Spanish wholesale electricity price dynamics

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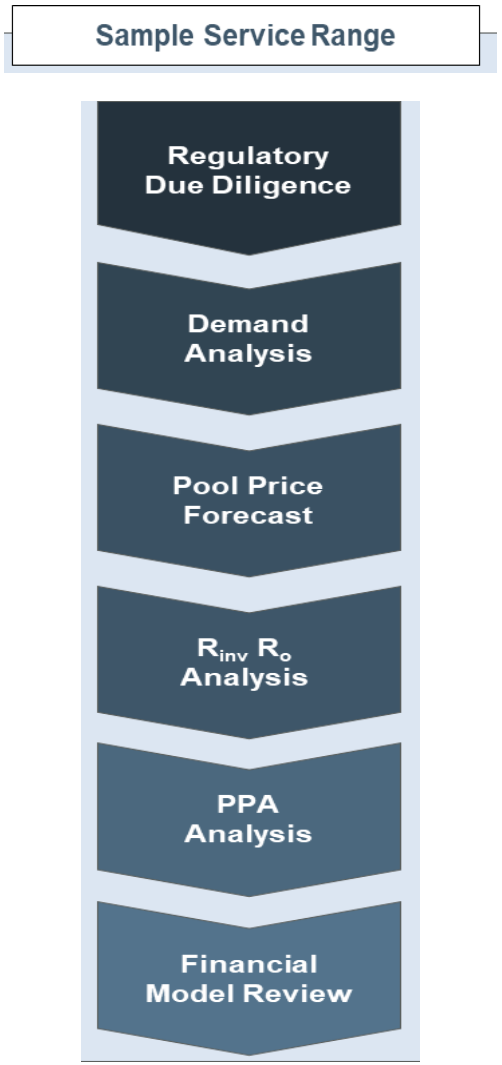
K4K services

- Broad range of services to financiers, utilities, IPPs and governmental agencies.
- Team background in energy consulting and strategic advisory.
- Regulatory and market due diligence reports that are relied upon by lenders.
- Supported successful completion of 72GW with a transaction value of US$44 billion, including 15GW in Spain.
- Recent Iberian track record developed as market modelling director of EKON Strategy Consulting during 2015-2022. EKON now a registered brand of K4K.



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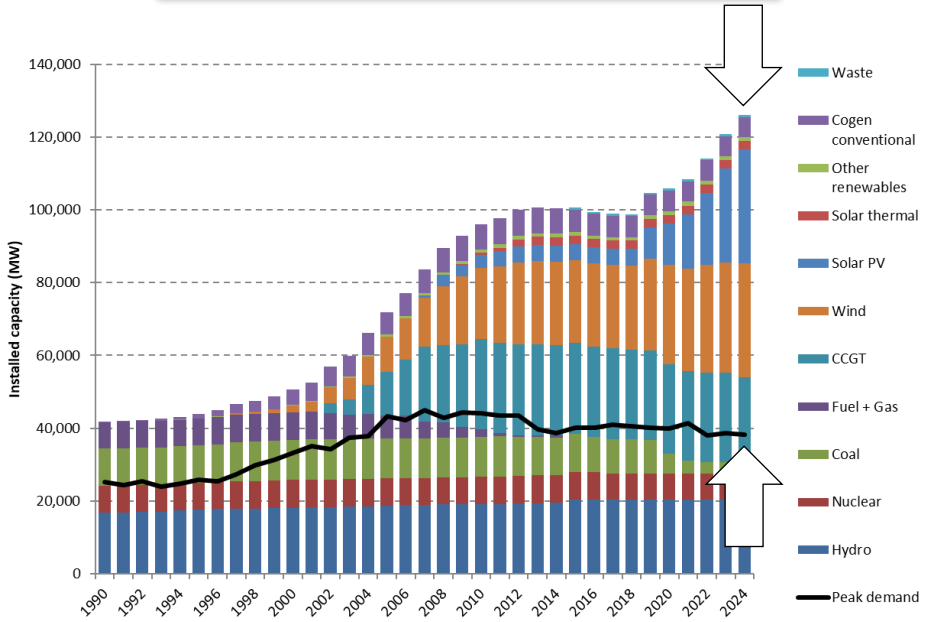
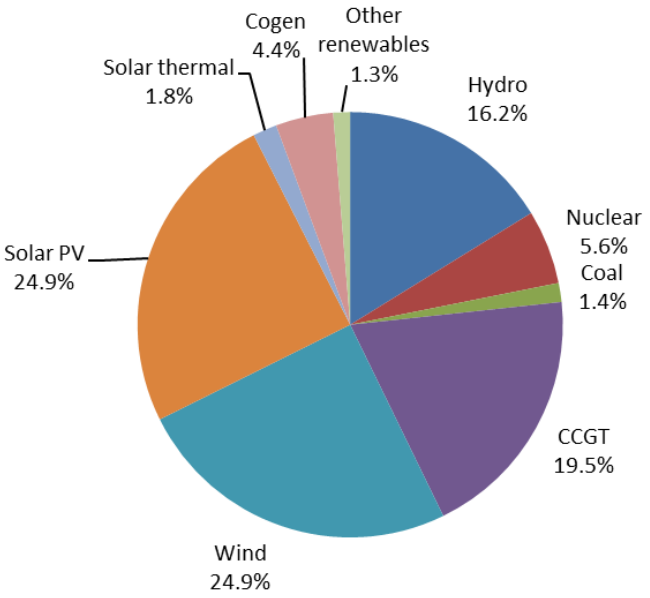
Historical capacity mix

- We are not building renewables cause the lights are about to go out…

Evolution of installed capacity



Capacity mix (end 2024)



Source: REE and K4K calcs.

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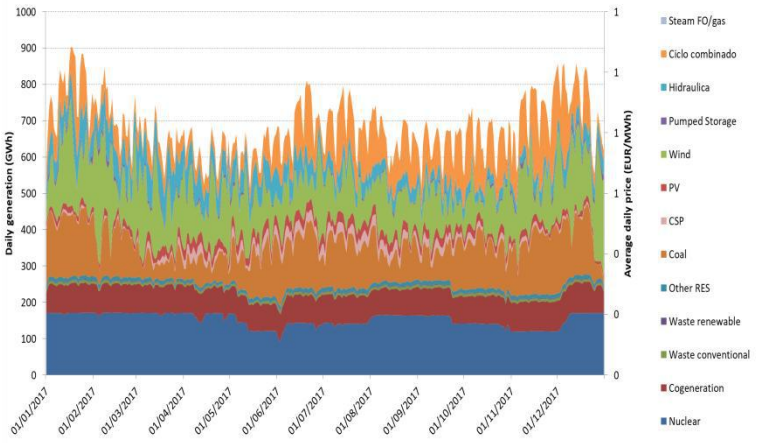
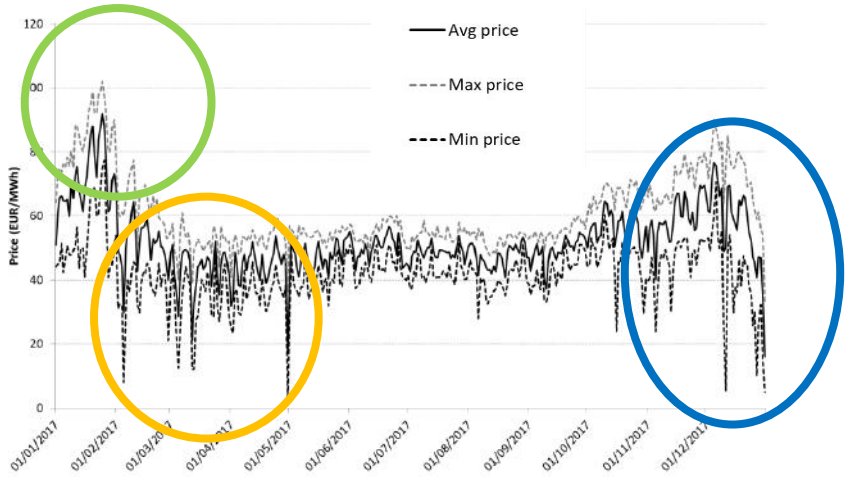
What to make of market outcomes?

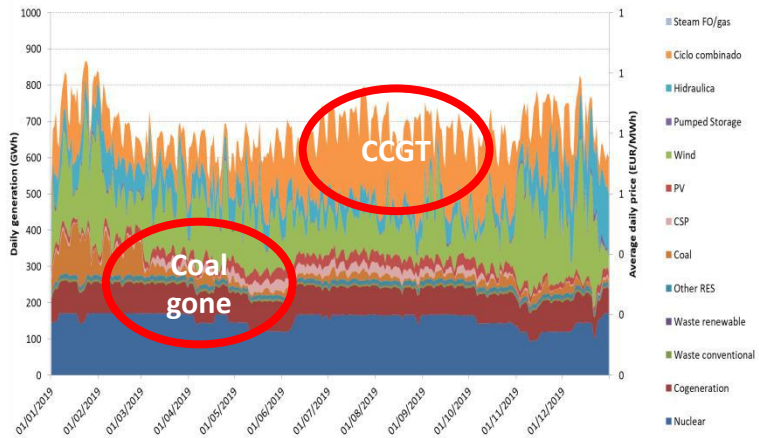
- Hourly data for 2017 and 2019 shows volatility of market prices and generation.

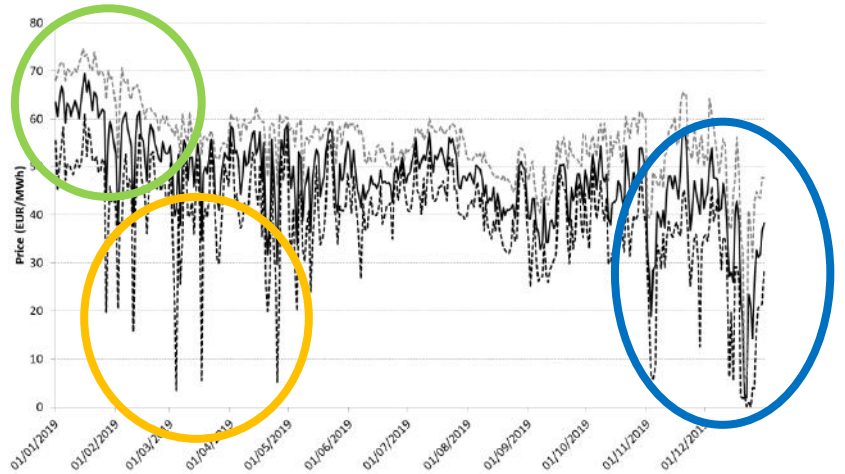
2017





2019





Source: REE ESIOS.

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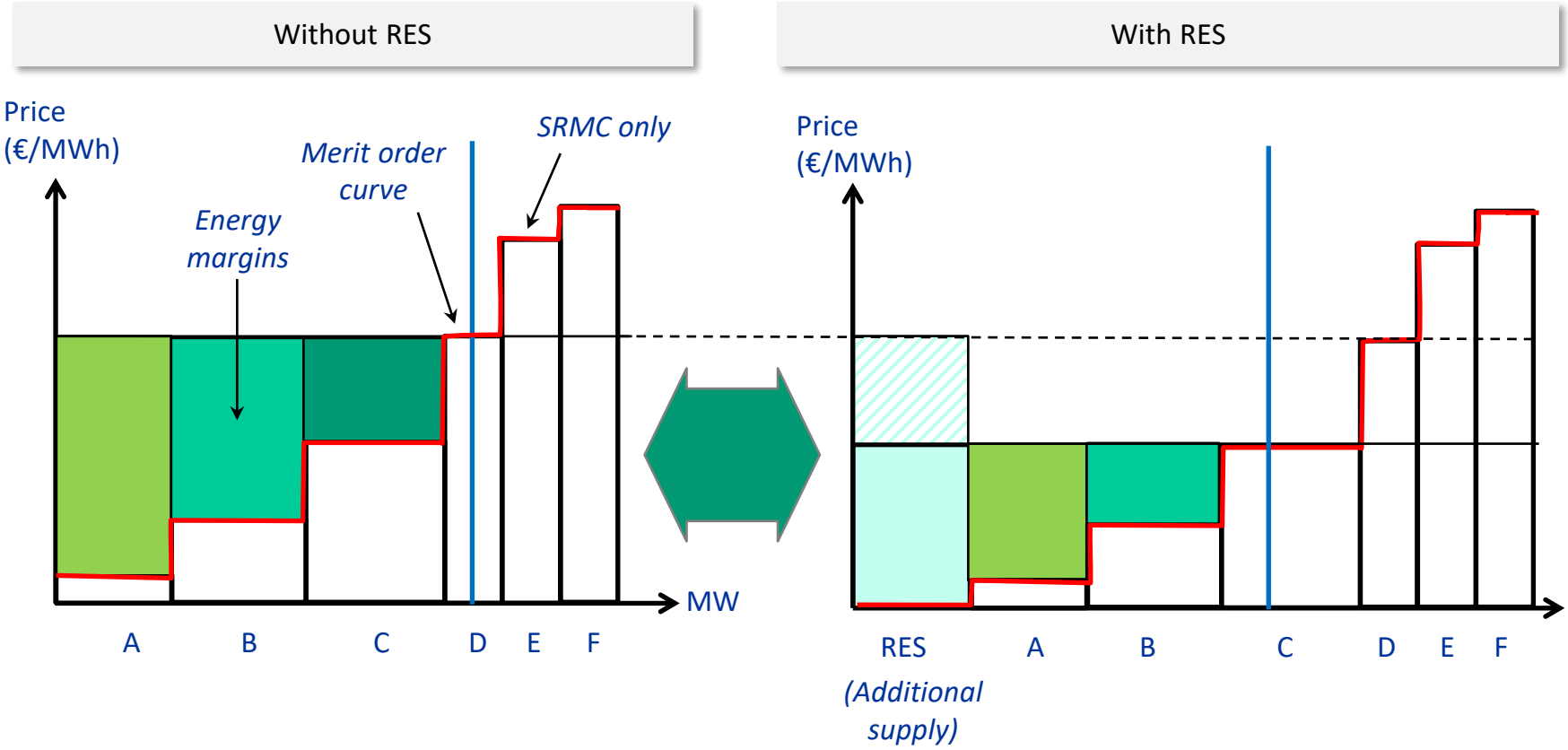
The chicken (duck?) and egg problem…

