La Energía Nuclear en la transición energética de España

April 2023

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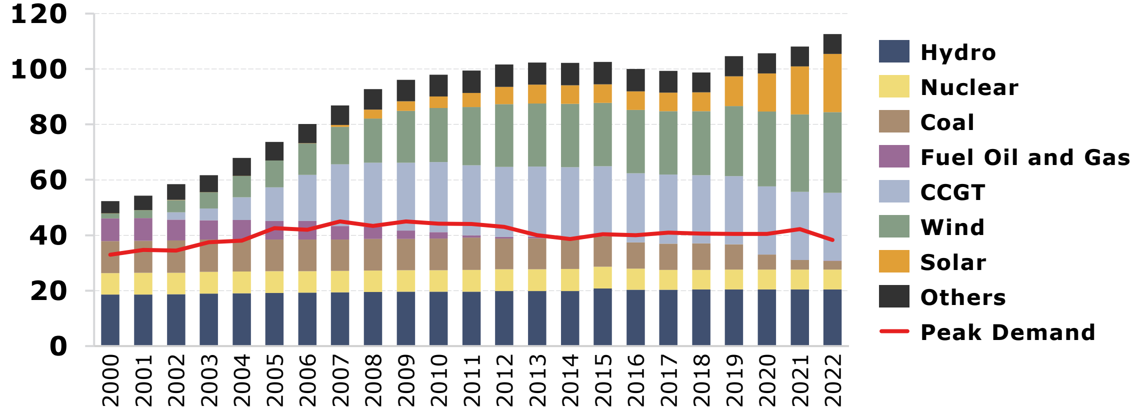
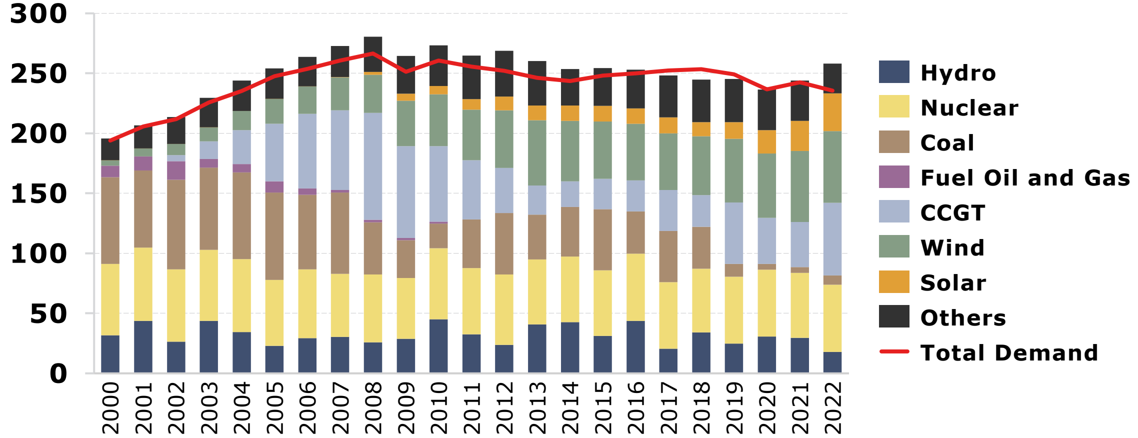
Capacity mix in Spain has undergone a significant shift; moving away from conventional thermal generation towards renewables

INSTALLED CAPACITY BY FUEL TYPE (GW)



NET ELECTRICITY GENERATION BY FUEL TYPE (TWH)



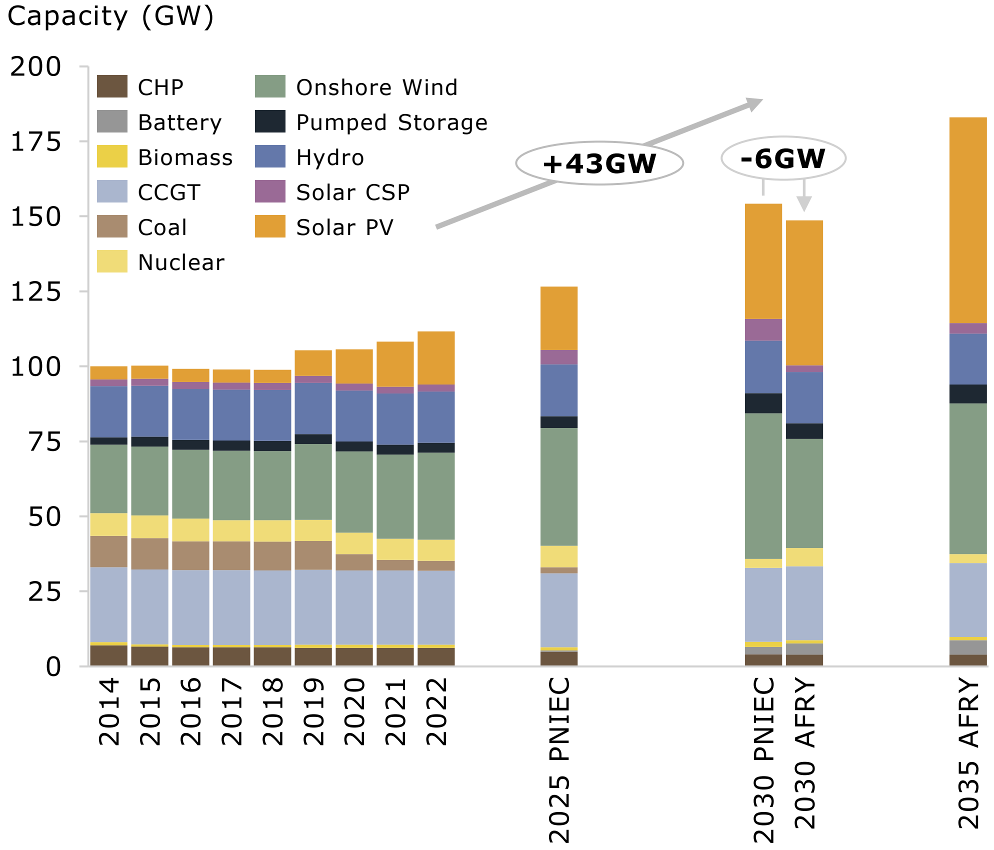
Sources: AFRY Management Consulting Notes: 1. Load factors in 2019

OVERVIEW

- Installed capacity in 2022 reached 112.7GW,
  - Wind: +1.6GW
  - Solar PV: +4.4GW
  - Self-consumption PV: 2.6GW
- Annual demand: 236TWh (-2.9%), excluding self-cons.
- Peak demand: 38.2GW (45GW in 2007, 42GW in 2021)
- Net export: -20TWh (typically close to neutral)

Need to adjust the NECP 2030 targets to incorporate latest developments, and start looking beyond for policy decisions (2035 or 2040?)

