers

** illustrative assumption of PPAs with 60% wind and 40% PV

DESCRIPTION

Available reports on the Spanish full blackout of 28th April 2025

- Report by the Analysis Committee for the electricity crisis of 28th April, presented by the Government (Working group on cybersecurity and Working group on Power System Operation)

<https://www.lamoncloa.gob.es/consejodeministros/resumenes/Documents/2025/Informe-no-confidencial-Comite-de-analisis-28A.pdf>

- Report by Red Eléctrica (System Operator), 18/06/2025

<https://www.ree.es/es/sala-de-prensa/actualidad/nota-de-prensa/2025/06/red-electrica-presenta-su-informe-del-incidente-del-28-de-abril-y-propone-recomendaciones>

<https://elperiodicodelaenergia.com/el-informe-de-red-electrica-sobre-el-apagon/> (download link)

- Report by AELEC (private utilities association) , June 2025

https://aelec.es/wp-content/uploads/2025/06/20250623_InformeBlackout.pdf

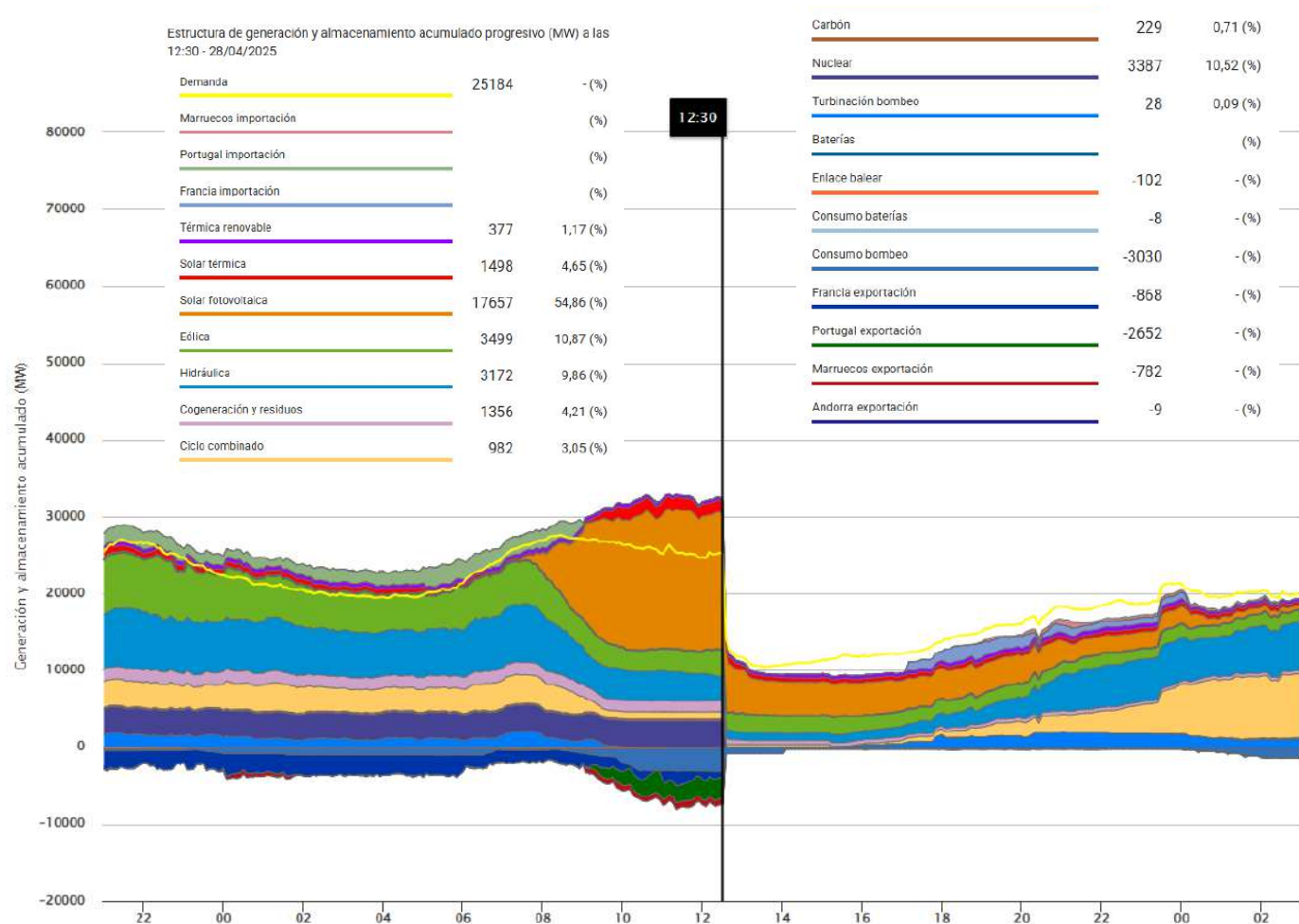
- ENTSO-E, working document

<https://www.entsoe.eu/publications/blackout/28-april-2025-iberian-blackout/>

DESCRIPTION

What we know

- at 12:33, a series of generators trip