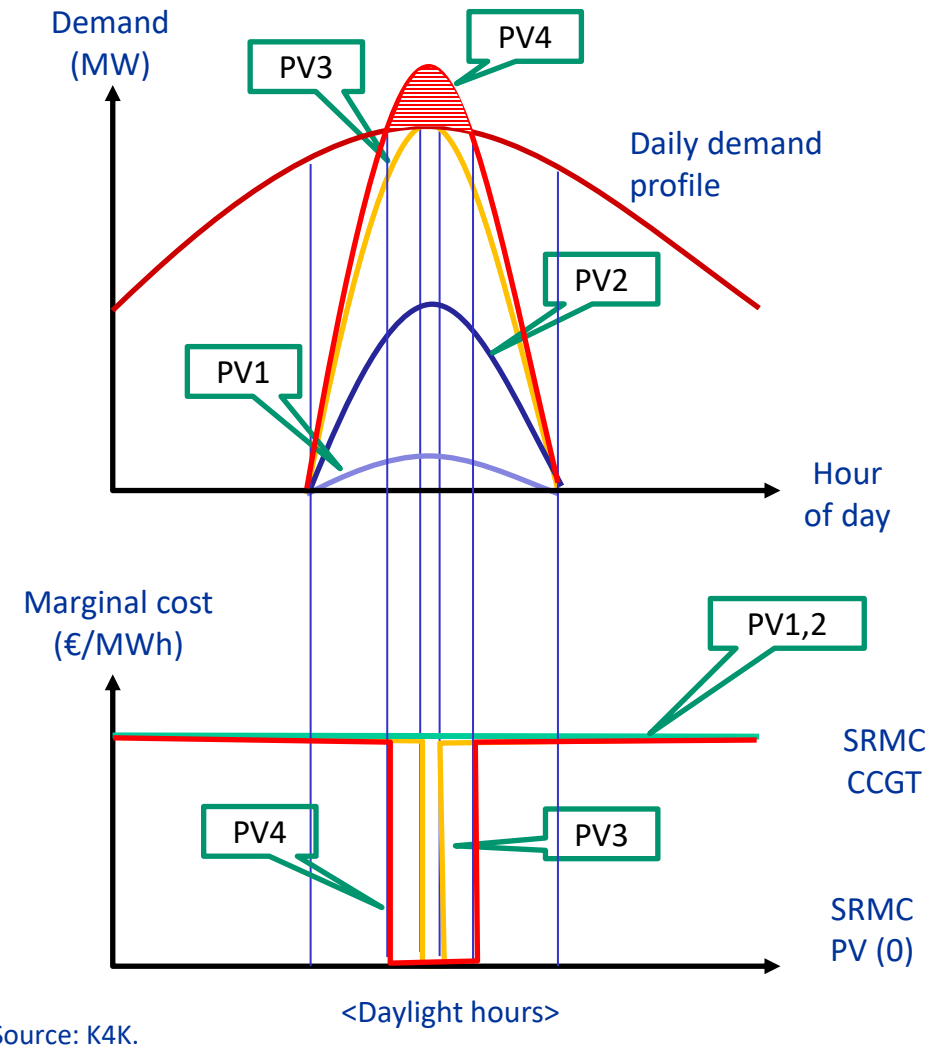
- Market participants make an assessment of profits from the energy market. Renewables energy sources ("RES") are price takers but will still affect market outcomes thereby reducing their remuneration the more they produce.



Source: K4K.

Recap https://www.youtube.com/watch?v=pHrUIGTlqt4.

PV saturation when realised price of PV = LCOE



- Consider simple 24-hour set-up with gas-fired CCGT. As you add PV capacity (PV1, PV2) prices will still be set by CCGT. After a point, the prices drop.
- After market reaches saturation point, there is no commercial incentive to build more PV. (Note that this point has no "missing money" problem, which happens when deployment is pushed beyond this limit .)
- Note that excess generation forms part of the market equilibrium!

Source: K4K.

Recap https://www.youtube.com/watch?v=pHrUIGTlqt4.

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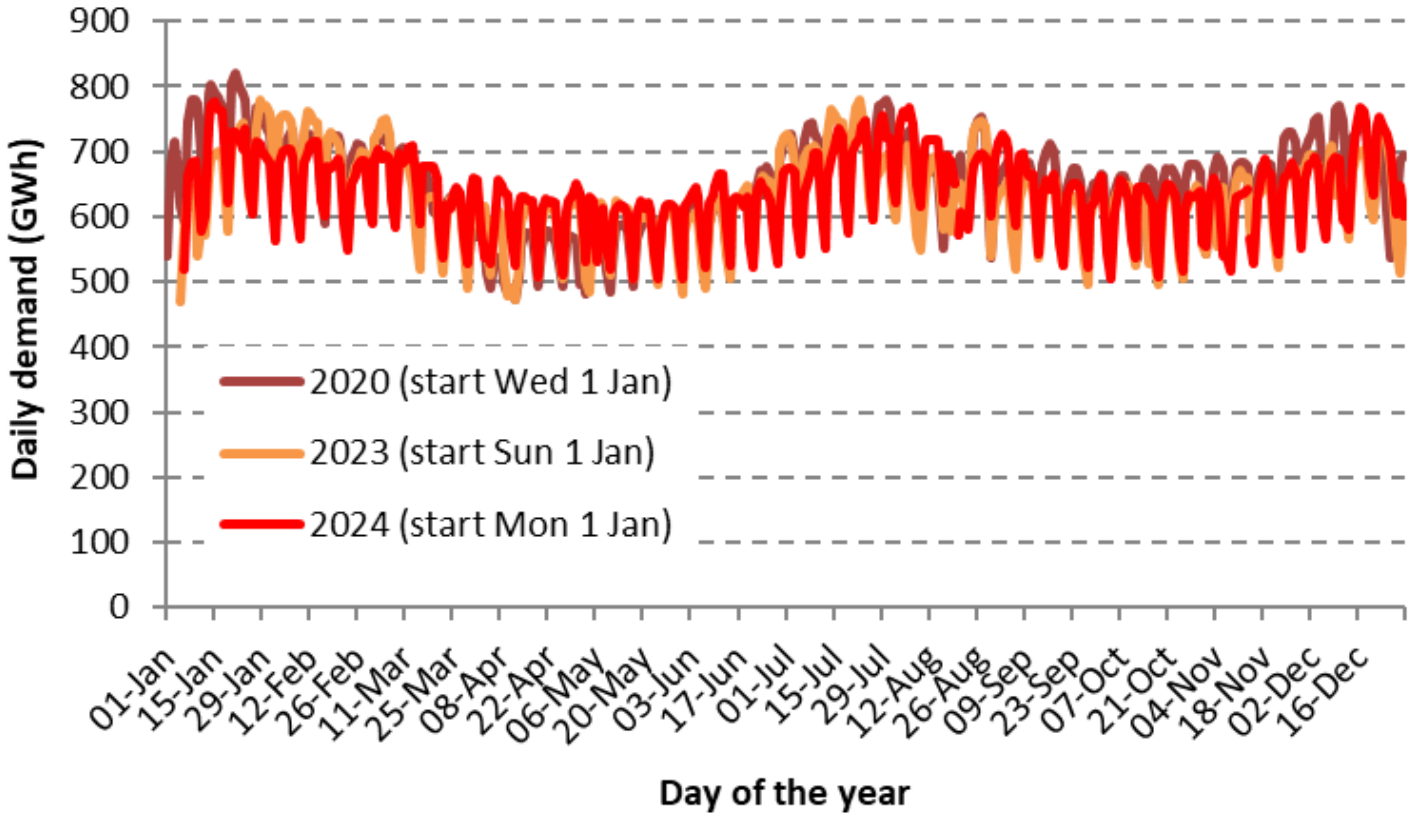
Evolution of demand in 2024

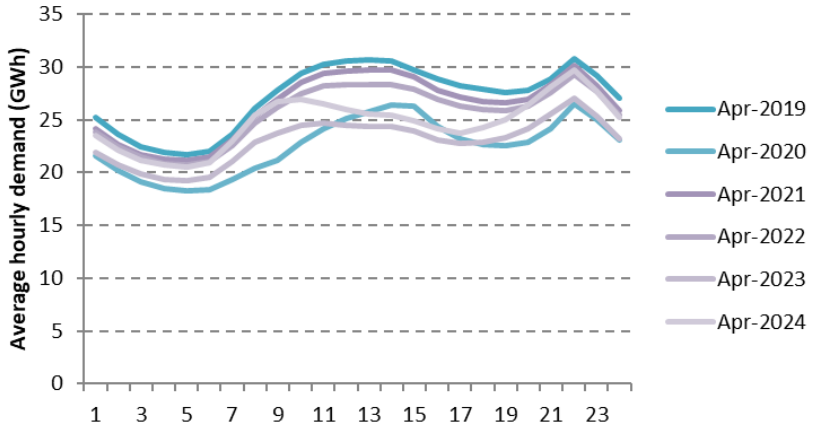
- Below shows REE daily demand (synched by weekday) for mainland Spain in 2020, 2023 and 2024. On cumulative basis, mainland demand in 2023 was 2.41% below that in 2022 but in 2024 it was 1.51% higher than in 2023. That said, demand in 2024 was still below (-1.43%) demand in 2020 when impacted by COVID-19.

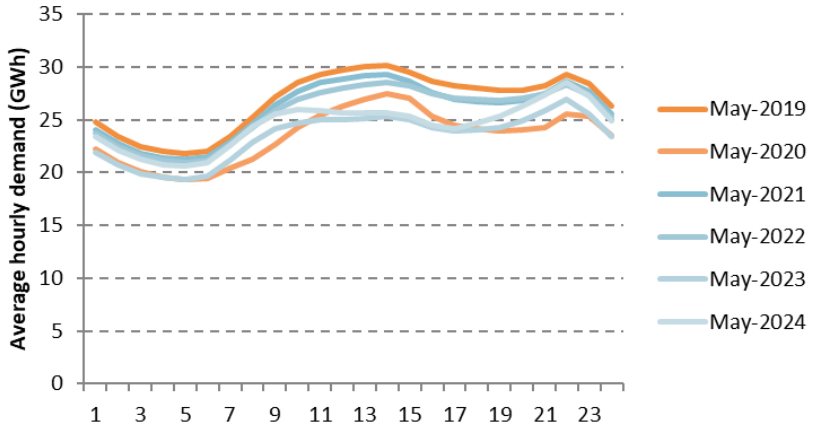


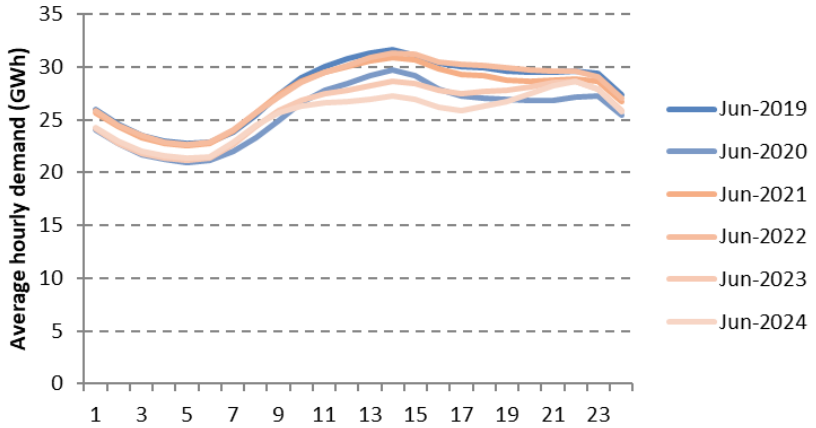
Source: REE and K4K calcs.

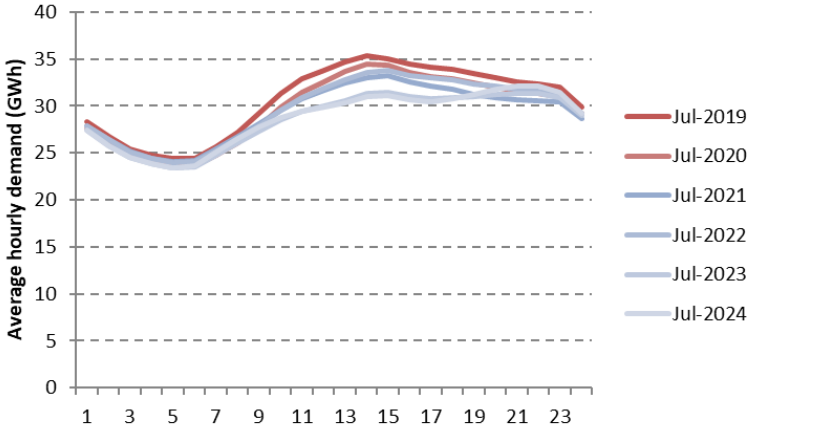
Changing load profile over time

- Charts below profile average hourly demand in April through July 2024. Demand is noticeably lower in the middle of the day. This could be explained by the increase in autoconsumption, mainly rooftop solar.