PNIEC CAPACITY (GW) & AFRY 2030 (GW)



Technology	Nov 2022	NECP 2030		Comment
Onshore Wind	29.0	48.6	2.4 GW/y	Very challenging, considering repowering
Solar PV	19+4	38.4	2.6 GW/y	Likely exceeded combining Utility Scale and Self-Consumption
Solar CSP	2.3	7.3	1 GW/y	Unlikely. Auctions? Political willingness to pay for CSP or similar service?
Biomass	1.1	1.7	0.1 GW/y	Reachable
Nuclear	7.1	3.1	-4 reactors	Possible but unlikely, Security of Supply
CCGT	24.7	24.7	0	Possible (with a CRM)
Coal	3.2	0	close all	Reachable.
CHP	6.1	4.0	-0.3 GW/y	?
Hydro	17.0	17.5	0.06 GW/y	Possible
Pumped Storage	3.3	6.7	+3.5 GW	Unlikely (permitting, economics)
Batteries	0.0	2.5	0.5 GW/y	Possible with EU funds, CRM, others
Inter Sp-Fr	3	10	+3 projects	Unlikely (permitting, technical, economics)

- Flexible scenarios for potential new demands (e.g. Hydrogen)
- Need to give investment signals >2030

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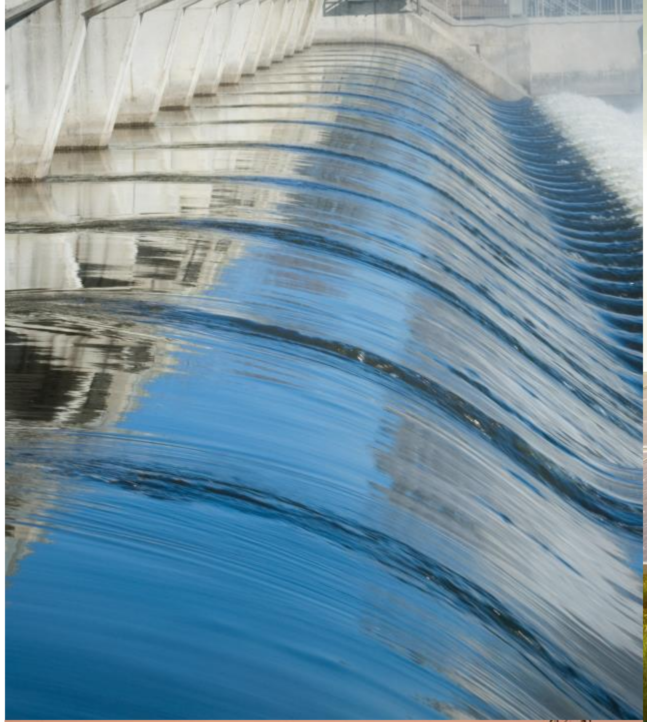
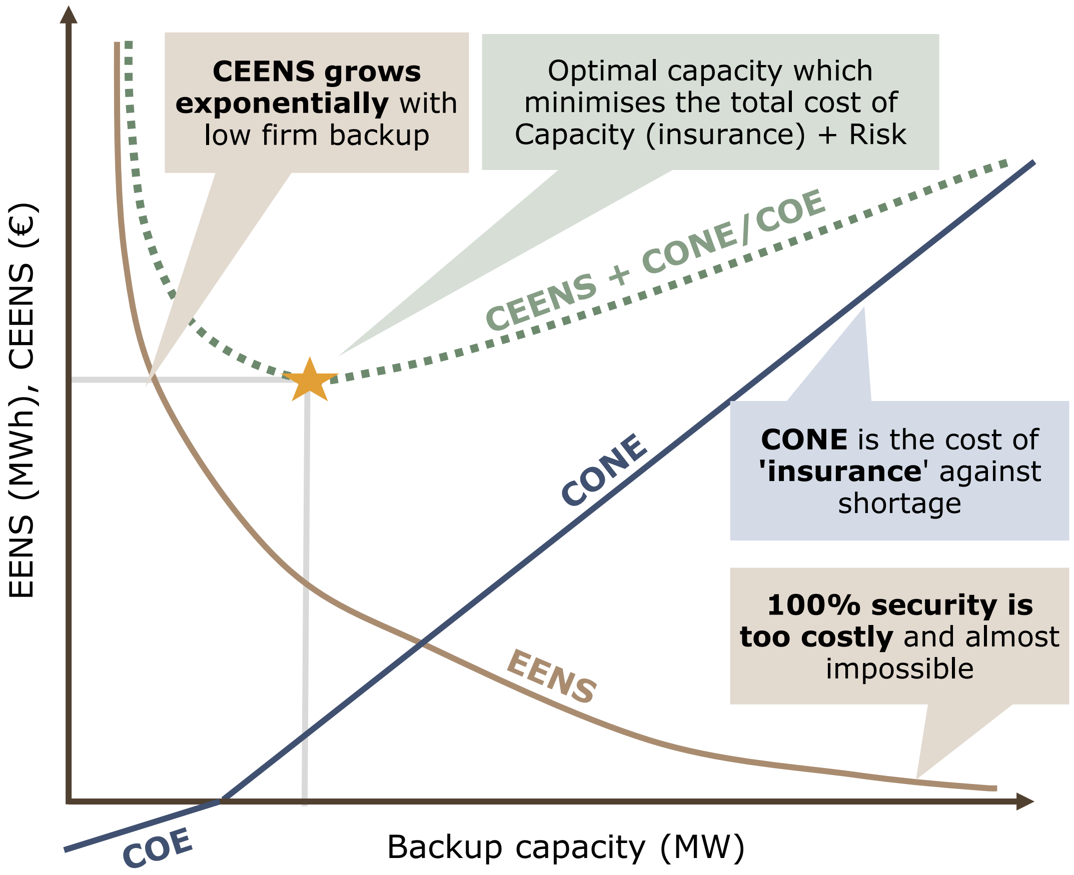


The most efficient system balances cost of backup versus the reduction in the risk of shortage

PHYLOSOPHY AROUND SOS



DESCRIPTION

- Once the simulations are finished, the outputs obtained must be compared to find which capacity mix gives the optimal economic system.
- The most efficient system balances cost of backup versus the reduction in the risk of shortage

Parameter	Unit	Value	Comment
LOLE	hours	-	Loss of Load Expectation
EENS	MWh	-	Expected Energy Not Supplied
VoLL	€/MWh	10,000	Value of Loss Load
CEENS	€	-	EENS multiplied by the VoLL
CONE	€/MW/y	20/30k	Cost of New Entry (Opex CCGT or Missing money of a battery)
COE	€/MW/y	20k	Cost of Extension (Opex CCGT)

AFRY Webinar on Security of Supply https://attendee.gotowebinar.com/recording/5480034530805074191