- System conditions:
 - 25GW demand, 32GW load
 - +3GW PSH, +4.4GW total exports
 - RES (~100% vs demand):
 - Non Synch (**67% vs load**): 18GW PV, 3.5GW Wind
 - Synch: ~3GW Hydro, 1.5GW CSP, 1.8GW CHP+other
 - Thermal: 3.4GW Nuclear, 1.2GW CCGT+Coal
- 2.2GW in 20 seconds, then 15GW
- loss of French interconnection after the 2.2GW loss
- activation of load sheddings insufficient
- frequency dropped to ~48Hz
- previous inter-area oscillations



Source: Red Eléctrica

POTENTIAL CAUSES

Rather than a single cause, a series of events with triggers and contributing factors that exceeded the 'N-1'. Was 'too much RES' involved?

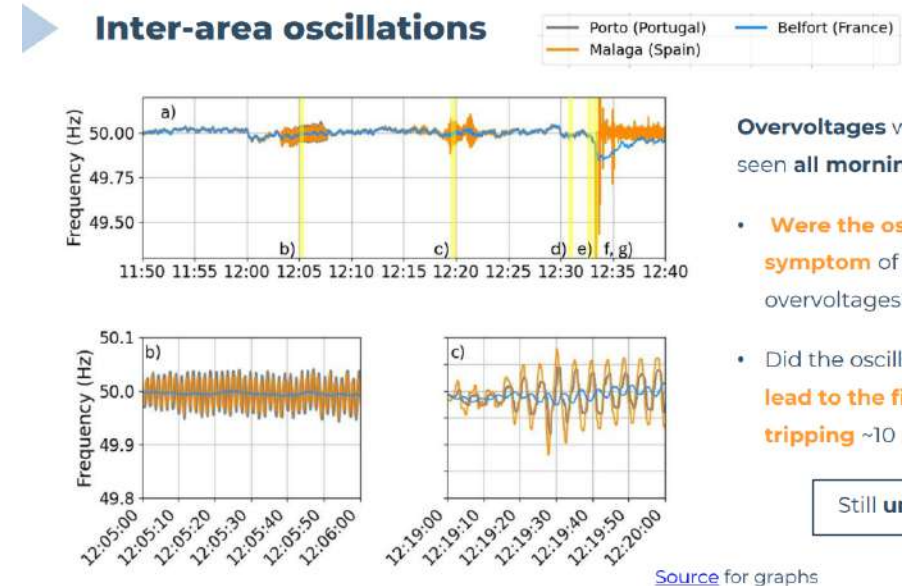
- Inertia
 - RoCoF
- Reserves: Primary (FCR), Secondary (aFRR), Tertiary (mFRR)
- Short-circuit power
 - Detection of faults?
 - Oscillation of GFL inverters or GFM inverters
- Damping of oscillations
 - PSS in synchronous generators
 - POD in PV inverters
 - Grid topology
- Voltage control
 - Grid elements
 - Sync generators
 - RES contribution
- Equipment failures

DESCRIPTION

What we knew initially...

INITIAL INFORMATION AND PRELIMINARY DOUBTS...