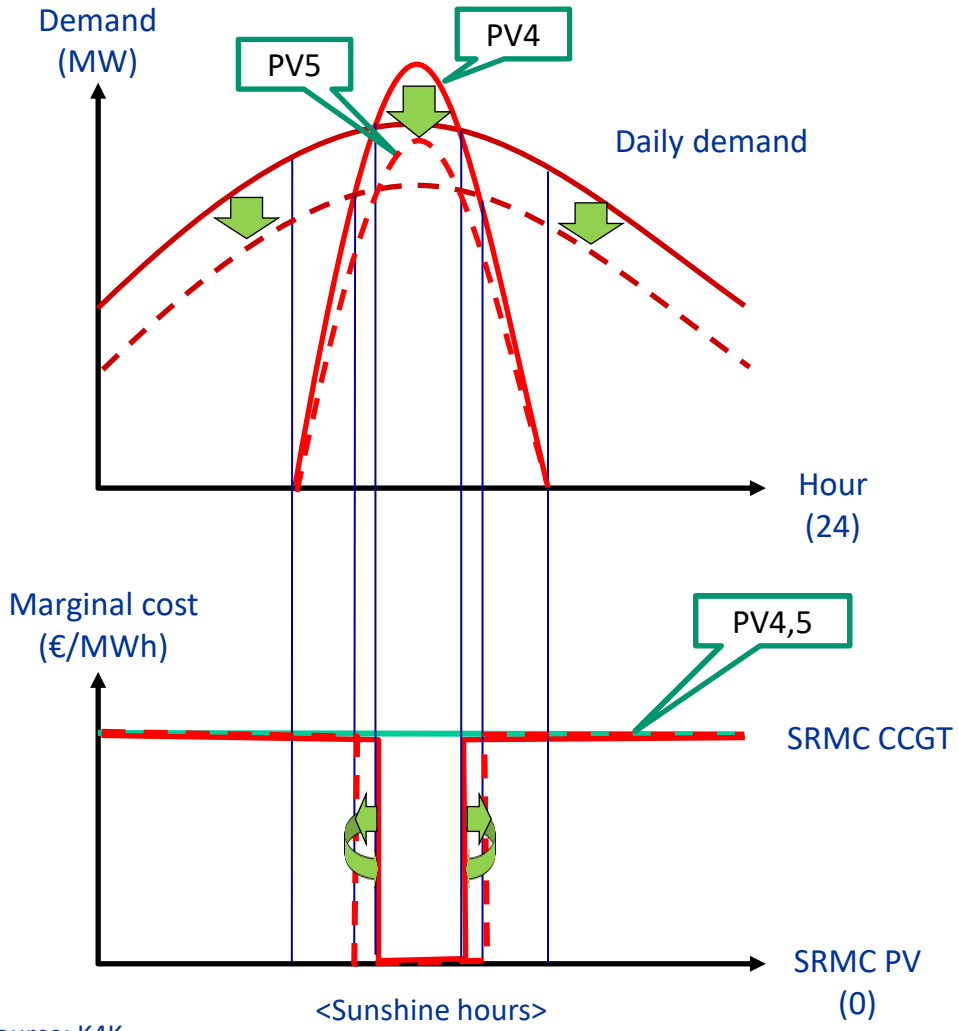






Source: REE and K4K calcs.

What happens when demand falls?



Source: K4K.

- If the demand falls and the capacity is equal to that of the starting point, there will be more hours with a low price.
- The solution is to decrease the penetration of PV so that the PV realised price does not fall below the Levelised Cost of Electricity ("LCOE").
- Notice that the distribution of prices (positive vs zero prices) is the same with CCGT retaining pivotal role!

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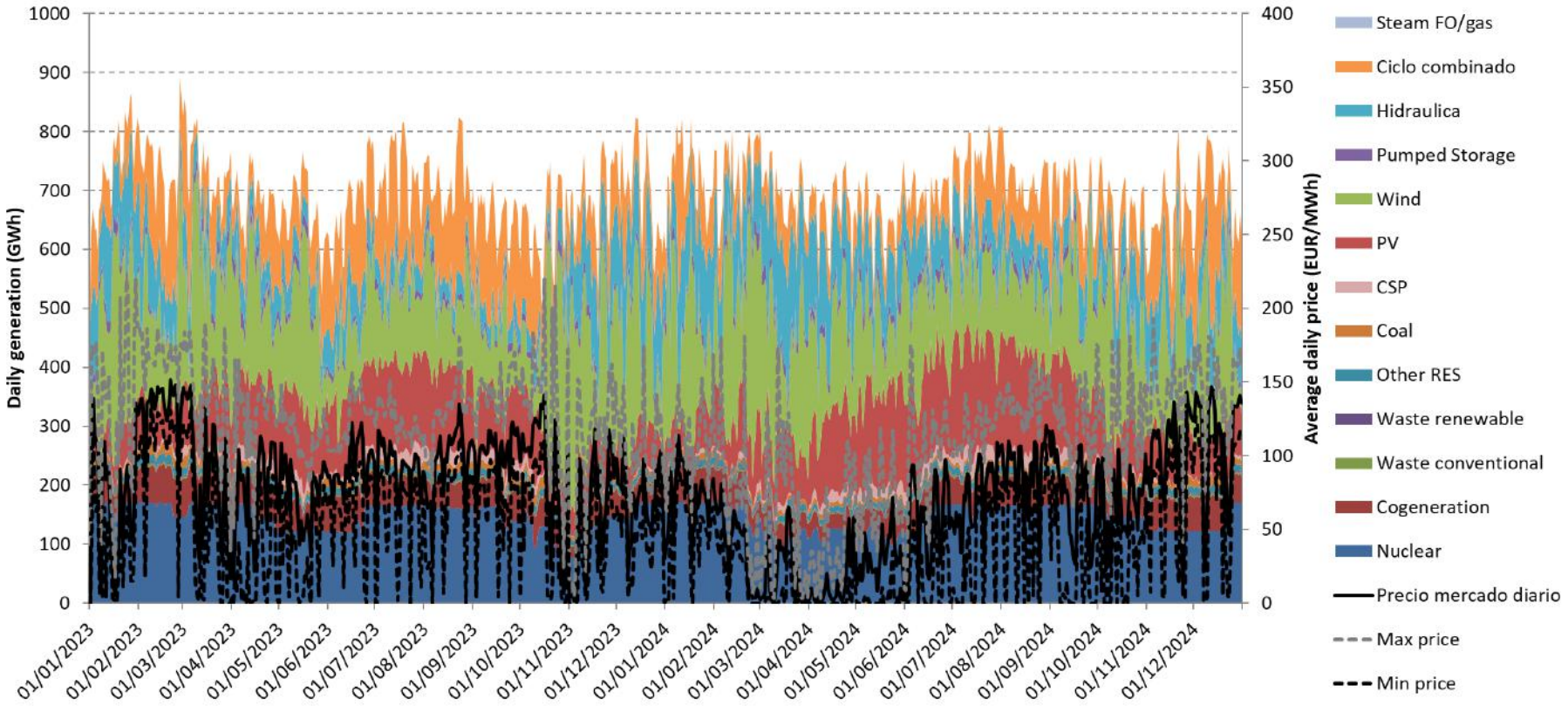
Evolution of generation and prices (1)

- Daily dispatch by technology and average daily spot prices for Spain in 2023-2024. If you look carefully one can see how the market works…
- Note the large amount of wind, flexibility of nuclear, and continuing balancing role of gas-fired CCGT.



Source: REE and ENTSO-E.

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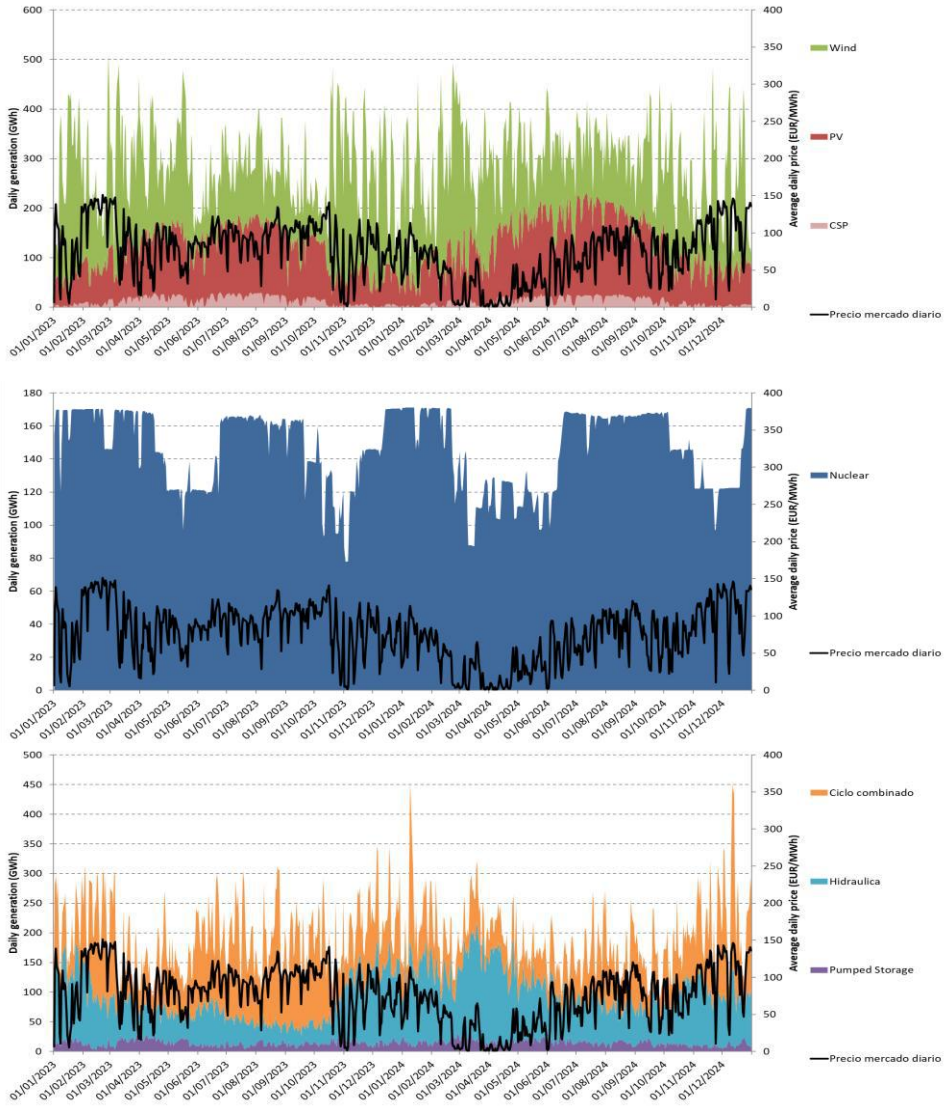
Evolution of generation and prices (2)



Source: REE and ENTSO-E.

- Renewable (especially wind) generation is inversely correlated with average spot prices. You can see the same thing at the hourly level.
- Programming of nuclear generation has proven to be flexible, even if this is less obvious at the hourly level. There is a price below which nuclear might reduce dispatch (~15€/MWh).
- CCGT retains balancing role with prices positively correlated with gas prices:
  - Electricity price (€/MWh)= 2.4 * gas price (€/MWh(f)) before June 2022.
- Flexible hydro always tends to shadow price of next most expensive flexible technology, i.e. CCGT, so dispatch of flexible hydro and CCGT positively correlated with prices. (Note that too much must-run hydro will depress prices.)

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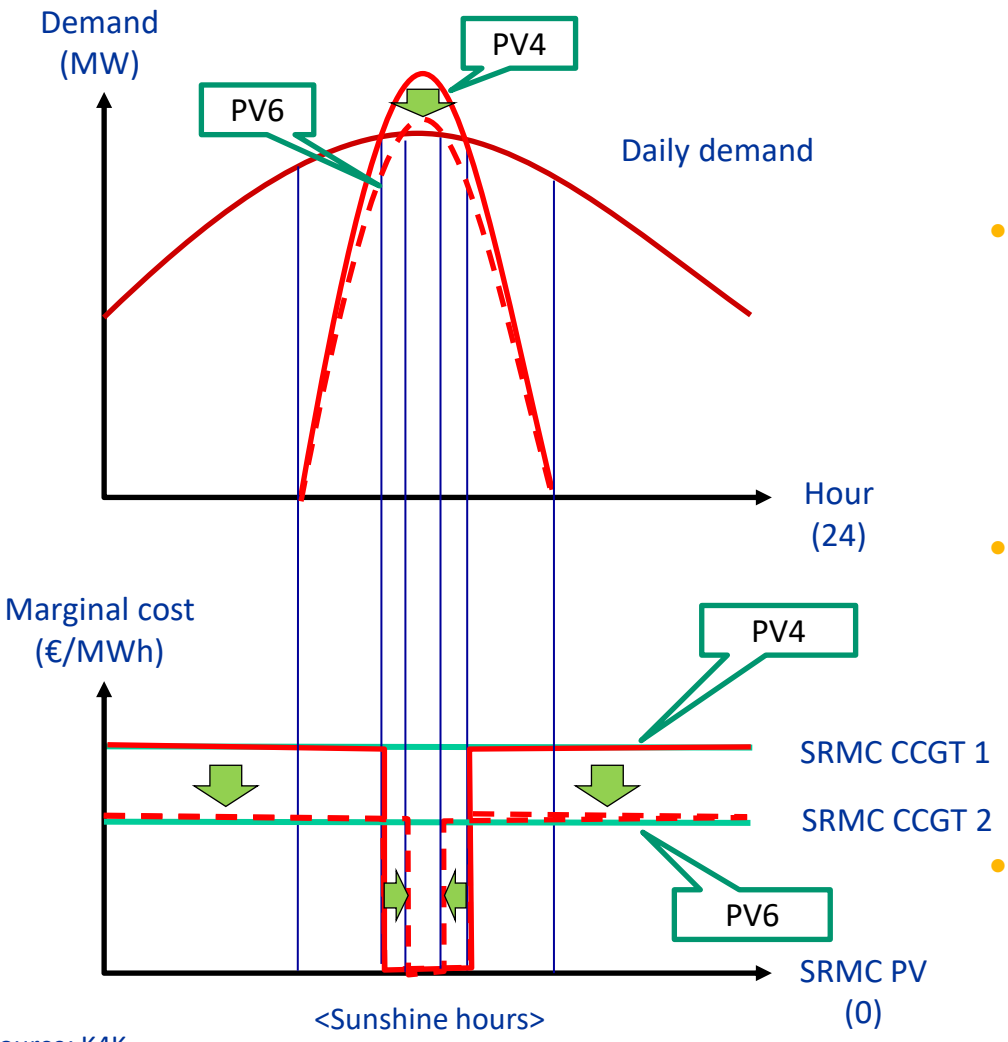
What happens when conventional generation cost falls?