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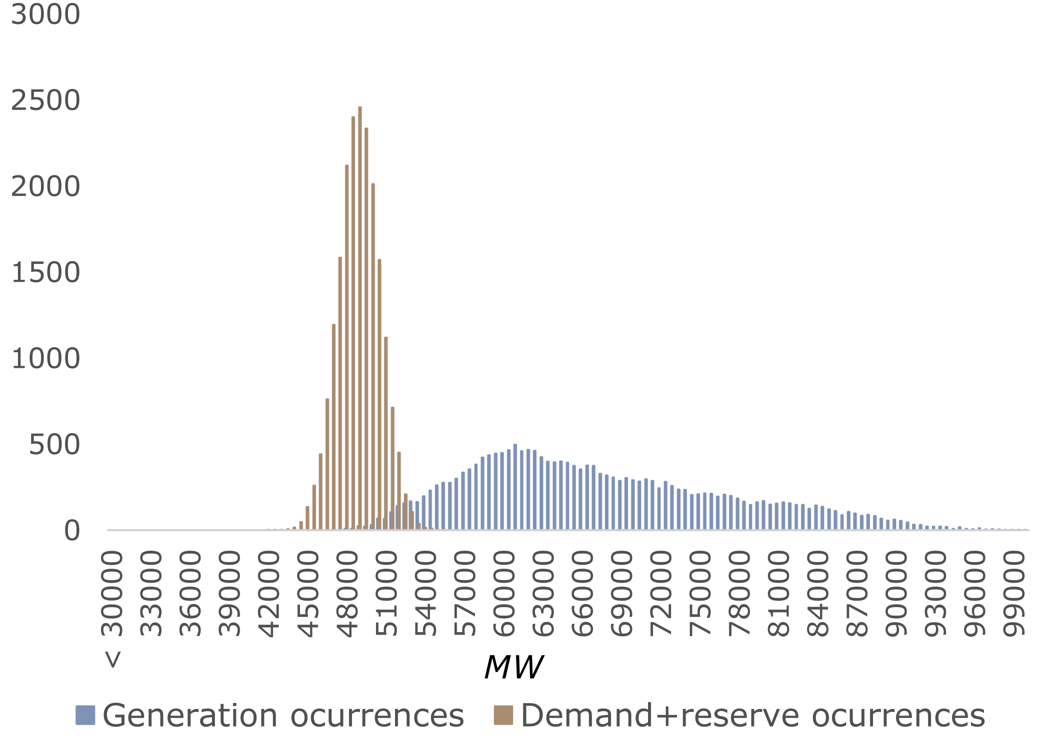
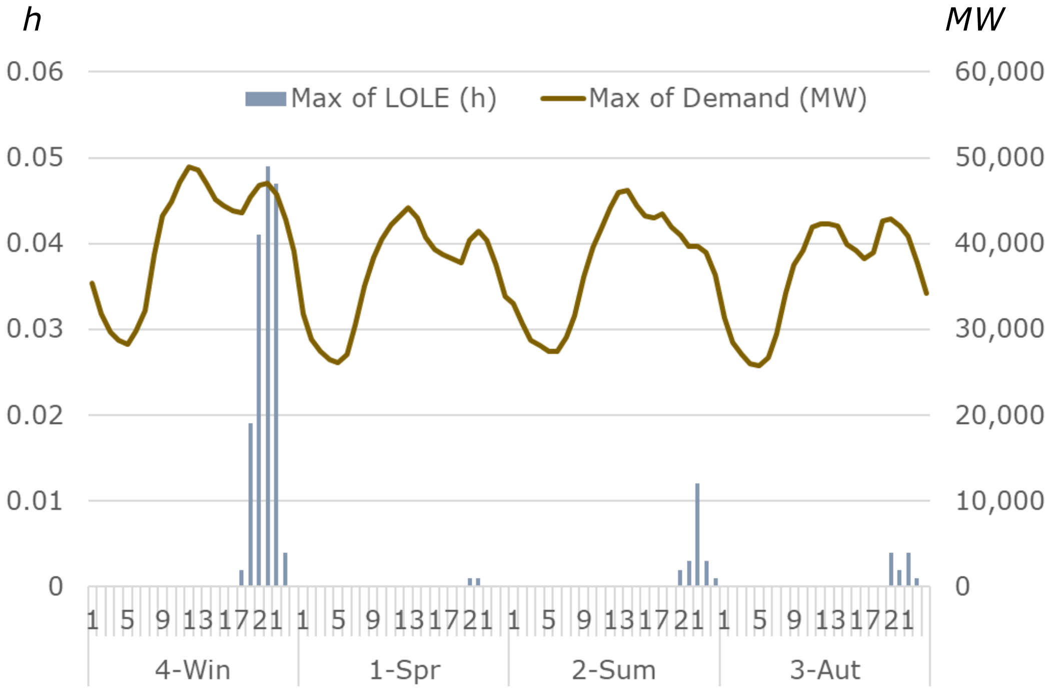
Critical demand is expected to remain in winter after sunset

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



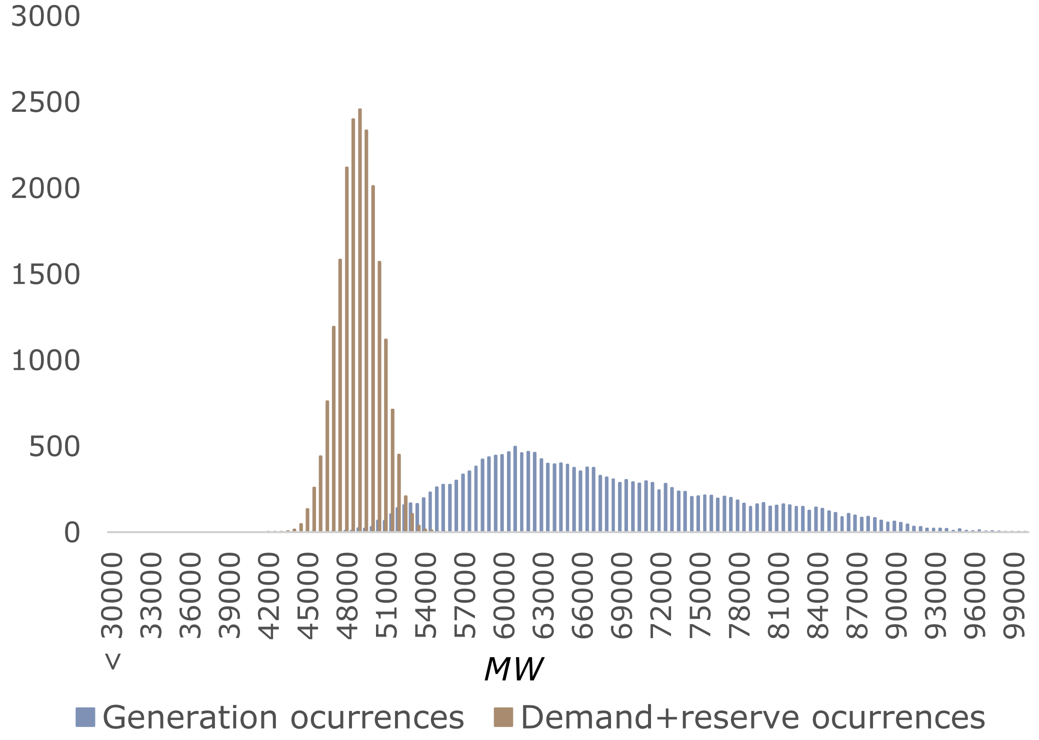
HOURLY DISTRIBUTION OF LOLE (SAMPLE 2030)



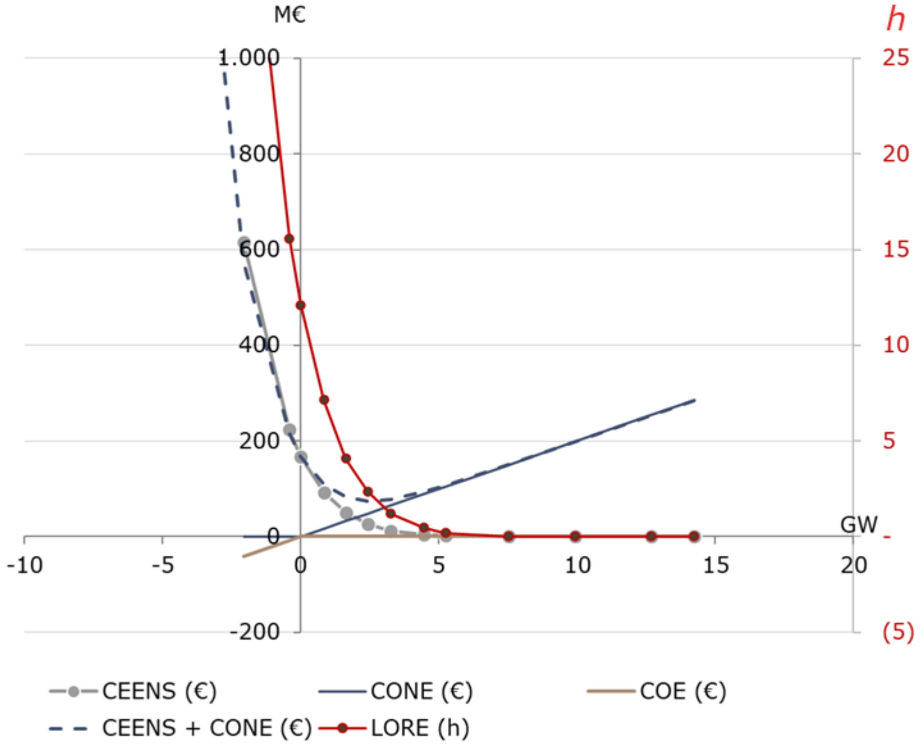
The Iberian power market will need reliable capacity after the sunset, mostly in Winter