Sources: [Red Eléctrica](#), [ENTSO-e](#), public da

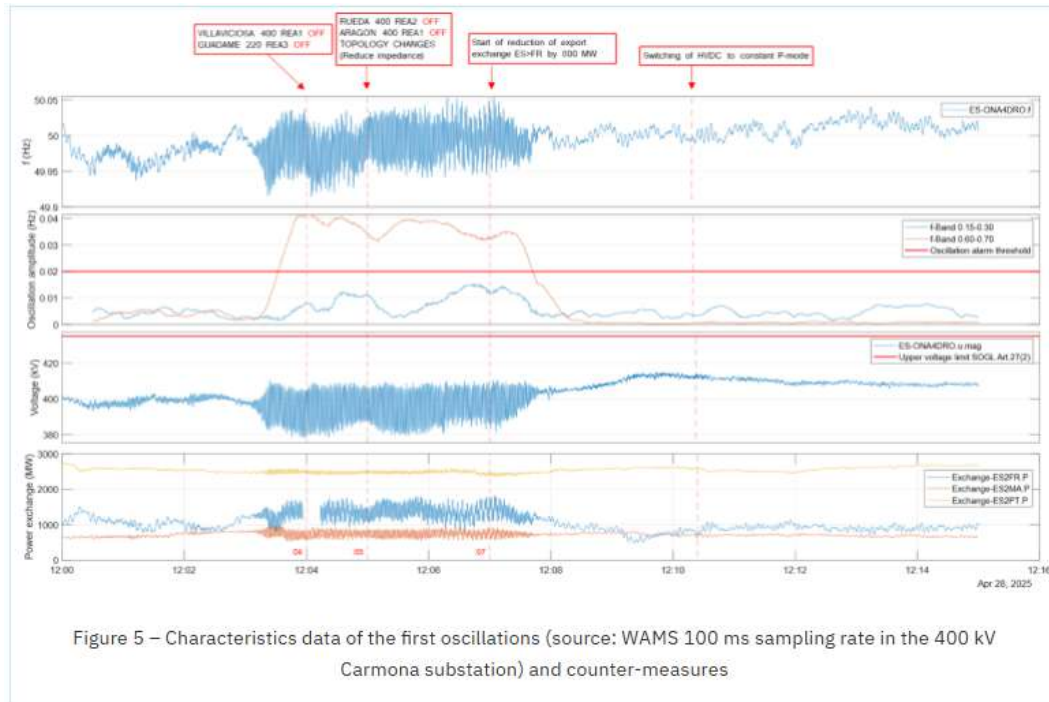


Source: Luis Badesa LinkedIn

DESCRIPTION

What we know: earlier local oscillations of PV trigger the TSO to take some mitigating actions that start reducing voltage control capabilities

BEFORE THE BLACKOUT...