Source: K4K.

- If the cost of generating with a CCGT falls - caused by a decrease in the price of natural gas or the cost of CO2 - prices in all hours of PV operation will fall.
- The New PV cannot survive with the same number of very low priced hours, so the penetration of PV must be reduced so that the PV realised price does not fall below the LCOE.
- You have to "close the curtain": the percentage of low prices has to drop enough for the realised price to stabilise at the LCOE. Means market can absorb less PV than before!
- Do we need to reassess 2030 targets and levels of support?

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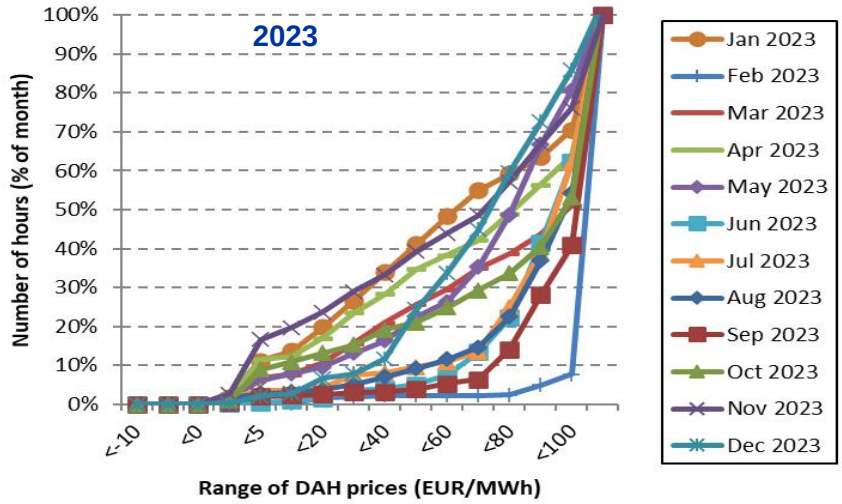
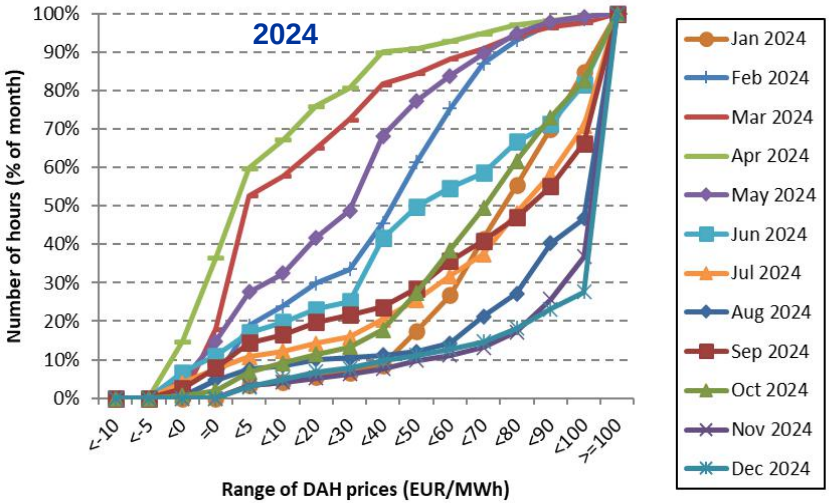
Distribution of hourly DAH pricing is changing rapidly





- As intermittent renewables play a more important role, market prices have dropped with noticeable increase in the number of low prices hours.
- Prices below 5EUR/MWh made up 6% of hours in 2023 but 19% in 2024.
- In contrast to other European markets, negative prices are uncommon probably explained by greater flexibility in the power system, peculiarity of the Specific Regime to support historical renewables, and increasing use of exemption clause in PPAs that will not clear if prices are zero or negative.

Source: ENTSO-E, K4K calcs.

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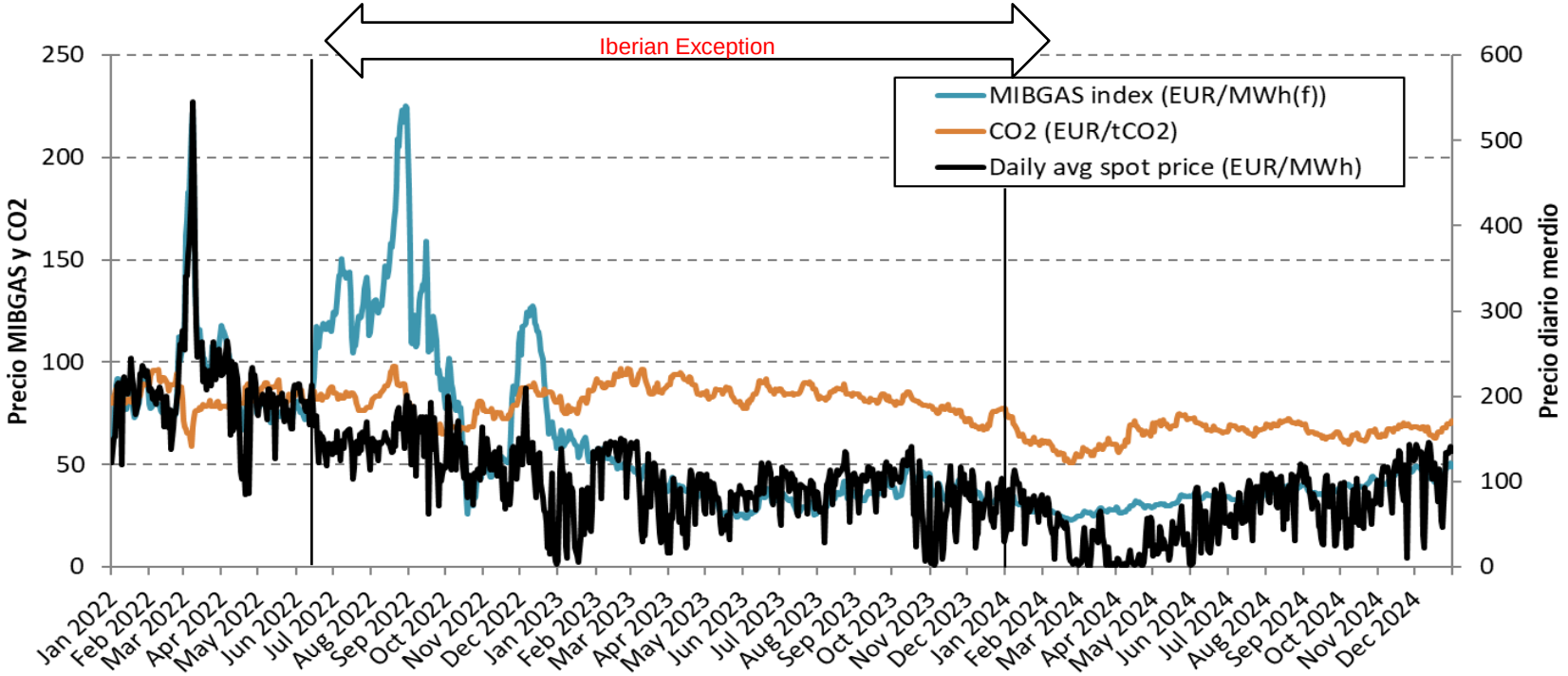
Higher prices can lead to regulatory intervention

- Spanish government responded to high wholesale prices by implementing series of short-term executive measures including a windfall profit tax (starting with RDL 17/2021) and a cap-on-gas (starting with RDL 10/2022). Both lasted until 31 Dec 2023.
- The cap-on-gas, also known as the "Iberian Exception", led to a significant reduction in spot prices although it had no effect after 26 Feb 2023 since gas prices were below the regulated gas price. The windfall profit tax had a benign impact on prices although generators would have been impacted depending on specific circumstances.



Source: MIBGAS , ENTSO-E and K4K calcs.

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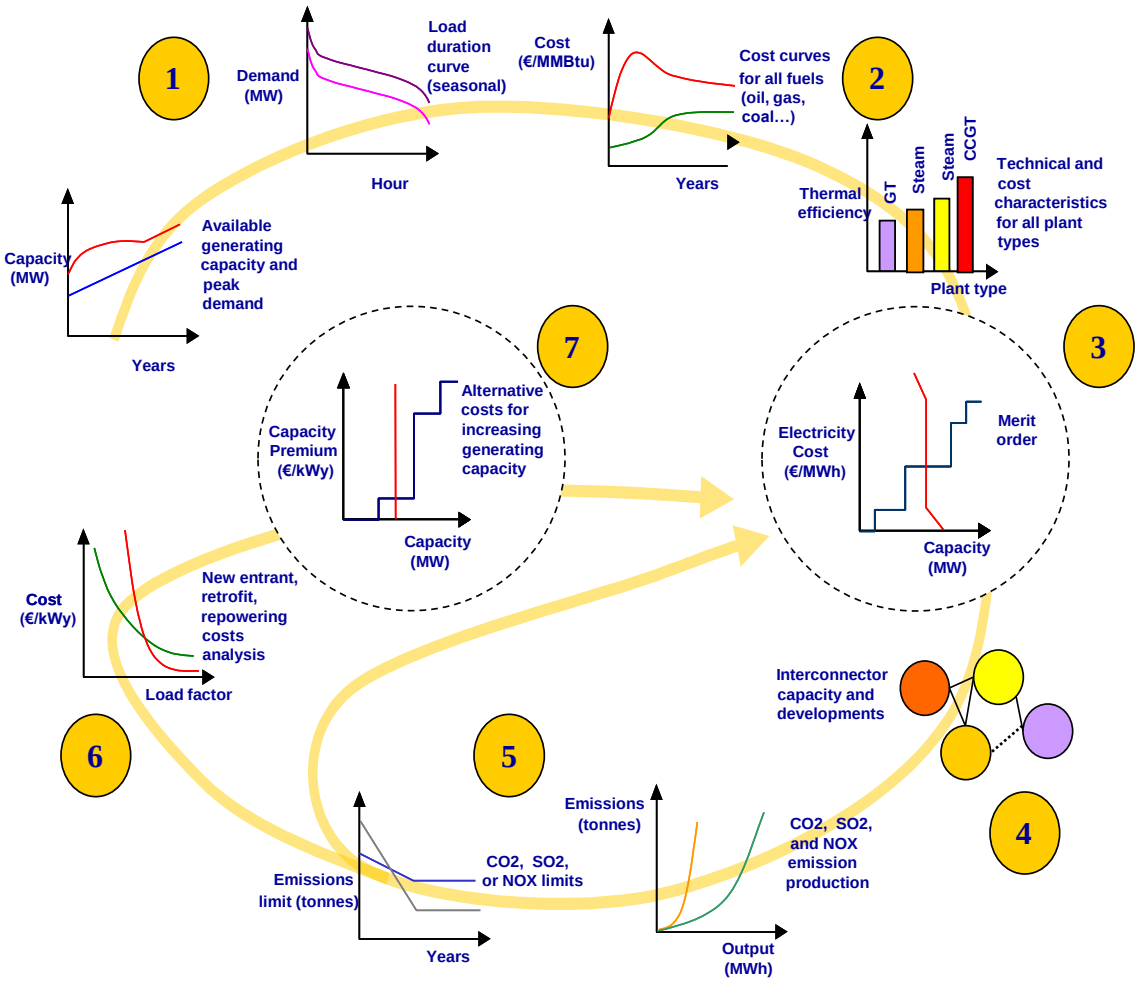
PMM in a nutshell

- PMM (Power Market Model) is designed to replicate the operations of the actual power system about which one is concerned.
- By including the economic and environmental constraints facing market participants in the real world, PMM replicates how actual decisions are made by stakeholders when subject to any slate of operational constraints, regardless of whether these constraints are physical, economic, or environmental.
- And everything in MS EXCEL.

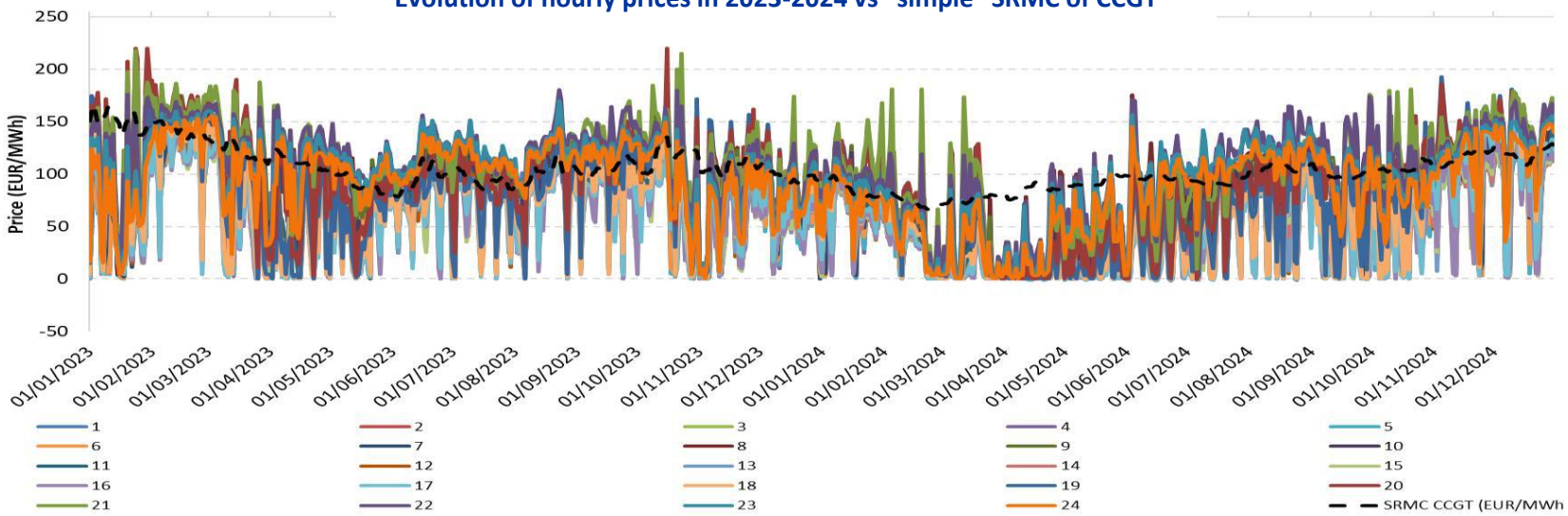


Modelling innovations adopted for 2025Q1

- Every quarter we update a series of standardised inputs which are summarised in the table in the next slide. But from 2024Q2, we have also incorporated a series of additional changes worth highlighting separately:

1. "Autoconsumo" adjustment– Demand is modelled on REE data which excludes the impact of behind-the-meter rooftop solar ("RTS"). To reflect additional cannibalisation of demand by RTS, based on APPA data, we have added 8,315MW of RTS by end of 2024 and adjusted REE annual demand upwards to reflect RTS's contribution based on EOH of 1,197, which would be lower than existing or New PV. We do not increase RTS over time but accommodate it as part of Firm and Economic New PV.
2. Gas TPA tariff up from 2 to 6 and then 10EUR/MWh(f) for 2025Q1– As CCGT dispatch has dropped, there has been an increase in offers above "simple" SRMC (=MIBGAS price / thermal efficiency of 50% + 0.4 (Carbon Emission Factor) * EUA price) as suggested by the chart below. This behaviour could also be explained by CCGT aiming to recover start-up costs over fewer operating hours, wear and tear from cycling, strategic bidding, etc.
3. Demand growth=1% in Central and High Cases, and 1.25% in Low Case – To accommodate higher degree of electrification (influenced by, though not following, the updated draft PNIECs).
4. Maximum instantaneous dispatch of flexible (pondage) hydro plants ("Pmax") reduced - From 2.0 to 1.5 * minimum dispatch ("Pmin") to reduce the degree of peak shaving to reduce the degree of intra-seasonal price flattening.
5. Increased competiveness of battery systems - Adjusted downwards TIC New Battery to 750EUR/kW, equal to TIC of New PV.

Evolution of hourly prices in 2023-2024 vs "simple" SRMC of CCGT



Note: Prices spiking above SRMC of CCGT implies offers made at a premium over pure commodity gas+CO2 cost.
Source: MIBGAS, Sendeco2, ENTSO-E, and K4K calcs.

Overview of Sensitivities

	Low Case *(Low1_20250205)*	Central Case *(Ref1_20250205)*	High Case *(High1_20250205)*
Fuel prices	Gas price cap, MIBGAS/TTF until 2027, CME futures	MIBGAS/TTF until 2027, CME futures	MIBGAS/TTF until 2027, CME futures
CO2 (EUA prices)	ICE futures	ICE futures	IEA WEO 2023 Announced Pledges
Domestic coal surcharge	None	None	Applied
IED coal output cap	None	None	Annual output caps applied
Generation Tax (7%)	None	7.0% in '25, 3.5% in '26 only	7.0% in '25, 3.5% in '26 only
Demand growth	1.25%	1.0%	1.0%
Green Cent Tax	None	Applied to Coal	Applied to Coal
Annual hours for New PV	2050	1736 (historical)	1736 (historical)
Annual hours for New Wind	3000	2500	2167 (historical)
TIC of New Wind , PV and Battery (€/kW)	-20%	1000/750/750	1000/750/750
Annual cap on economic New Wind/PV	3/4GW from 2025, uncapped from 2031	2.0/2.0GW from 2025	2.0/2.0GW from 2025

Most important

Note: Prices real 2025€.

- NECP growth rates. Brent, coal and CO2 prices based on CME and ICE futures. Gas indexed to oil from 2028 but linked to MIBGAS in 2025-2026 and TTF in 2027. RDL 10/2022 gas-indexed subsidy extended in LC although low gas prices mean no impact.
- HC applies coal transportation surcharge for domestic coal and a more restrictive view of Industrial Emissions Directive ("IED").
- Generation tax removed due to over-recovery in 2021-2022 and national fund (FNSSE).
- "Firm" additions in 2025 of 2.0GW New PV in CC and HC. Apply annual caps on the deployment of other "economic" New Wind and PV until 2030 in the Low Case but forever in other cases. No cap on New Battery.

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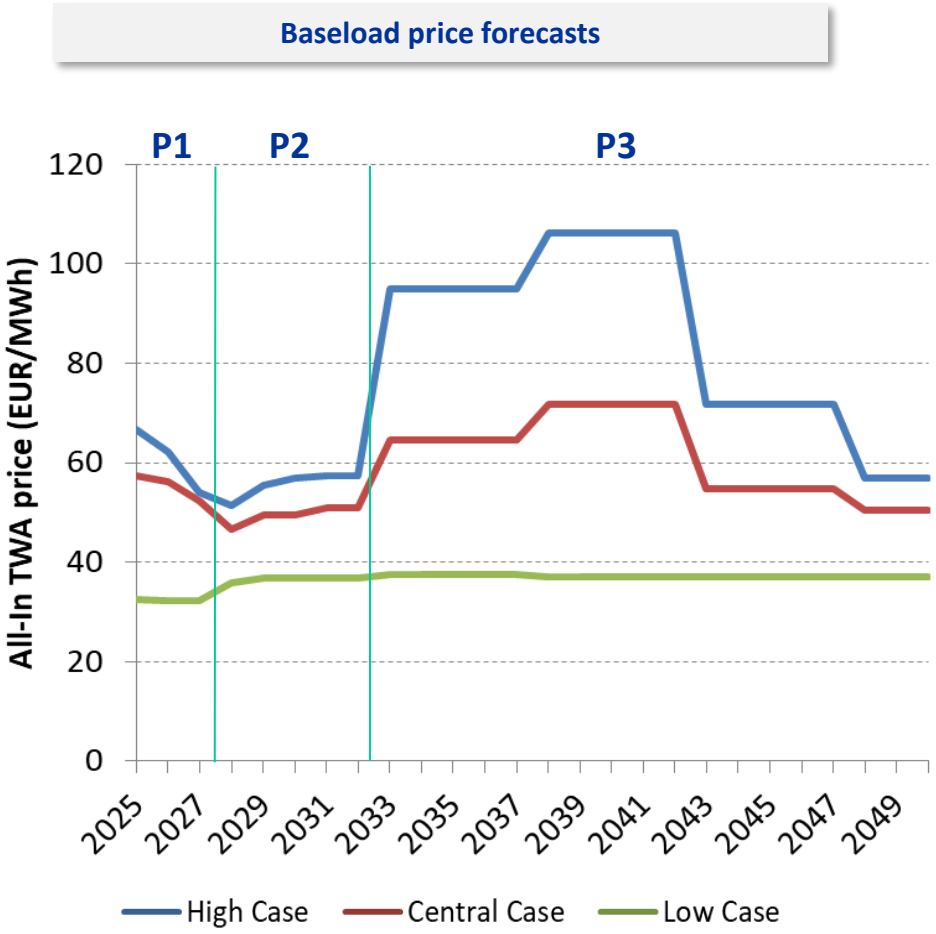
Market price forecasts



- Prices first move in line with commodity prices and adjust to new additions (P1) and then plateau (P2).
- As a lot of thermal capacity retires in the 2030s, a step-up in prices is expected in the Central and High Cases (P3).
- But even in these cases, renewable capacity eventually catches up and prices drop.

Source: K4K 2025Q1. Prices real 2025€.

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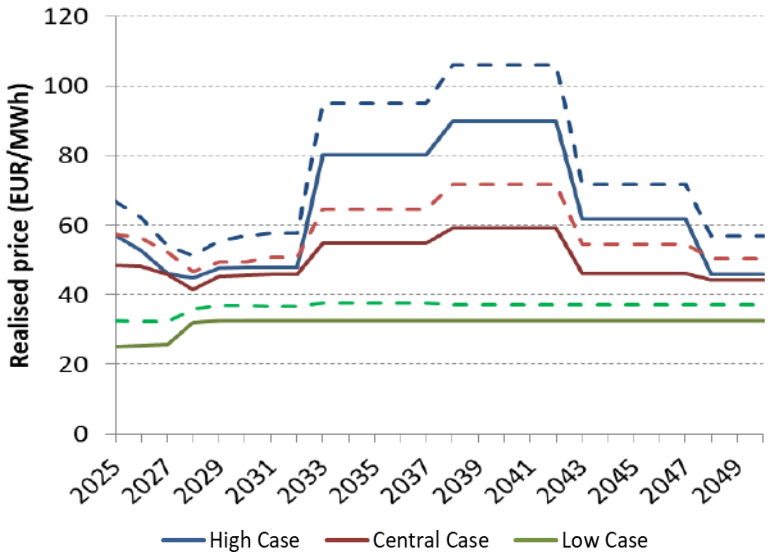
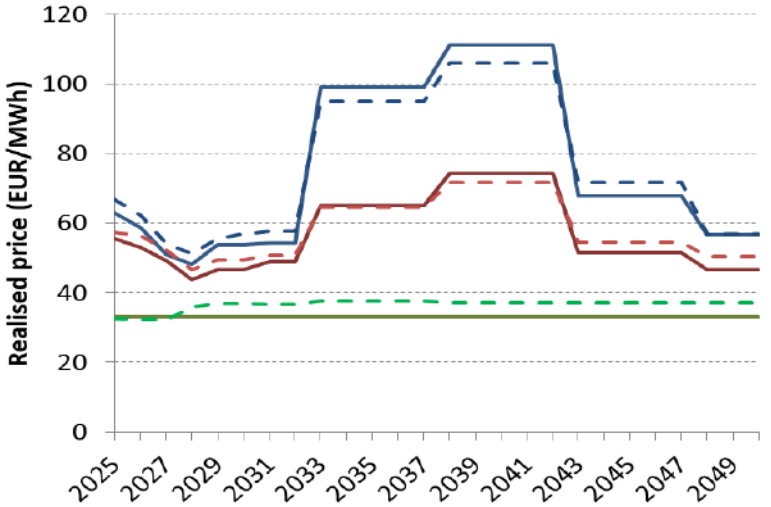
Realised price forecasts

- The PV and Wind Capture Prices track the market price. But as more renewable capacity is introduced, the Capture Prices tend to drop below the baseload price.
- K4K remains optimistic that profitability of renewables will be satisfactory. But we are also more pessimistic since we do not believe that market conditions (grid and planning constraints, project "bankability", liquidity of PPAs, etc.) are adequate to reach the government's aggressive capacity goals under the NECP.

PV Capture Price



Wind Capture Price



Source: K4K 2025Q1. Prices real 2025€. Dashed line = Baseload prices.

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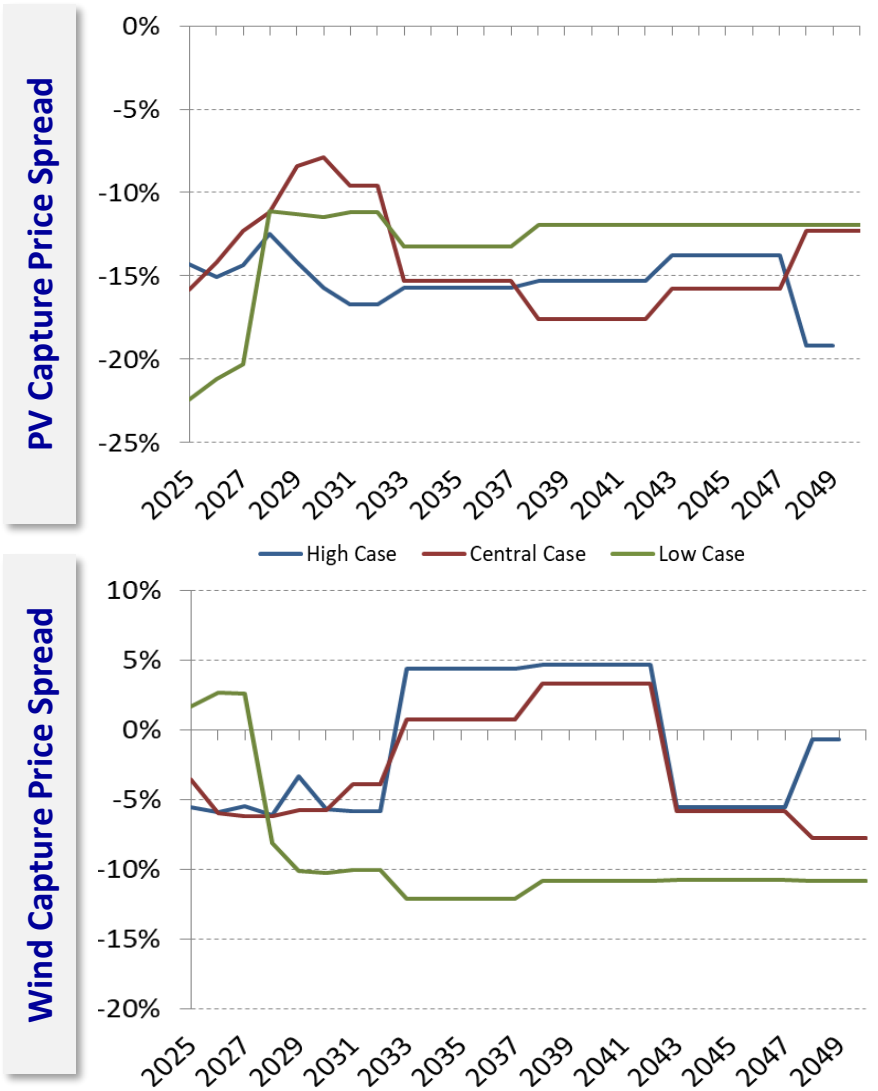
PV and Wind capture price spreads

- K4K predicts that the PV Capture Price Spread will drop to between -10% and -20%. The Wind Capture Price Spread will fall less.
- When New PV and New Wind capacity are deployed until the Capture Prices converge on LCOE levels, since New Wind is "quasi-baseload" (since the wind blows both during the day and at night), then
  - Wind Capture Price Spread = ~0
  - PV Capture Price Spread = ~(LCOE PV – LCOE Wind) / LCOE Wind



Source: K4K 2025Q1.