Below a threshold of cost-effective backup LOLE and CEENS rise exponentially

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



IMPACT OF CAPACITY ON LOLE/CEENS



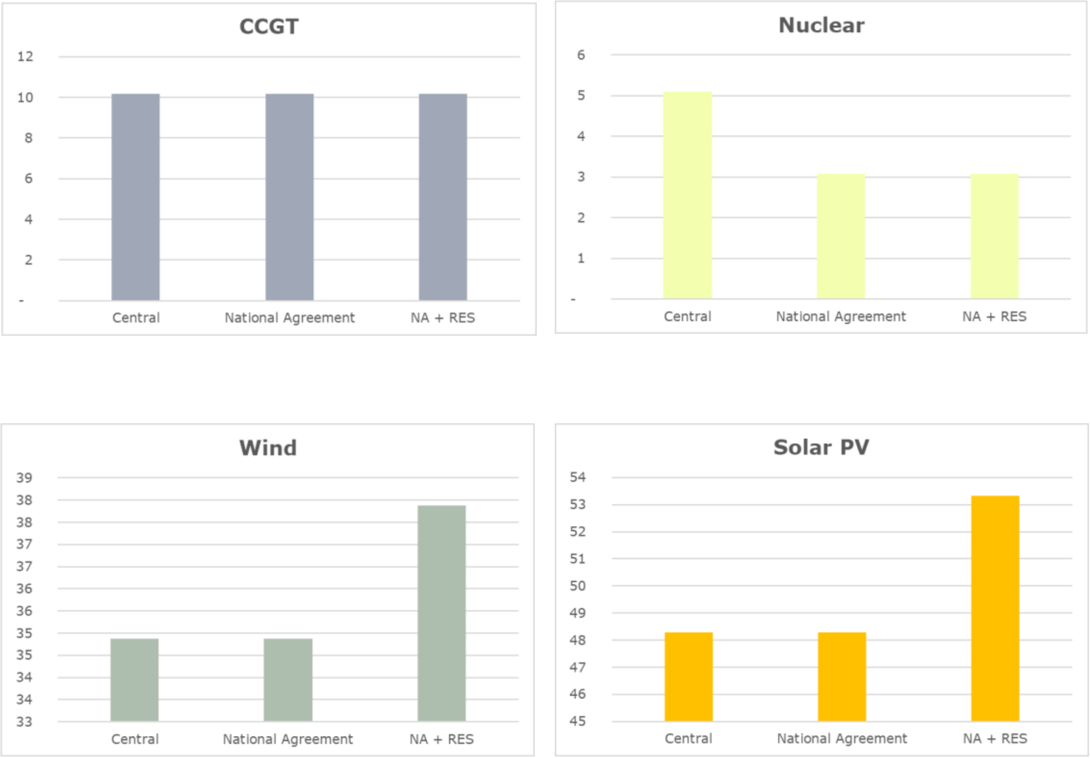
The Iberian power market will need reliable capacity after the sunset, mostly in Winter

Security of Supply was assessed for 3 scenarios, based on AFRY and political assumptions with minimum CCGTs viable without capacity payments

SCENARIO DESCRIPTION

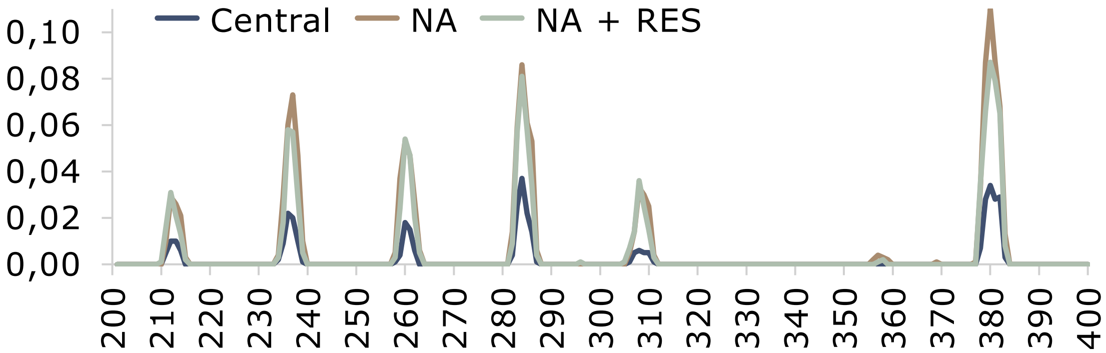
- The analysis was carried out based on three adapted scenarios:
  - **Central**: AFRY's best view of the capacity mix evolution adapted with closure of 2 nuclear reactors by 2030 and only economic CCGTs without Capacity Payments
  - **National Agreement**: an adapted version of the official NECP plan, including AFRY's best view on some system elements
  - **NA + RES**: presents a scenario with additional RES to compensate for the closure of 2 nuclear reactors
- In all scenarios, we have assumed a 'base scenario' without capacity at risk of closure without a Capacity Payment, which means that up to 14GW of CCGTs are not considered in the base case (they could mothball, or stay operational with poor economics, or precisely receive a capacity payment based on the SoS study).
- Regarding thermal capacity, we have considered in AFRY Central and the Political scenarios that only 10.2GW will be operating with positive cash flows, the remaining 14GW closed or mothballed if no capacity payment is given. A more aggressive view is applied in the High Res scenario.

CAPACITY MIX



Scenarios with lower nuclear capacity have a higher probability of loss of load even with strong renewable development

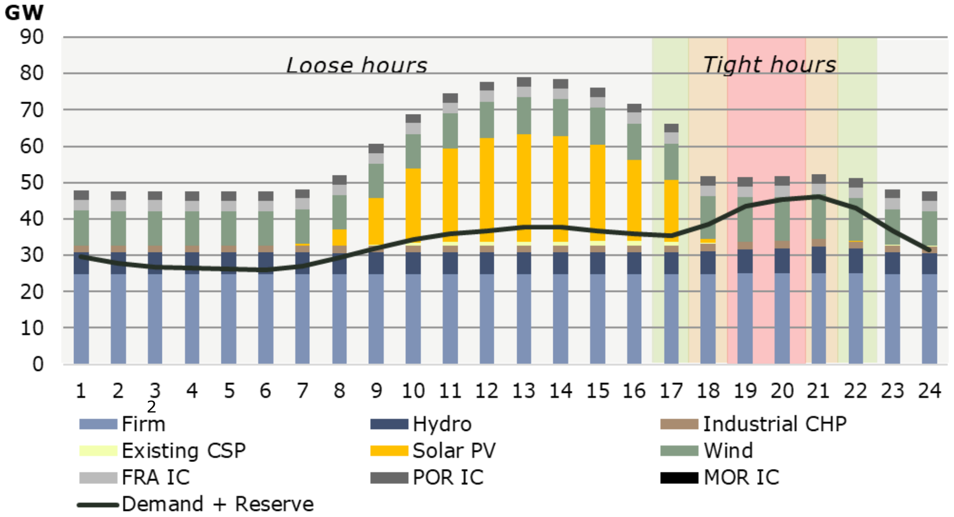
LOLE PER SCENARIO (H)