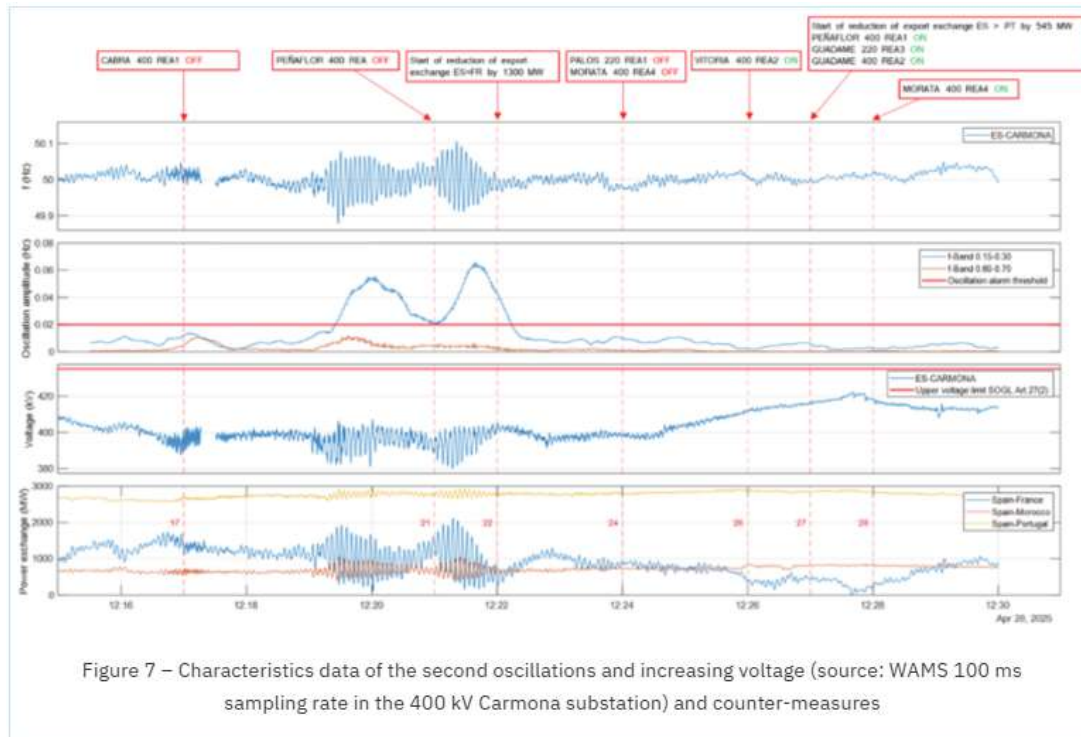


- [...] two main periods of oscillations (power, voltage and frequency swings) were observed in the Continental Europe Synchronous Area (CE SA).
- 1) from 12:03 to 12:07 CEST. A preliminary analysis of the available information indicates that this was a **local**, forced oscillation (i.e. induced by an external source: a power plant), with a dominant frequency of 0.64 Hz, primarily affecting the Spanish and Portuguese power systems. As shown in Figure 5, the forced oscillation also excites the interarea mode East-Centre-West (0.21 Hz) with a small amplitude. [...] These two areas result from the high impedance seen by the generators.
- Actions:
 - Lines switched to decrease system impedance
 - HVDC link with France switched to fixed power
 - Flow Spain-->France was reduced
 - Disconnection of shunt reactors to recover low voltage

DESCRIPTION

What we know: additional measures to control oscillations further impact voltage control capabilities

BEFORE THE BLACKOUT...



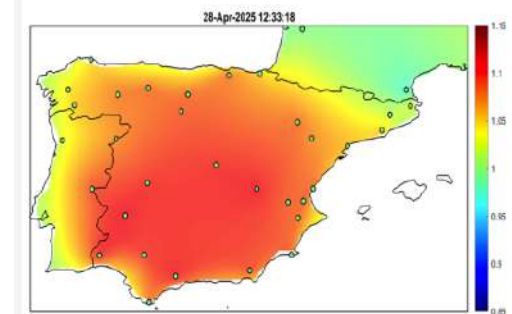
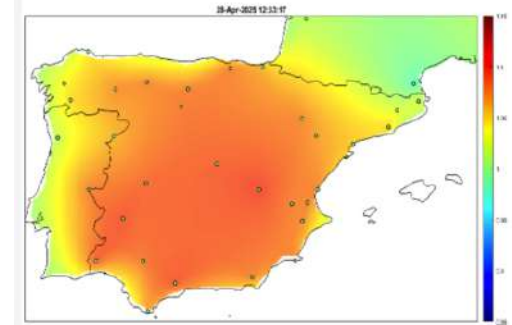
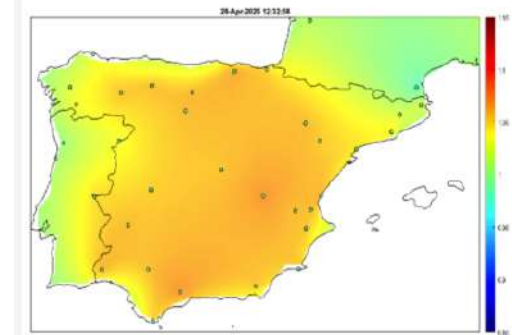
- [...] two main periods of oscillations (power, voltage and frequency swings) were observed in the Continental Europe Synchronous Area (CE SA).
- 2) between 12:19 and 12:22 CEST. This was an **inter-area** oscillation, with a dominant frequency of 0.21 Hz, corresponding to the well-known East-Centre-West Continental mode.
- Actions:
 - Reduced flows Spain-->France
 - Coupling internal power lines
 - Injection of reactive power increases voltage