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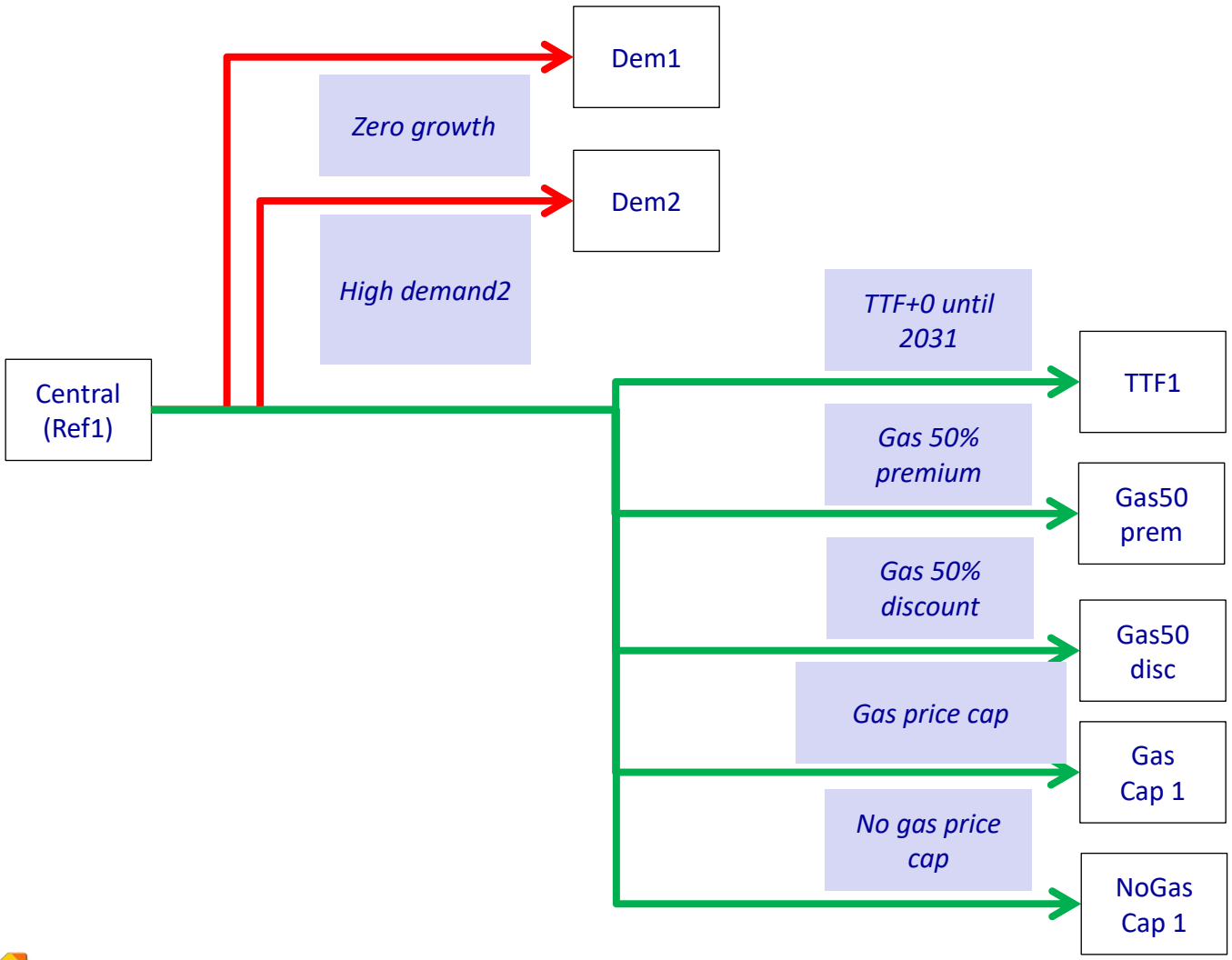
Using the PMM to test different hypotheses

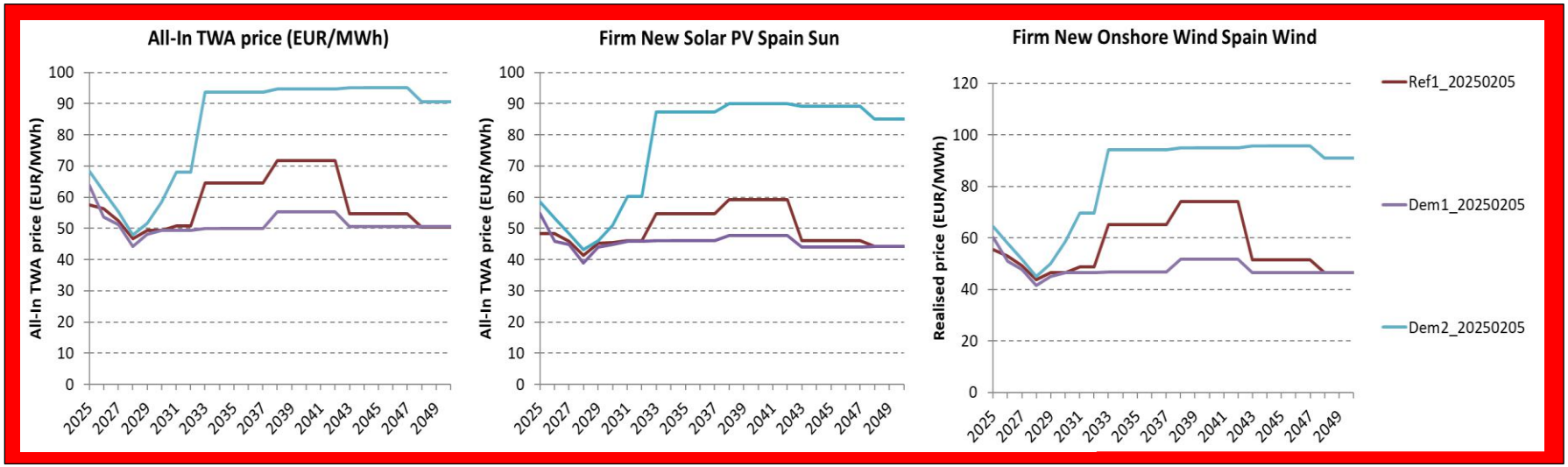
- We had plenty of questions at the end of this exercise so we went ahead and ran some path-specific sensitivities to explore what could affect market and realised prices most. This was done by defining a series of changes - shown below - and applying them in a cumulative manner to the Central and Low Cases. We also defined two Combined Cases.

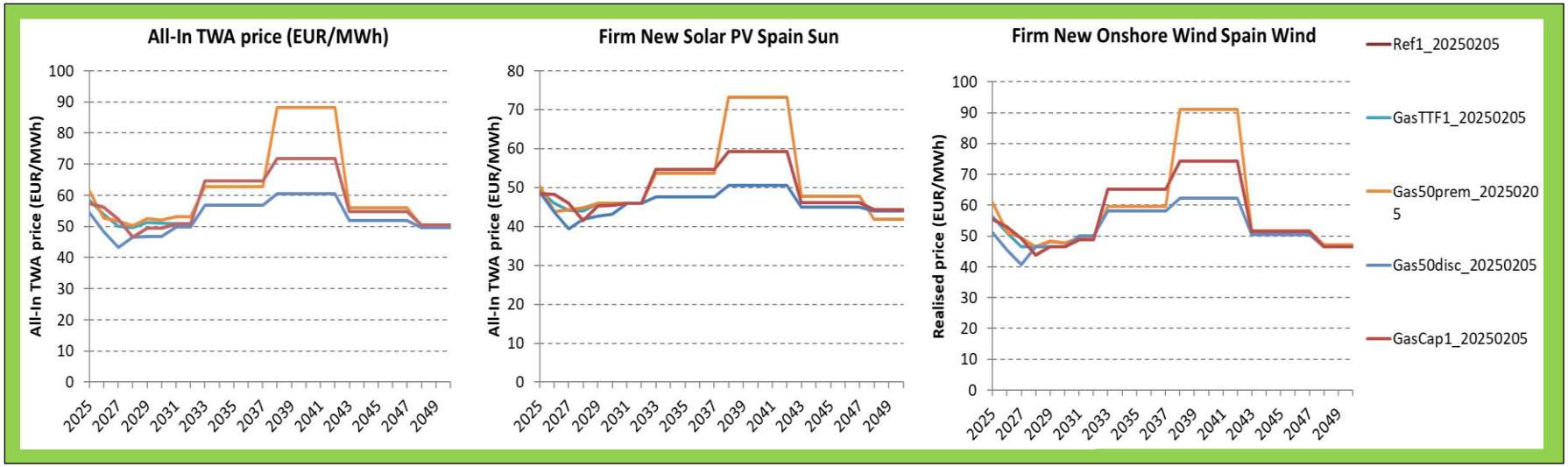
Change applied	Explanation
High demand1	Demand as in Low1.
High demand2	2.5% growth 2025-2035 and 2.0% thereafter, reaching 1.5x CC demand by 2050.
Zero growth	Zero demand growth.
Firm New Build 1	Add 1.5/2.0GW annually until 2030 of Firm New Wind/PV (additional to Economic New Build limits).
Firm New Build 2	Add 1.5/7.0GW annually until 2025 of Firm New Wind/PV (additional to Economic New Build limits).
Uncap from 2025	Uncap Economic New Builds from 2025 onwards.
X/YGW(+) annual caps	Annual caps of New Wind XGW and New PV YGW, uncapped from 2031 if followed by "+".
RES target	Set generation requirement from RES to 70% of total demand in 2030 and increase to 95% in 2050. (If binding, we can track the price of renewable certificates ("REC"). Remember there is no "missing money" problem in our cases: if prices dip, income will be made up by RECs.)
High ACF for New RES	Increase annual hours of New Wind and New PV to 3000 and 2050 respectively.
Low TIC (-X%)	Reduce the TIC of New Wind, PV, and Battery by percentage shown relative to the Ref1 case.
TIC (gradual) step-down	€/kW 2025-2050: New Wind=1000 to 725, New PV and New Battery =750 to 392.
No RES closure	Never close the existing RES (and cogens).
Endogenous closure	Allow model to close Coal, CCGT, and Nuclear on economic basis.
Gas X discount/premium	Discount /premium on delivered gas price.
Gas price cap	Treatment of RDL 10/2022 (extension or not).
TTF until 2031	TTF commodity price until 2031.
Hydro ACF	Up or down by 25%.
RMC of New Wind and PV	RMC1 halves RMC so New PV=7.5% and New Wind =16%, whilst RMC2 set both to zero.

Defining modelling paths (1-2)



Sensitivity results (path 1-2)





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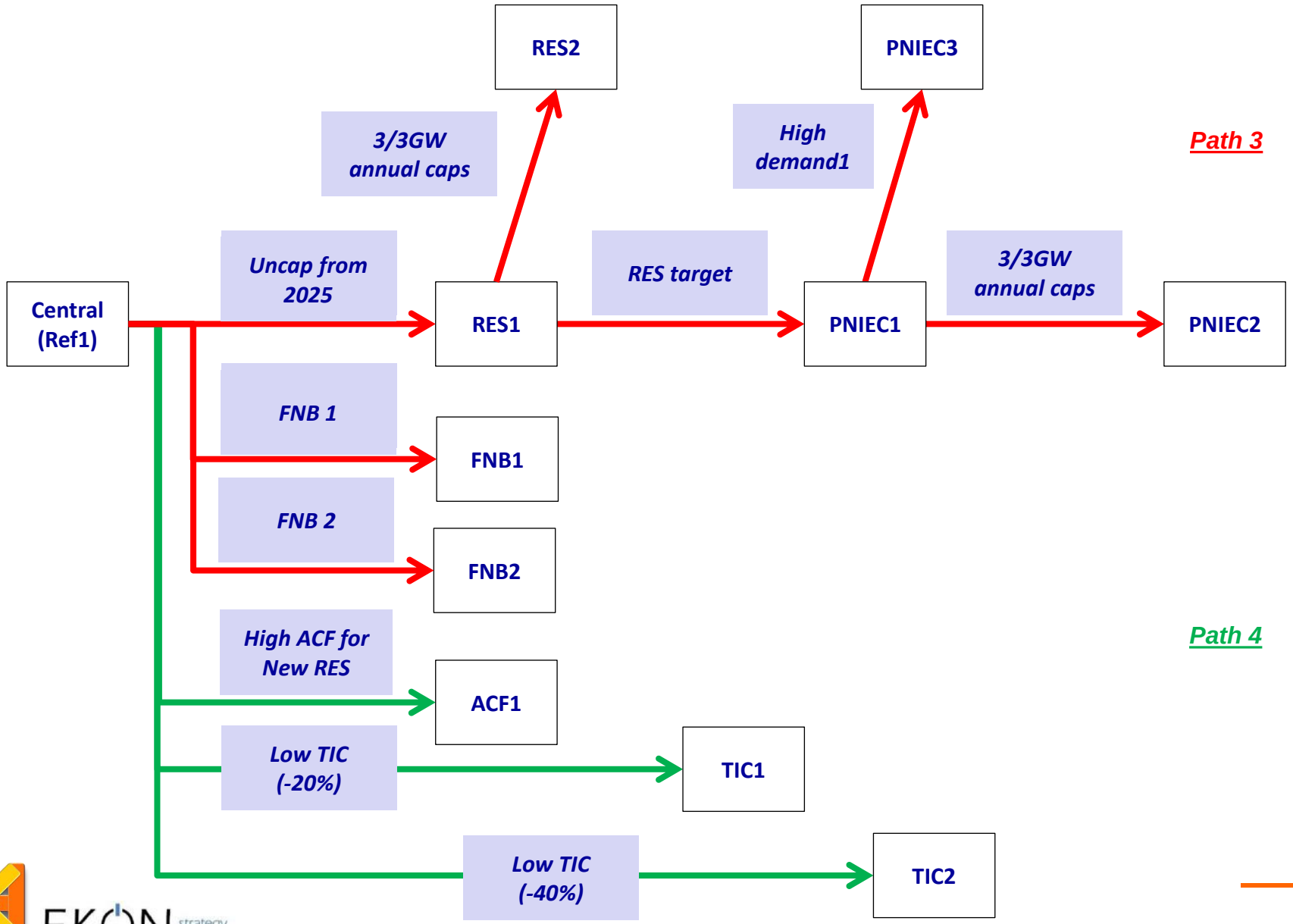
Defining modelling paths (3-4)