Scenario	Nuclear (GW)	RES (GW)	Peak demand (GW)	LOLE (h)	ERNS (GWh)
Central +7GW	7.1	85.5	45.7	0.96	0.19
Central +5GW	5.1	85.5	45.7	4.02	21.31
NA	3.1	85.5	45.7	13.33	67.69
NA + RES	3.1	95.5	45.7	11.48	58.14

GENERATION & DEMAND BALANCE THROUGHOUT THE DAY

- average day of 2030, shows critical hours are after sunset
- What matters to security of supply is not average resource, but probability distribution of low resource periods



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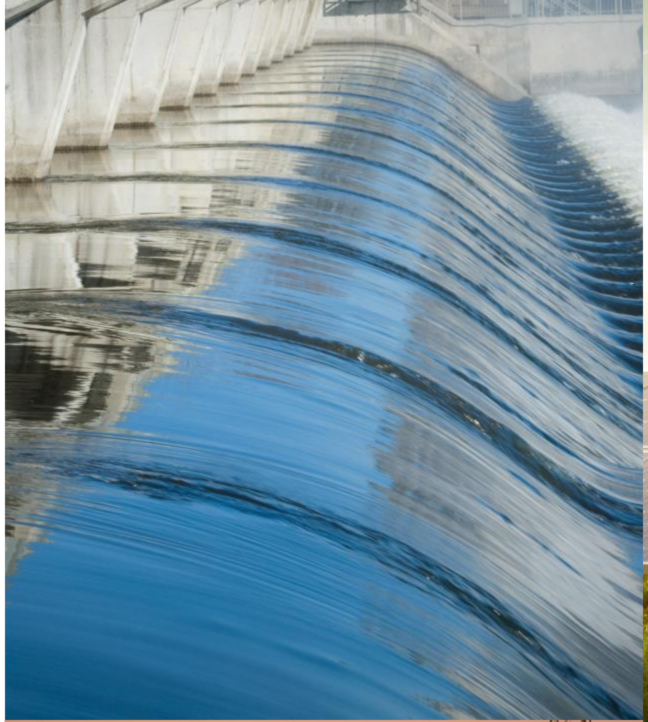
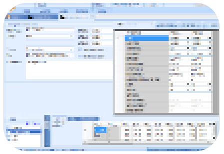
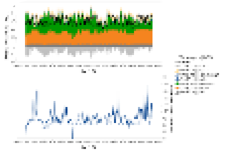
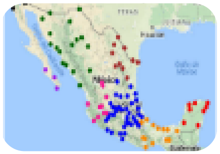


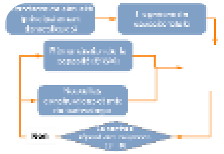
Our hourly market model BID3 simulates the behaviour of the European power market with hourly resolution out until 2060

Key features


Detailed power station database

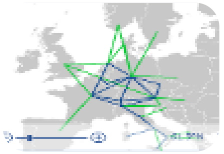

Flexible charting and pivoting of any data

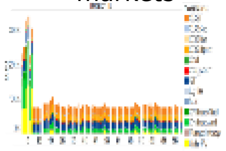

Zonal, FBMC and nodal pricing

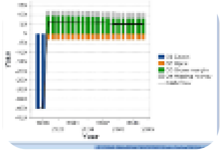

Energy-only and energy + capacity markets

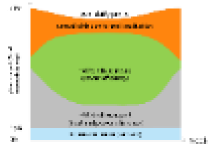

Sophisticated hydro modelling

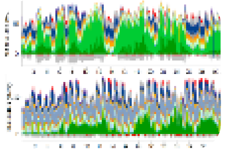

Supply curves, marginal plant


Flexible pricing areas + fixed flows

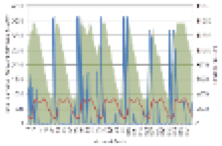

Auto Build module

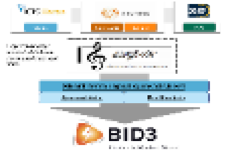

Profitability, IRR calculations

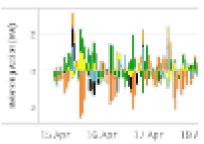

Detailed CHP modelling

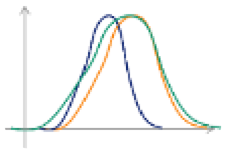

Intermittent generation


Reserve and response


Demand-side management


Short-term modelling


Within-day calculations


Monte Carlo analysis

Inputs and outputs of BID3

Inputs

- **Power station data** (efficiency, capacity, fuel, MSG, …)
- **Demand**
- **Fuels, commodity prices**
- **Interconnectors**
- **Weather data (hourly wind, solar, demand, hydro…)**
- **New build/retiral**

BID3
Electricity Market Model

Economic new build of all technologies

Outputs

- **Prices**
- **Load factors**
- **Interconnection**
- **Emissions**
- **Plant revenue**

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Power price drivers

Demand growth
- Population
- GDP
- Efficiency
- E.V.
- Electrification

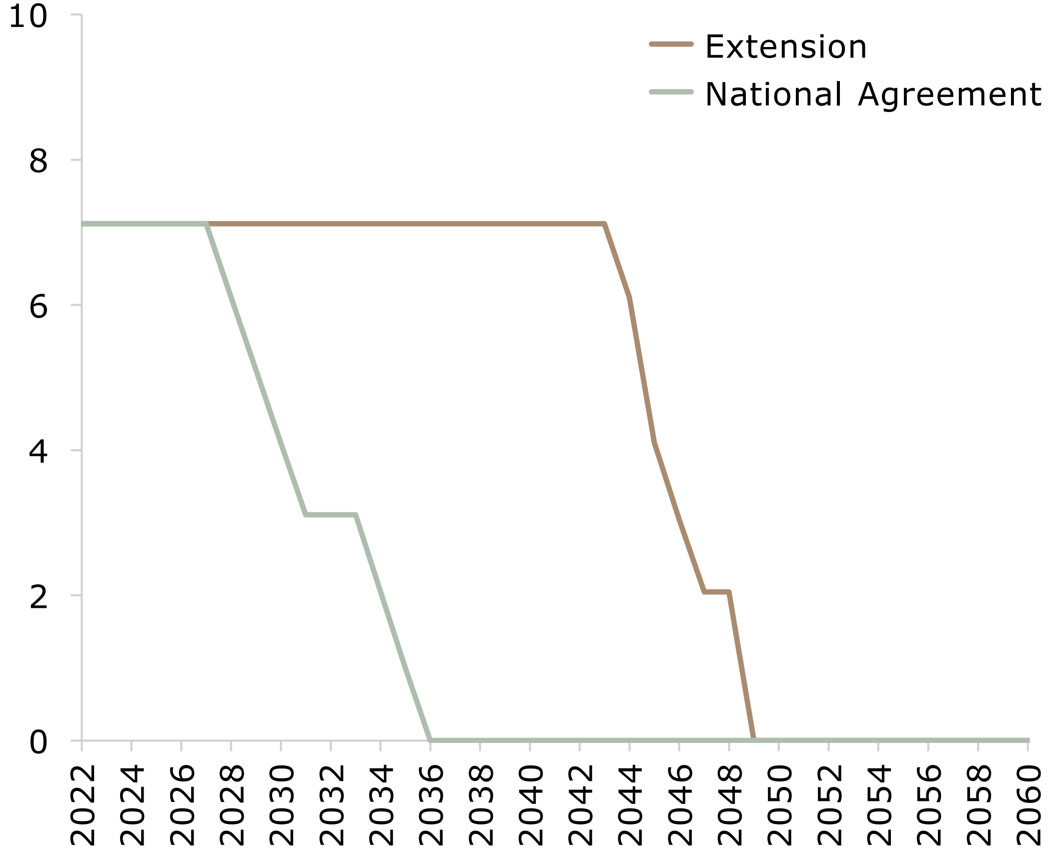
Political decisions
- RES targets
- Taxes
- Grid charges
- Capacity Payments