DESCRIPTION

What we know: widespread overvoltages trigger the blackout with some unclear response of system elements

BLACKOUT SEQUENCE

- 12:32:57, 12:33:16 and 12:33:17, loss of 2.2GW generation in the south west
 - Tripping of Transformer in Granada (overfrequency or overvoltage), 355MW
 - Tripping of PV and CSP at 400kV near Badajoz, 720MW
 - <1 second, wind in Segovia and Huelva, PV and CSP in the south west, 1100MW
- --> voltages increase, frequency decreases
- 12:33:18 and 12:33:21: rapid voltage increase, more generation trips, frequency drops
- 12:33:19, the Iberian system starts losing synchronism with Europe
- 12:33:19 to 12:33:22
 - Load sheddings start <49.5Hz (PSH) and <49Hz (~15% of demand every 0.3Hz)
 - Timed Generators protections for underfrequency or overvoltage
 - Unable to prevent collapse
 - 12:33:21 AC lines Spain-France disconnect by protection against loss of synchronism
- 12:33:24 full system collapse



Figures 12a, 12b & 12c - Heat maps of the voltage in the 400 kV network (in p.u.) one second after each of the first three generation trips (source: PMU data from Red Eléctrica, REN and RTE)

DESCRIPTION

20 seconds sequence... 'cooked' hours, days and years earlier

BLACKOUT SEQUENCE

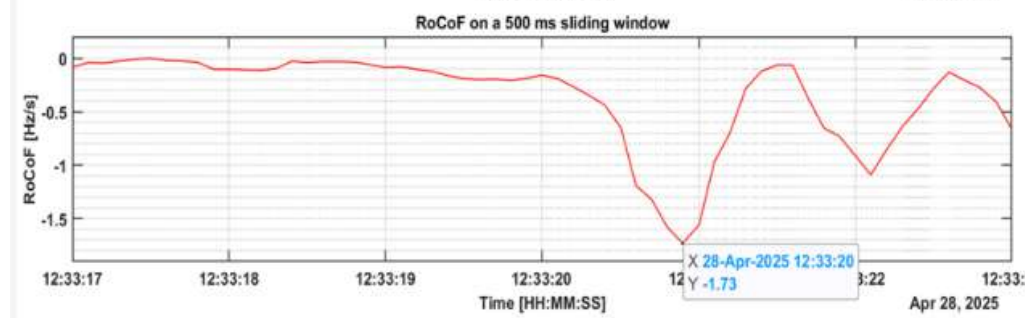
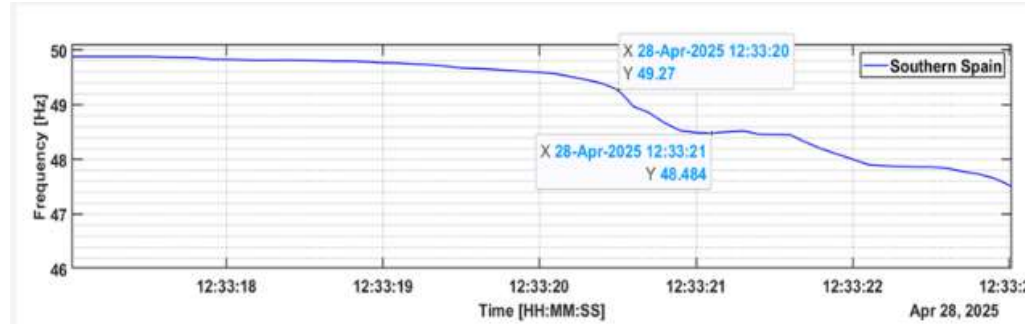
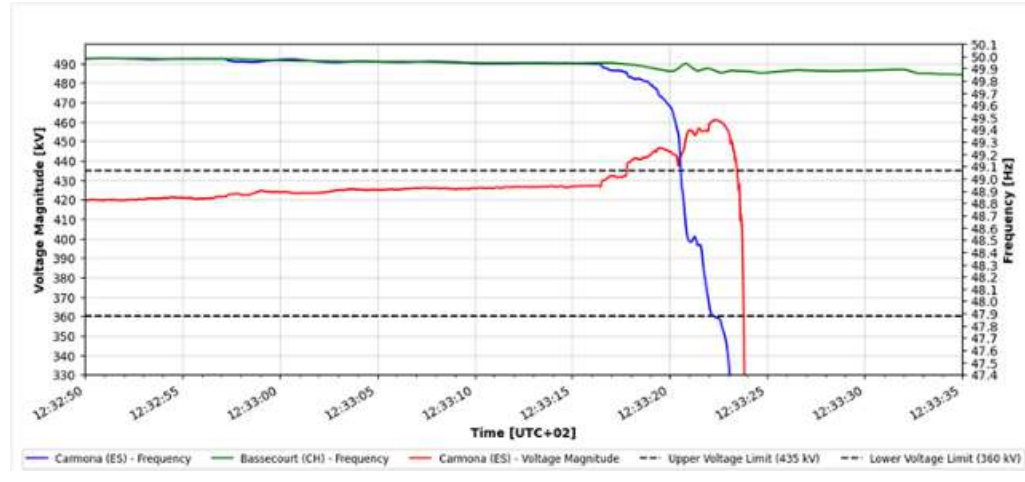