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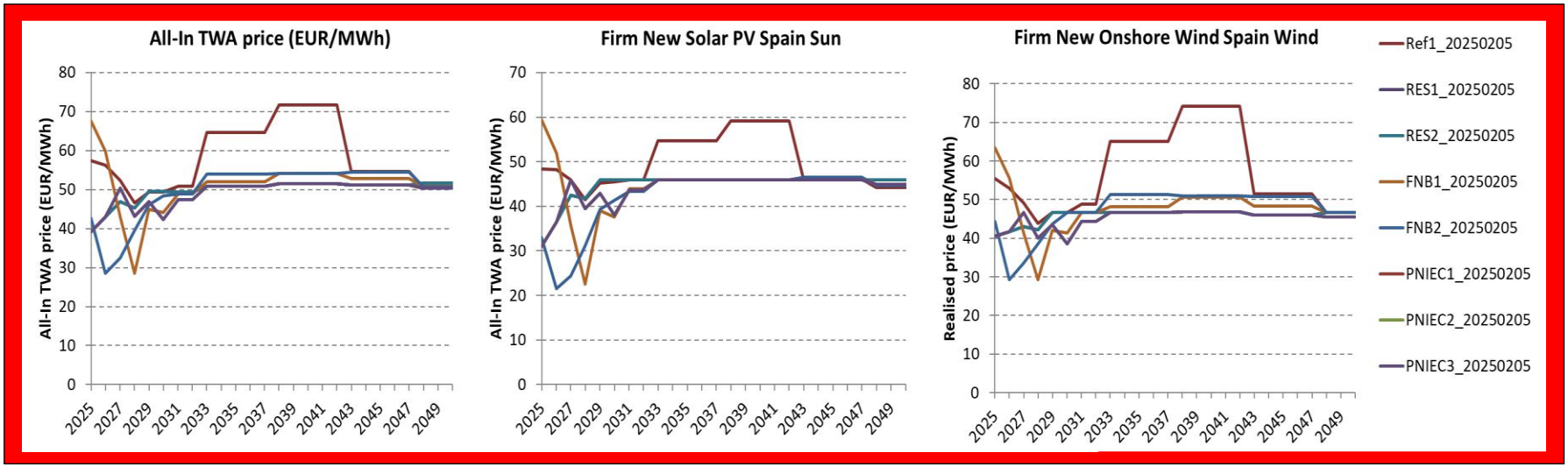
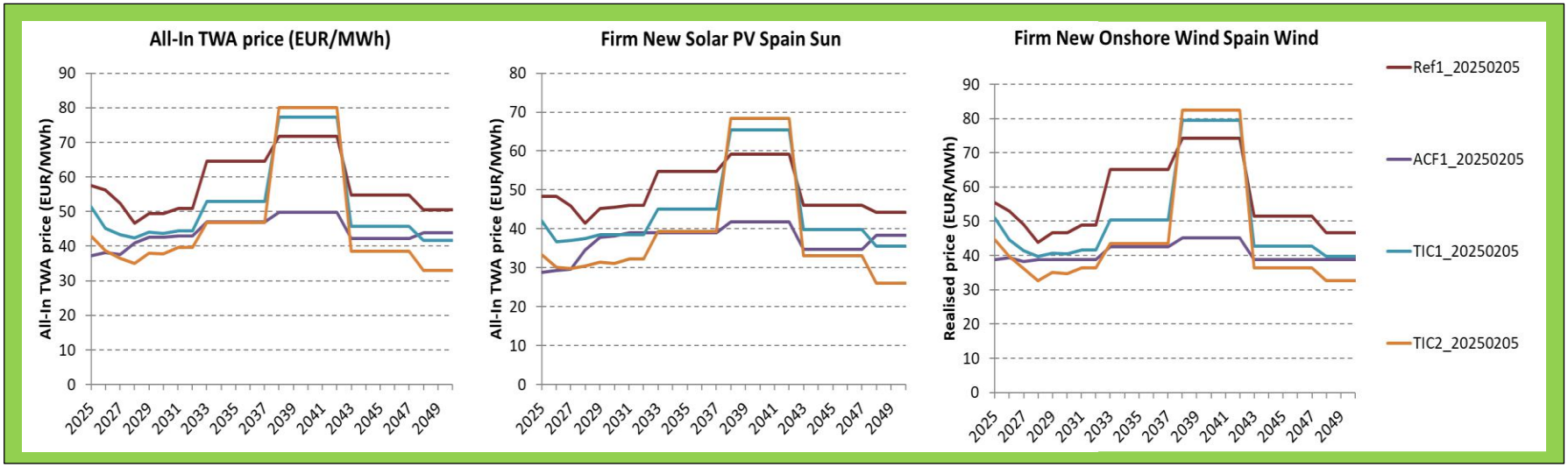
Sensitivity results (path 3-4)





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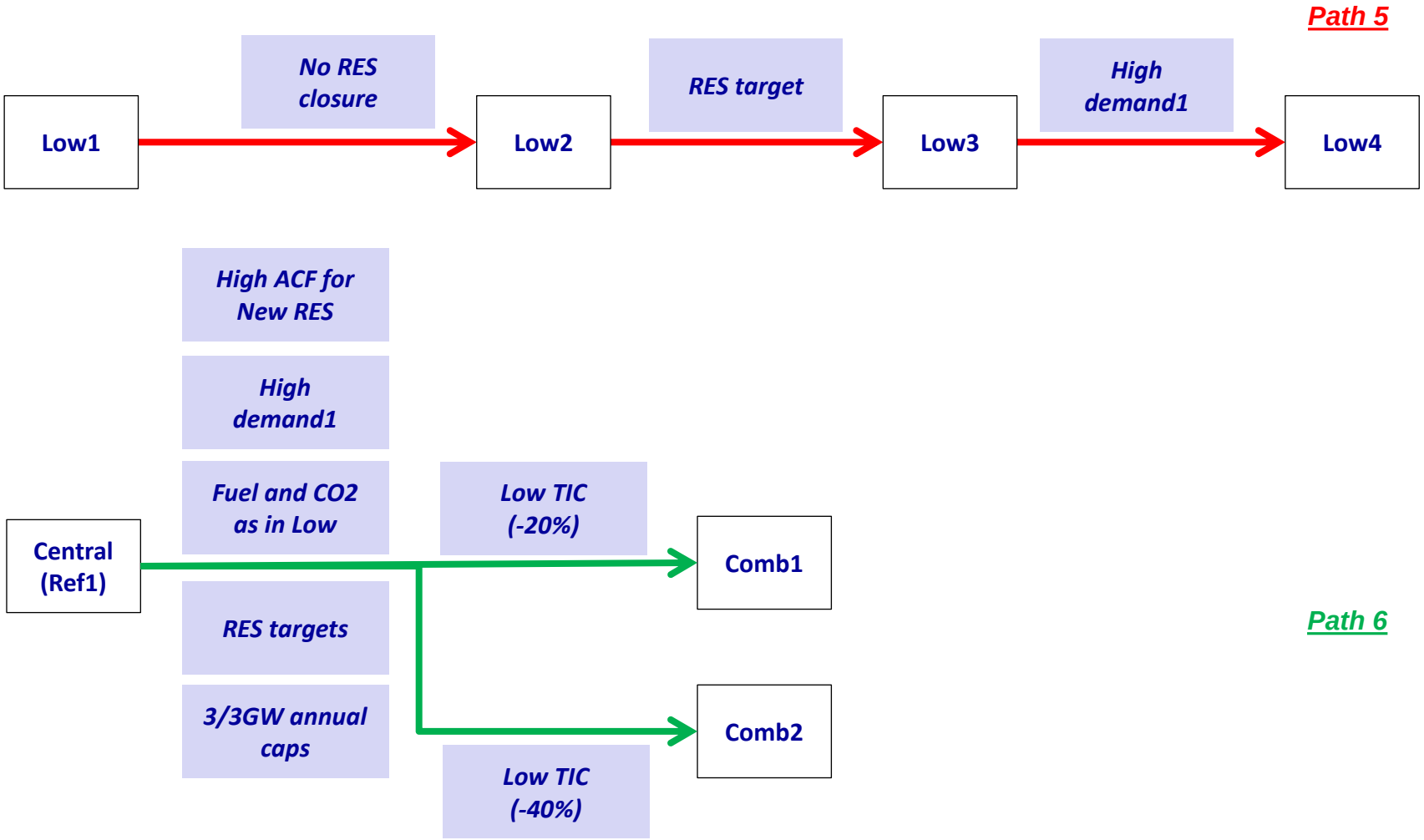
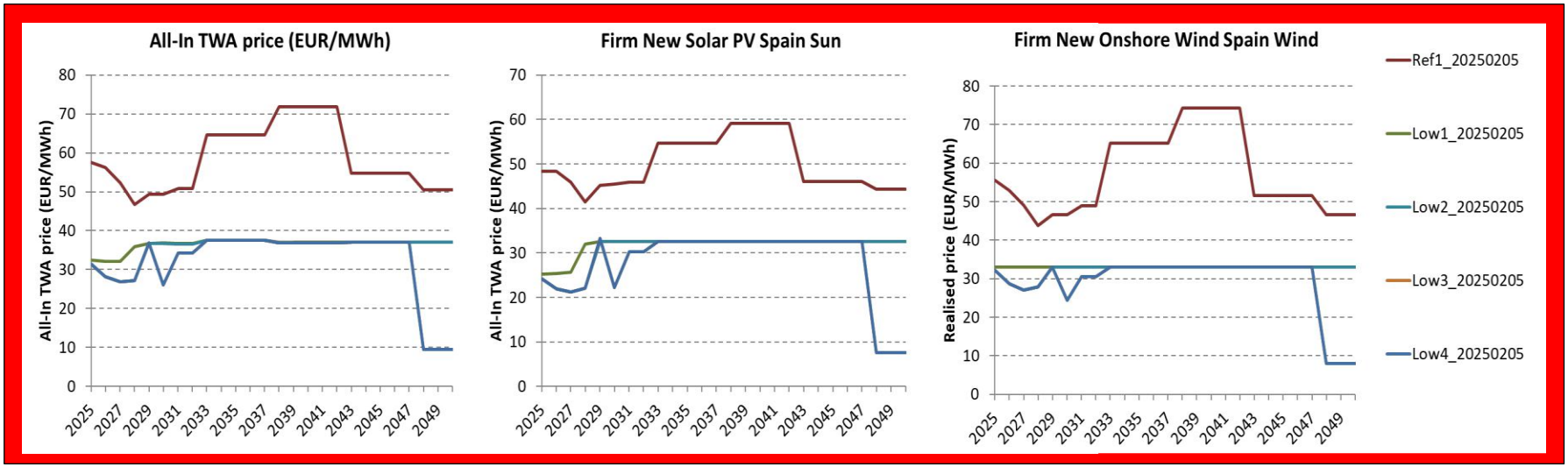
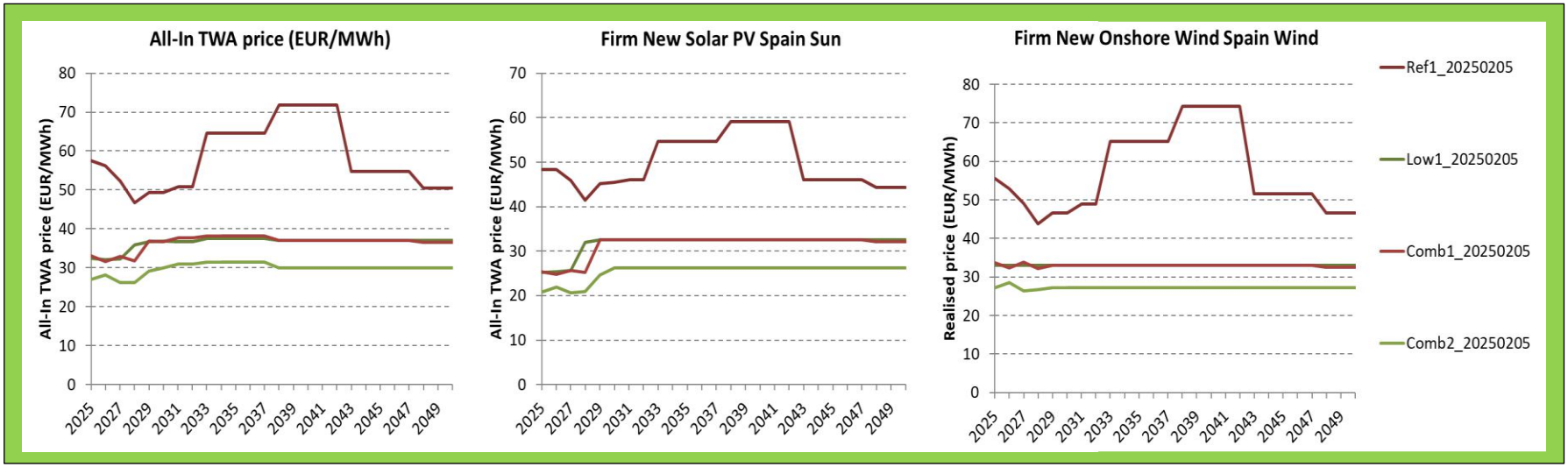
Defining modelling paths (5-6)



Sensitivity results (path 5-6)