Commodities
- Oil
- Gas
- Coal
- CO_2

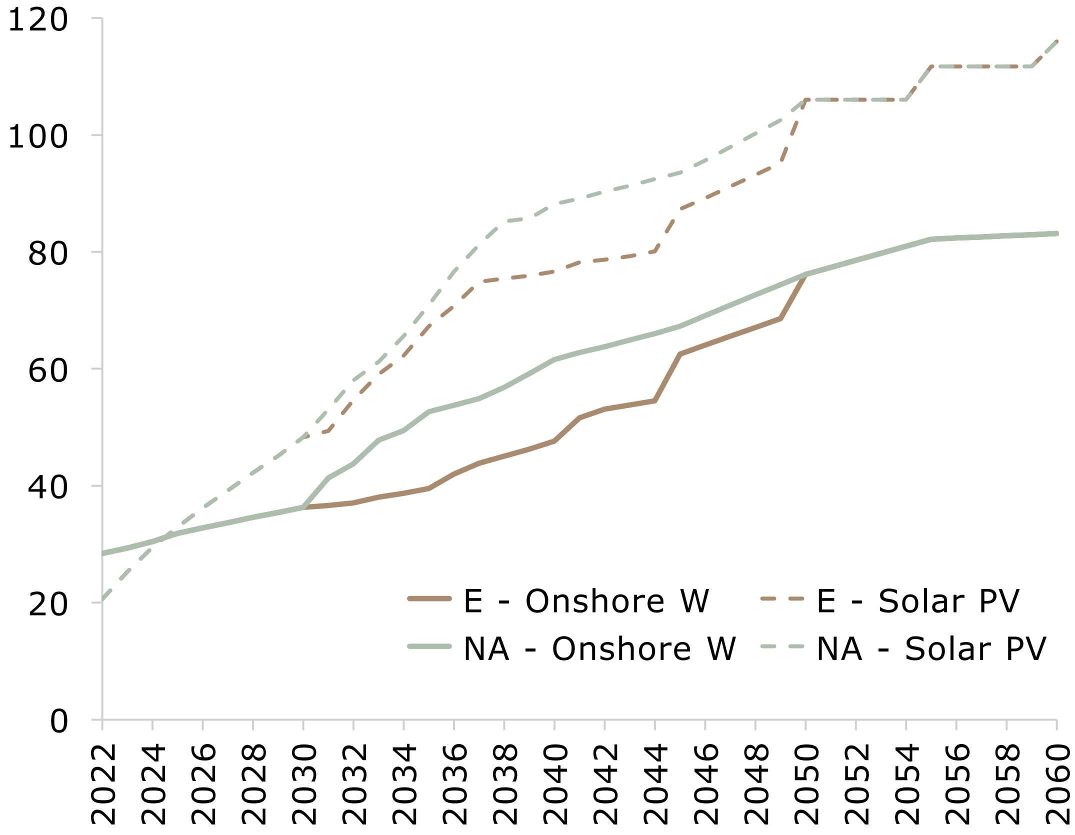
System development
- Interconnections
- New capacity
- Decommissionning

There are opposing political views around nuclear technology, therefore investors and consumers ought to assess scenarios

NUCLEAR CAPACITY (GW)

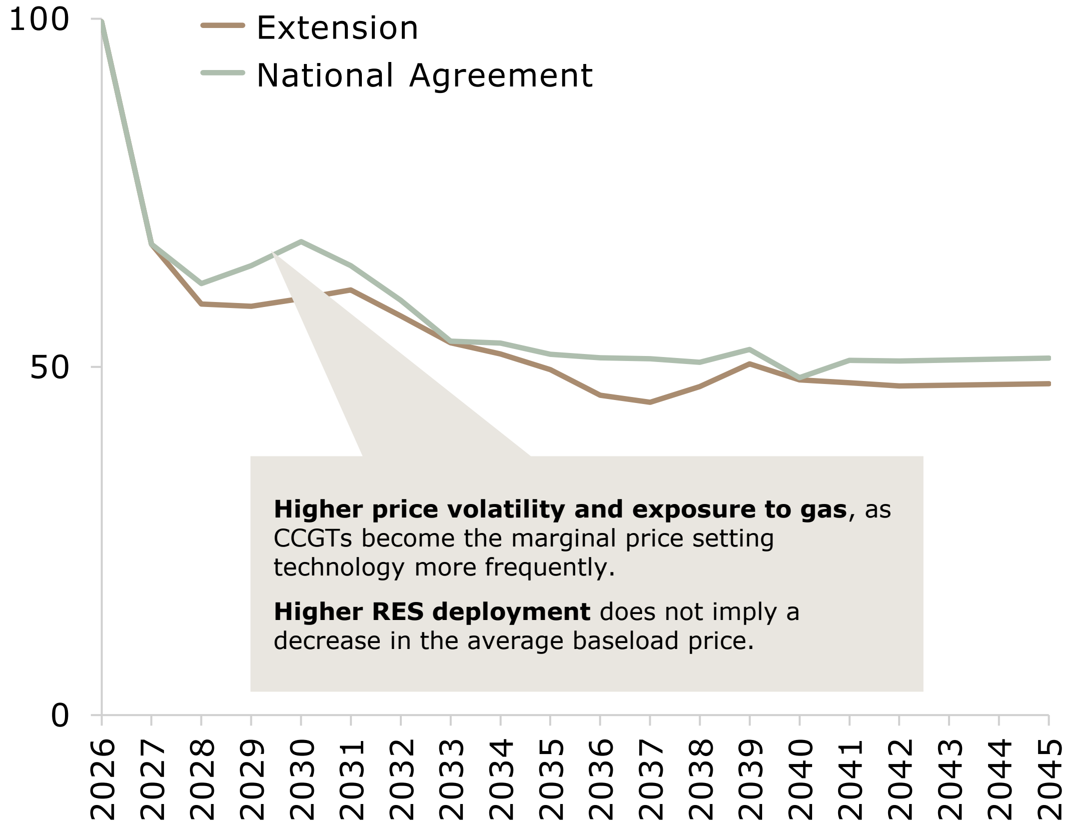


ONSHORE WIND & SOLAR PV CAPACITY (GW)



Nuclear shutdown would increase baseload prices as well as the volatility associated with CCGT generation and total emissions