Figure 15 - Evolution of the frequency and RoCoF in the seconds before the blackout (source : PMU data from Red Eléctrica)

POTENTIAL SOLUTIONS

Solutions will likely combine technology and regulatory incentives

- First, exact causes and contributing factors to be fully understood
- Request to generators specifications
 - Grid code
 - Technology
 - Grid forming batteries
 - Synthetic inertia
 - Primary response
 - Voltage control (Shunt reactors, Synchronous compensators, flywheels, Statcoms)
 - Grid elements vs. market services
- Regulatory incentives
 - Market services
 - TSO dispatch
 - Hourly scheduling and voltage during change of programs



POTENTIAL SOLUTIONS

Solutions will likely combine technology and regulatory incentives

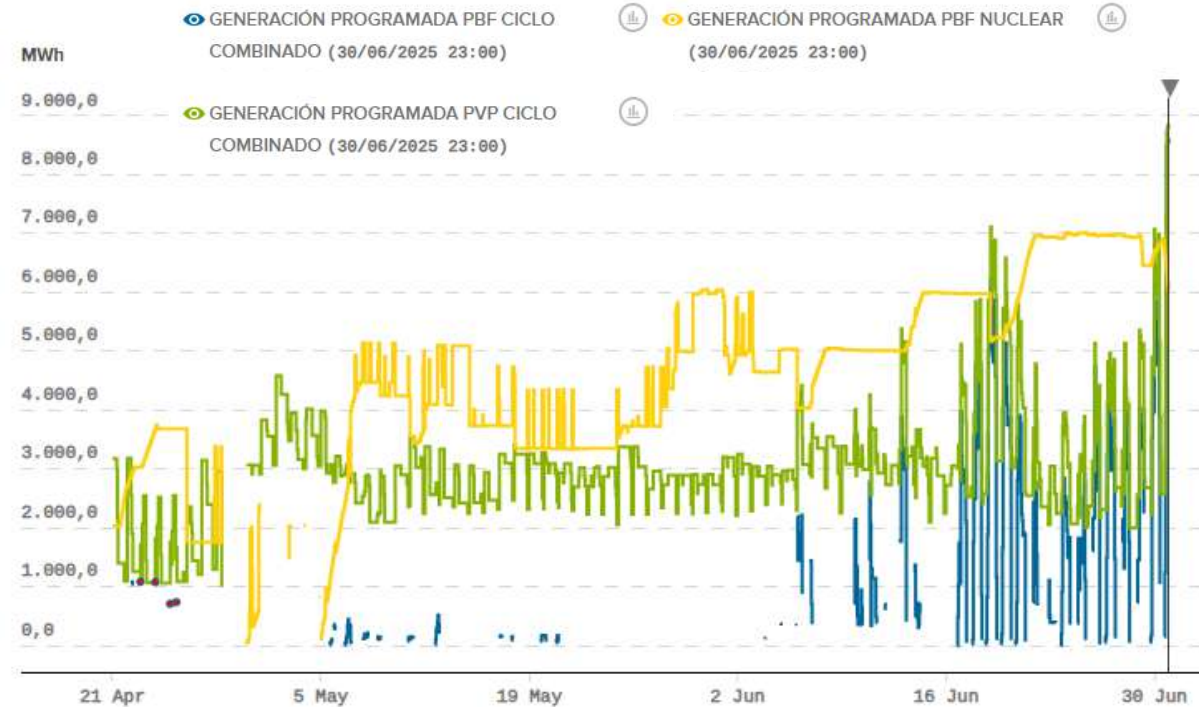
- First, exact causes and contributing factors to be fully understood
- Request to generators specifications
 - Grid code
 - Technology
 - Grid forming batteries
 - Synthetic inertia
 - Primary response
 - Voltage control (Shunt reactors, Synchronous compensators, flywheels, Statcoms)
 - Grid elements vs. market services
- Regulatory incentives
 - Market services
 - TSO dispatch
 - Hourly scheduling and voltage during change of programs



- 65 new elements for voltage, oscillations, grid reinforcement:
 - 10 shunt reactors
 - 11 synchronous compensators
 - FACTS for inter-area oscillations, 66 new relays

RES integration will likely continue with proper integration elements

- Fully understand the sequence, triggers, contributing factors
- Operational measures:
 - Preventative system operation with more curtailments
 - Voltage control
- Technology specifications
 - Grid following vs. grid forming inverters
 - BESS?
 - Other system elements
- RES in Spain likely slowed down by market prices, not by energy policy measures



BLACKOUT CONCLUSIONS

...bad luck? Or a combination of elements?

20 seconds sequence... 'cooked' hours, days and years earlier:

- 'unknown unknowns'?
- behaviour of inverters
- generators/protections behaviour
- system planning elements?
- system operation safety margins?



Preventing blackouts will never be 100% guaranteed, but risks can be mitigated strongly with analysis, technology and regulation

- Target RES penetration driven by energy policy (economics, energy dependence, trade balance, jobs...)
- Grid studies:
 - Static loadflow, network elements
 - Dynamic transient stability (frequency and voltages), role of GRID FORMING inverters
 - Grid code requirements (Grid forming specifications) and protection systems for a safe system operation
 - Iteration: Technology – Costs – RES penetration – Regulation
- Lessons learnt:
 - Inertia: 'real', 'synthetic', 'emulated'
 - Voltage control: synchronous generators, non synchronous generators, a range of system elements
 - Importance of regulation and compliance monitoring
- What next for Spain, and other markets?
 - Very high RES penetration is possible with proper integration tools and regulatory developments
 - Sector collaborative work, between political ambitions, technology and total system costs
 - No single right answer, but a set of options to minimize risks
 - Plenty of other studies required beyond blackouts: fuel supply, market price risks, reserves, thermal flexibility...

OUTLOOK

Wind and PV will continue, with changing paces and changing investment drivers

DIRECT INVESTMENT DRIVERS

- **Merchant**
 - LCOE, sunk costs, uncertain projections
- **Hybridations**
- **PPAs**
 - Data centers
 - Synthetic fuels
 - Industry
- **Auctions**
 - NECP calendar
 - Volume and design TBD
- **Self-consumption**
 - New construction, ESG
 - Electrification of homes and industry
 - Independence and 'a good sleep'

INDIRECT INVESTMENT DRIVERS

- Capacity Market
- Funds and grants
 - EU reconstruction funds.
 - Other grants.
 - Flexibility markets?
- Demand...

WHAT'S NEXT?