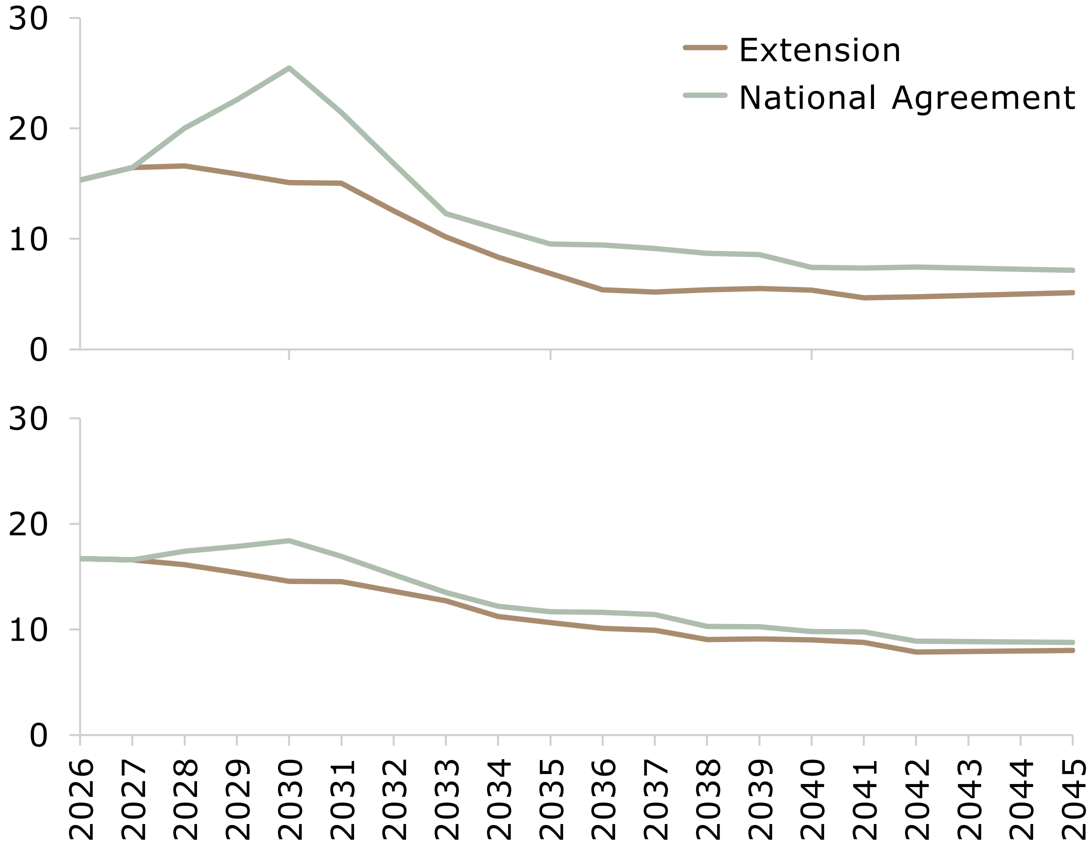
BASELOAD PRICE (€/MWH)



Higher price volatility and exposure to gas, as CCGTs become the marginal price setting technology more frequently.

Higher RES deployment does not imply a decrease in the average baseload price.

CCGT GENERATION (TWH)/CO2 EMISSIONS (MT)



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Grid stability study will be required, resulting in redispatches to incorporate synchronous generation to the market schedule

SCENARIOS WITHOUT NUCLEAR CAPACITY

- Voltage control without nuclear units
- Transient stability after faults
- New energy flows, network planning

--> expected redispatches of CCGTs in the daily constraints analysis, to provide 'grid control' and inertia, taking part of the nuclear production removed from the system

Agenda

A new world where geopolitics will be increasingly driven by minerals...

SOME DATA ABOUT THE ENERGY TRANSITION

- Mining industry is 8-10% of world energy consumption (IEA)
- 'transition' from oil&gas&coal to minerals for electrification
  - x2 (STEPS) to x3 (SDS) critical minerals for RES by 2040
  - Ni and Zi for electrolysers, Cu and Pl for FCEVs
  - rare earths x3 (STEPS) to x7 (SDS) for EVs and Wind
  - Wind and PV require >x10 critical minerals per MWh
  - Wind and PV by 2040: 40% of Cu, 65% Ni/Co, 90% Li

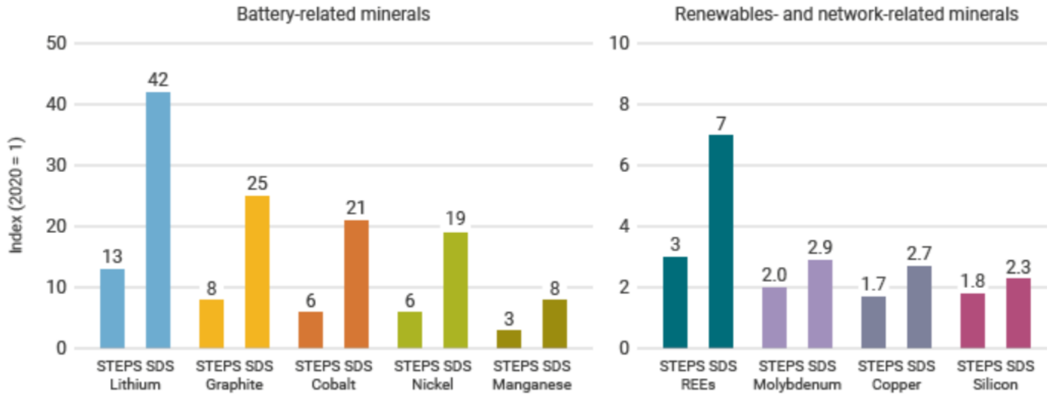

Figure 1: Growth in demand to 2040 for some critical minerals in IEA STEPS and SDS scenarios (source: IEA)

CRITICAL MINERALS TO MONITOR

- Essential minerals for low-carbon future:
  - Copper, Nickel, Manganese, Cobalt, Chromium, Zinc, Molybdenum, Rare Earths (17: neodymium, dysprosium..), Silicon
  - Lithium and graphite (EVs and batteries)
  - Indium, Galium
- Non critical but high volumes:
  - Steel (1000-1500 t/MW), Aluminum (20-300 t/MW),

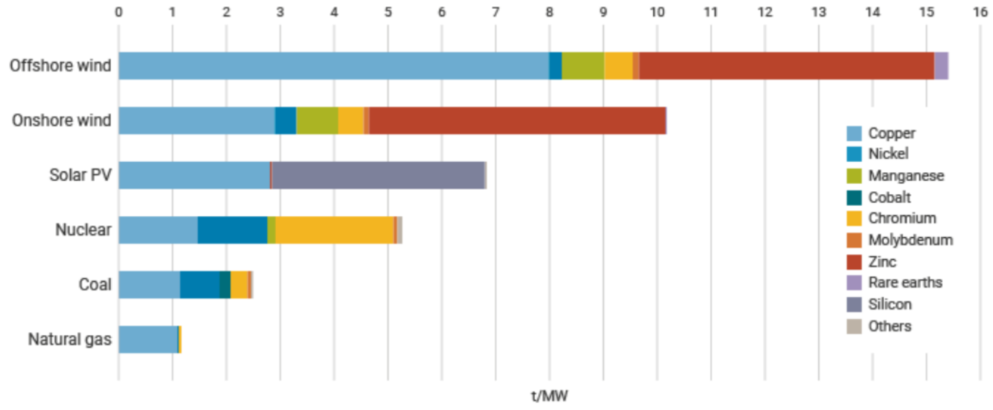

Figure 2: Critical minerals required for different generating technologies (source: IEA)

Price volatility and security of supply do not disappear during nor after the transition to a minerals based energy and transportation system

WORLD PRODUCTION AND EVOLUTION

- higher market concentration of minerals than oil
- Despite high reserves, potential shortage of extraction before 2050 of lithium, cobalt , REE (neodymium), copper...
- Every generation (20y) expected to equal all historic demand
  - Copper x2 every 25y
- competition across sectors, market driven? (i.e. nickel for steel vs batteries)