A very active market with different paces during the 2020's, 2030's and 2040's

Self-consumption, heat pumps, Energy efficiency solutions

- High appetite for distributed generation as 'anti black swan' energy sourcing
- High potential for heat pumps, insulation

EV infrastructure

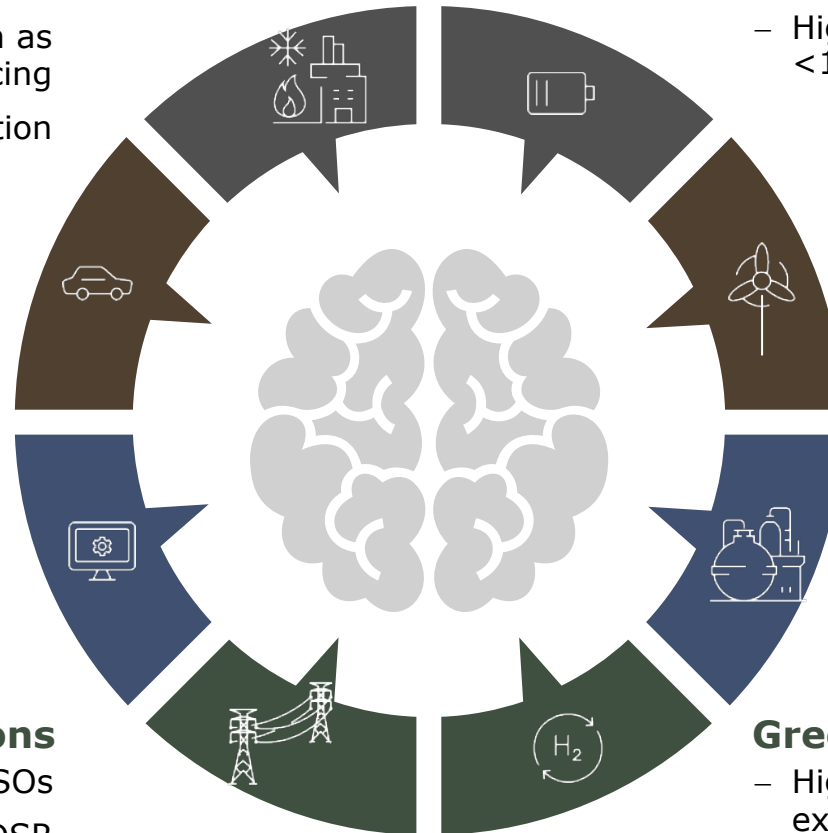
- Mandatory targets, public funding, expectation of high rise of EV market

Demand response, digitalisation

- High Price volatility within day
- High potential for demand shifting (industrial processes, Heating&Cooling)

Grids and interconnections

- Investments required by TSO/DSOs
- Potential design of new services and DSR
- Interconnections for pan-European efficiency



Storage

- High capacity in batteries, rapidly decreasing Capex, 15' trading, hybridisation and stand-alone
- High potential PHS ('10GW mixed inflow PSH <1m€/MW')

Wind power onshore/offshore

- High onshore targets with high resource and positive economics
- 3GW offshore target with upcoming auctions TBD

Biomethane

- High potential (>30TWh at least up to a long-term potential of 100TWh) and appetite among offtakers and investors

Green Hydrogen

- High # of potential projects, and possibility to export high volumes to EU
- Production of e-fuels, green ammonia, Green Steel

Contacts



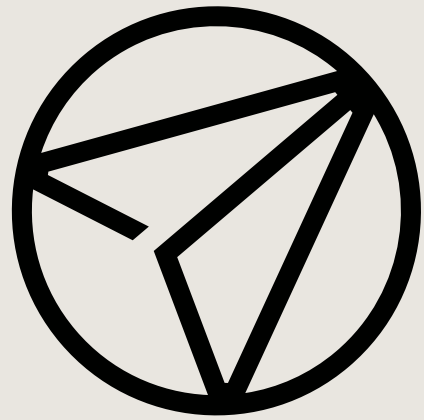
JAVIER REVUELTA
Senior Principal
javier.revuelta@afry.com
+34 647624451



IGNACIO COBO
Senior Principal
Ignacio.cobo@afry.com
+34 611 481 021

A woman with dark hair, wearing a light-colored jacket, is shown in profile from the chest up, looking towards the right. She is standing in front of a blurred city skyline at night, with many lights from buildings creating a bokeh effect. The overall color palette is cool, dominated by blues and greys, with warm yellow and orange lights from the buildings.

Making Future



AFRY