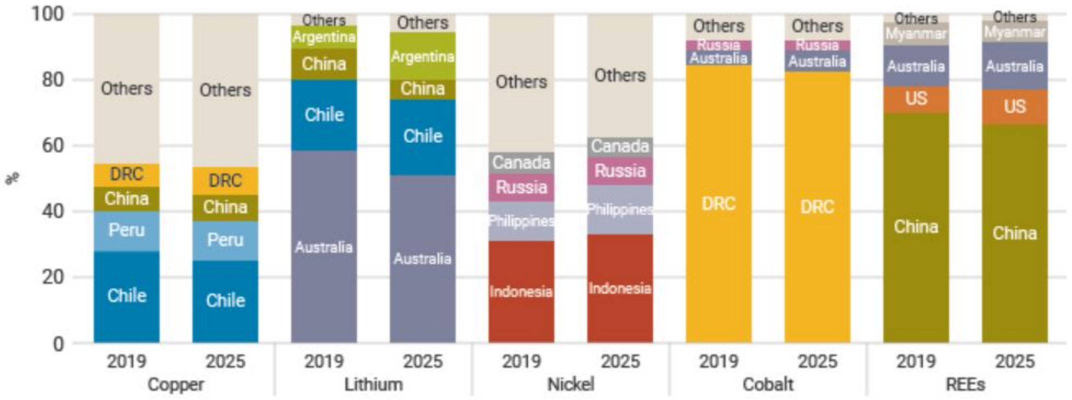

Figure 9: Sources of some critical minerals (source: IEA)

WORLD RESERVES AND GEOPOLITICS

- Resource > reserves, at high energy costs given low ore grade
  - 1% to 2% of global energy demand for copper by 2050
  - water usage, land use, biodiversity
  - environmental impact of chemicals (<0.01%?)
- Typically 30y to 400y of reserves at current rate, but exponential growth for many minerals
  - Even at high recycling, e.g. aluminum x2 every 35y vs. 40y
  - Difficult/impossible recycling for many minerals
- Geopolitics and environmental issues for ocean resources
- Ethics of production labour (e.g. cobalt)
- OPEC for minerals, shifting power to Africa-Latam? China, Russia, Australia
- 'economic colonisation' of China for raw materials ownership and processing
  - 80% of production control of REE (2011 export crisis)

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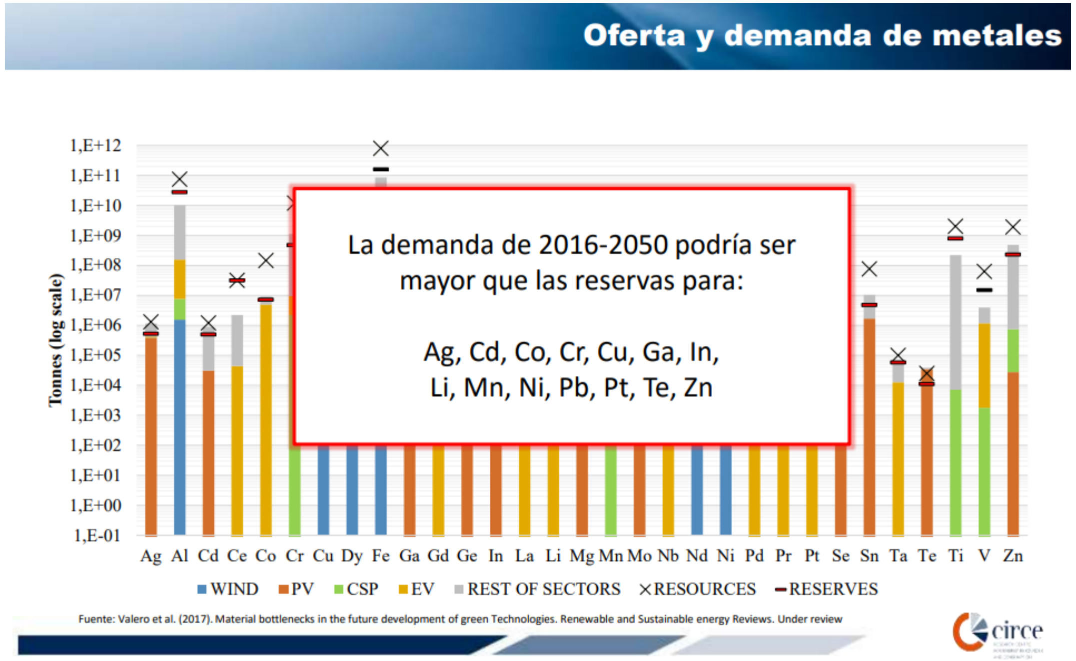
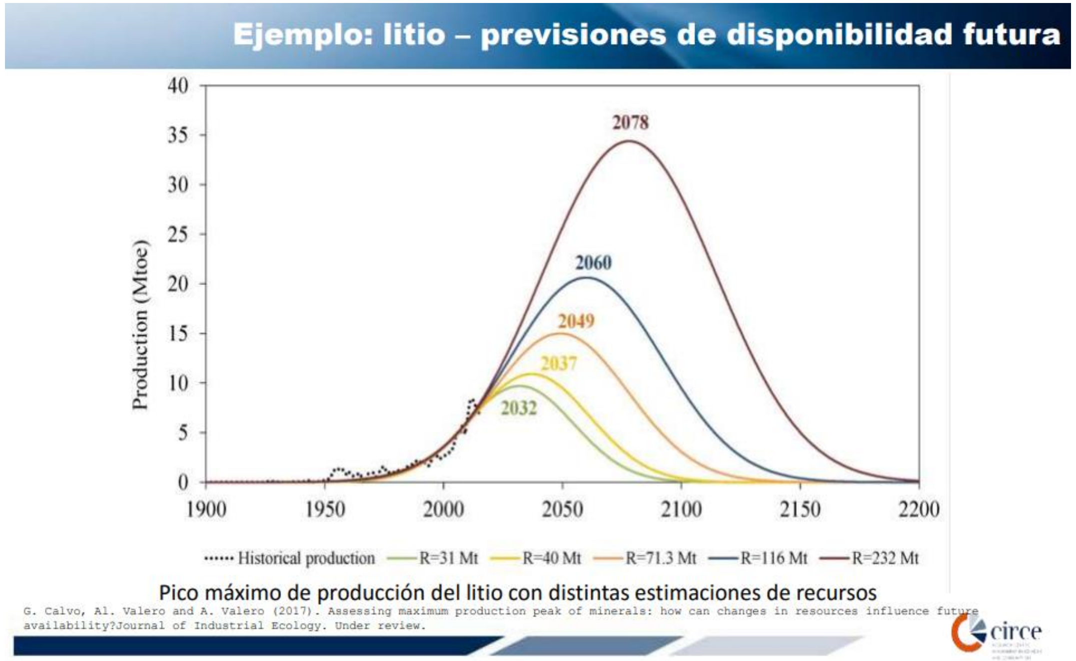
Experts project risks of potential shortage of some critical minerals before 2050 under BAU exponential growth scenarios





- Partial substitutions vs. low recycling
- New reserves and resources vs. new uses

- x2 reserves delays peak production over a decade
- rising oil consumption for rising demand

Notes: Silver, Cadmium, Cobalt, Chromium, Copper, Galium, Indium, Lithium, Manganese, Nickel, Lead, Platinum, Telurium, Zinc
Source: Alicia Valero (Circe)

Other social concerns about nuclear

- Nuclear waste vs waste of alternative scenarios
- Risks of nuclear accidents
- Nuclear weapons proliferation
- Dependency on minerals for RES
- Diversification of fuel risks
- Construction time / Construction & Operational costs
- Social acceptance

It is possible to reduce the contribution of nuclear in the Spanish mix but...

1. Security of supply:
   1. nuclear has high contribution to SoS, which is not replaced by equal RES energy
   2. high storage capacity with >4h is required to keep similar SoS standards
   3. the speed of deployment of economic RES capacity required without nuclear is questionable
   4. grid stability studies will be required, based on a realistic capacity scenario

2. Market behaviour
   1. higher use of CCGTs even if additional RES is built to compensate nuclear energy loss
   2. annual prices and carbon emissions are projected to increase

3. New dependencies
   1. (much) higher mineral requirement per MWh by RES over nuclear
   2. understand exposure to availability of minerals during 30+ years of Energy Transition

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