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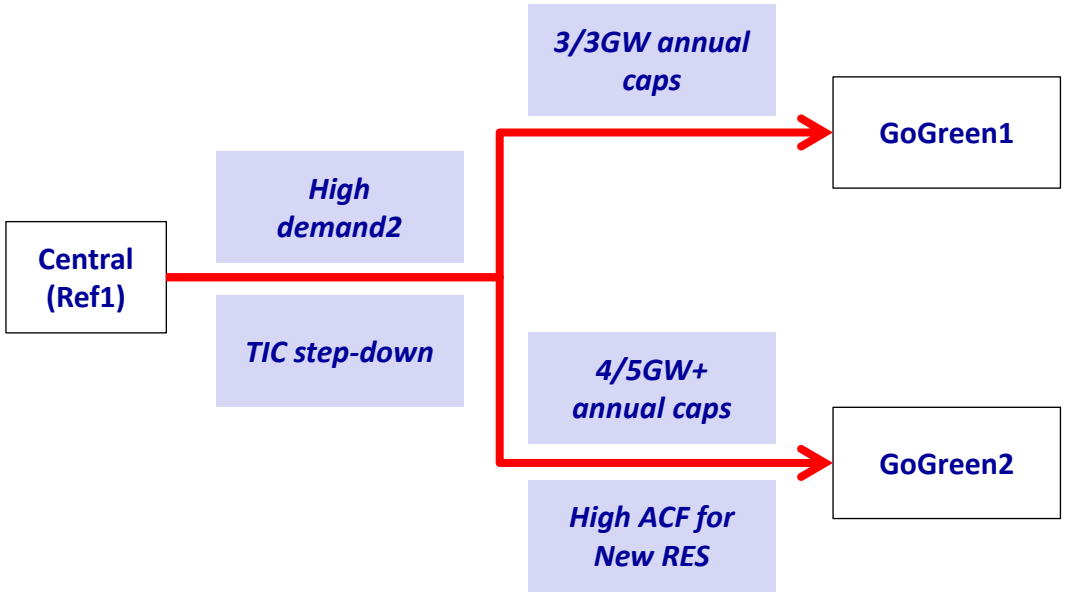
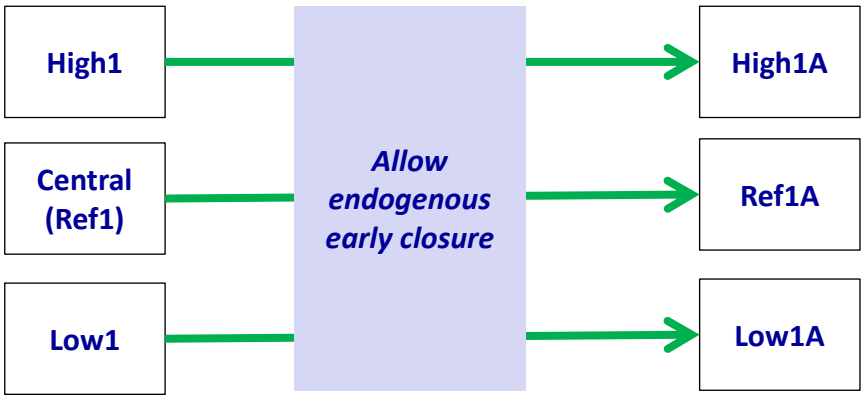
Defining modelling paths (7-8)

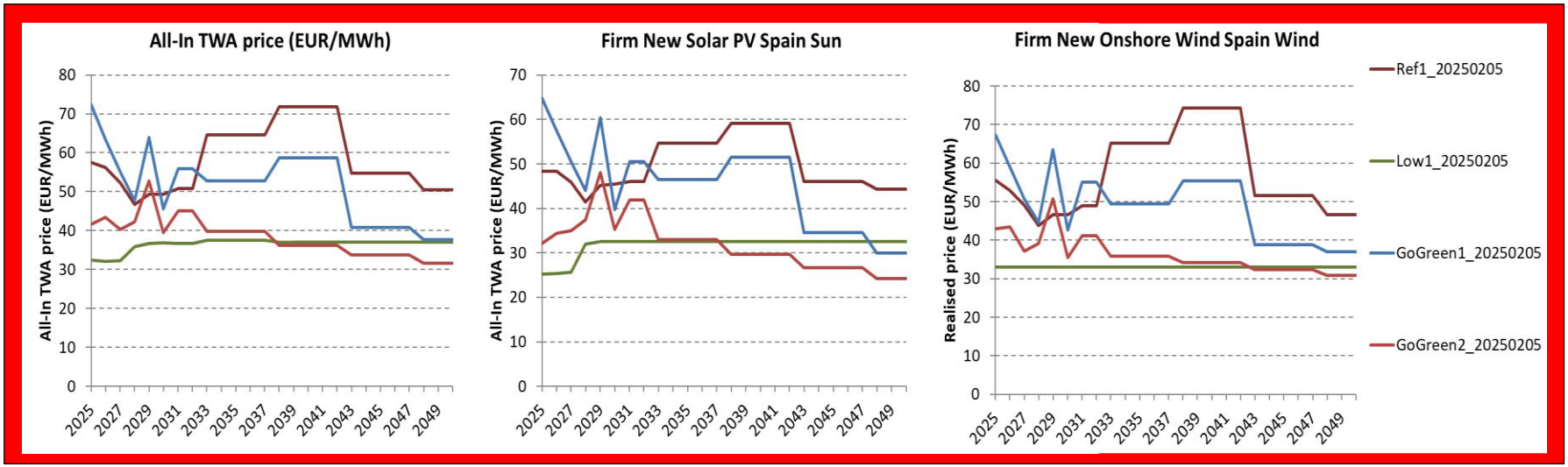


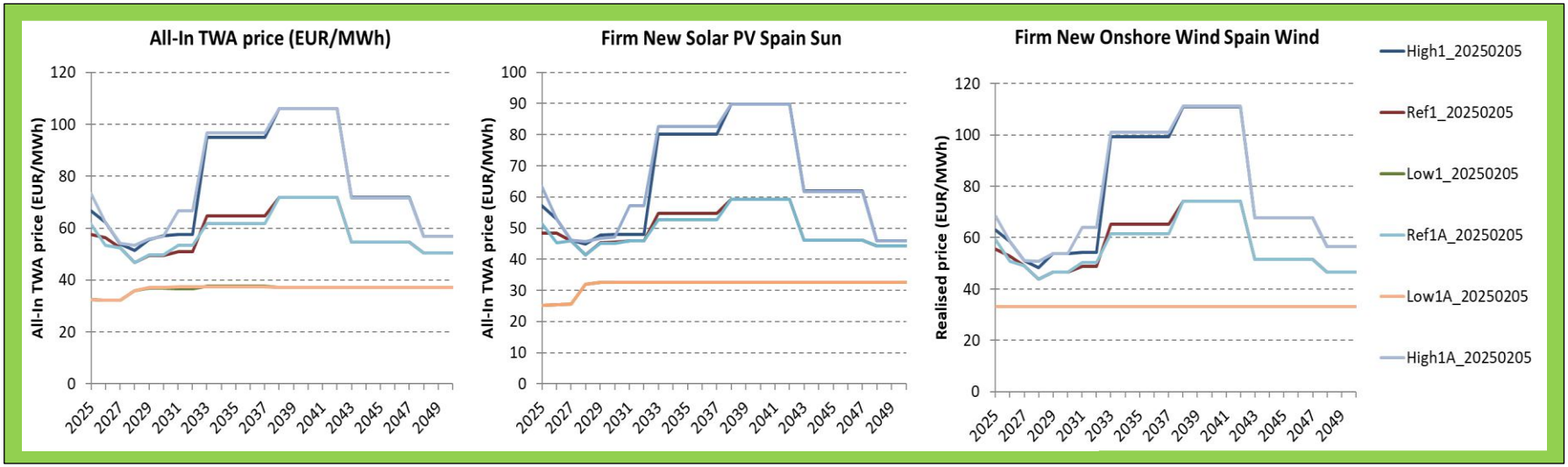
Path 7



Path 8

Sensitivity results (path 7-8)





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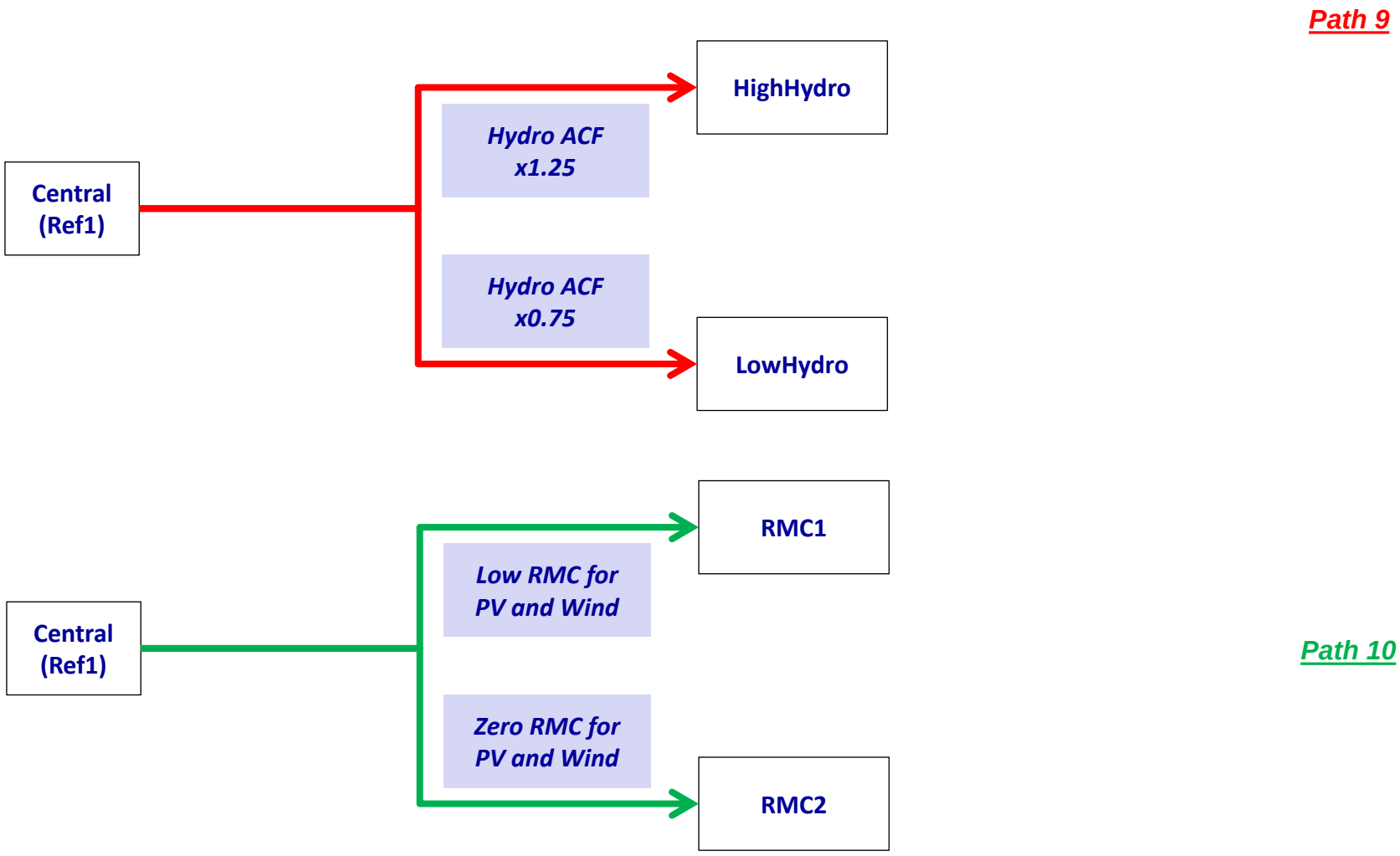
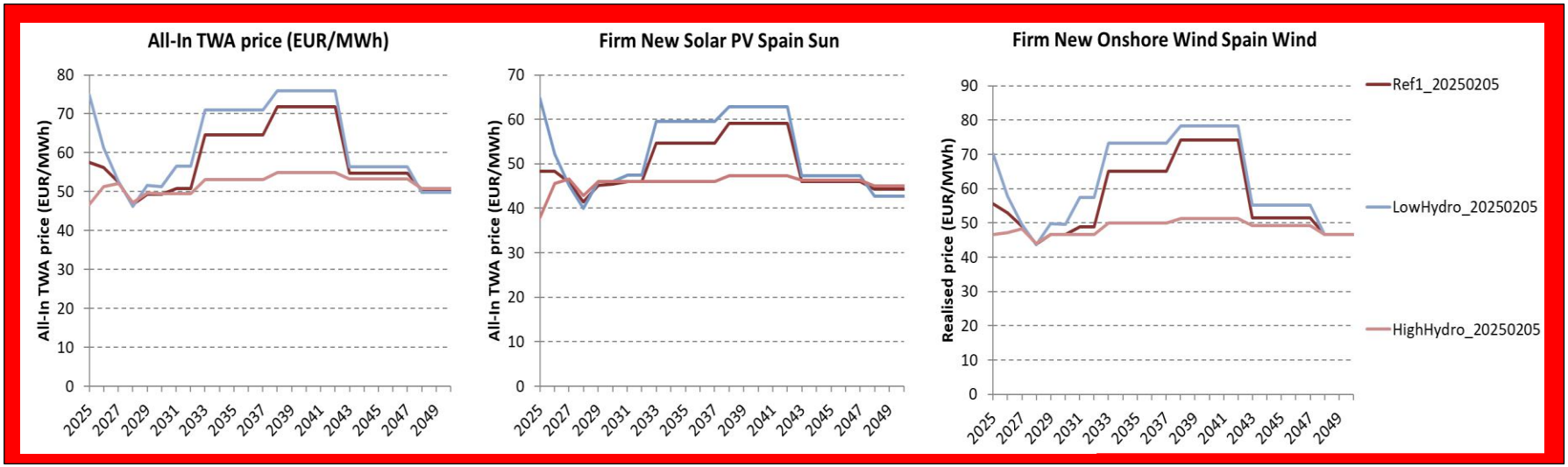
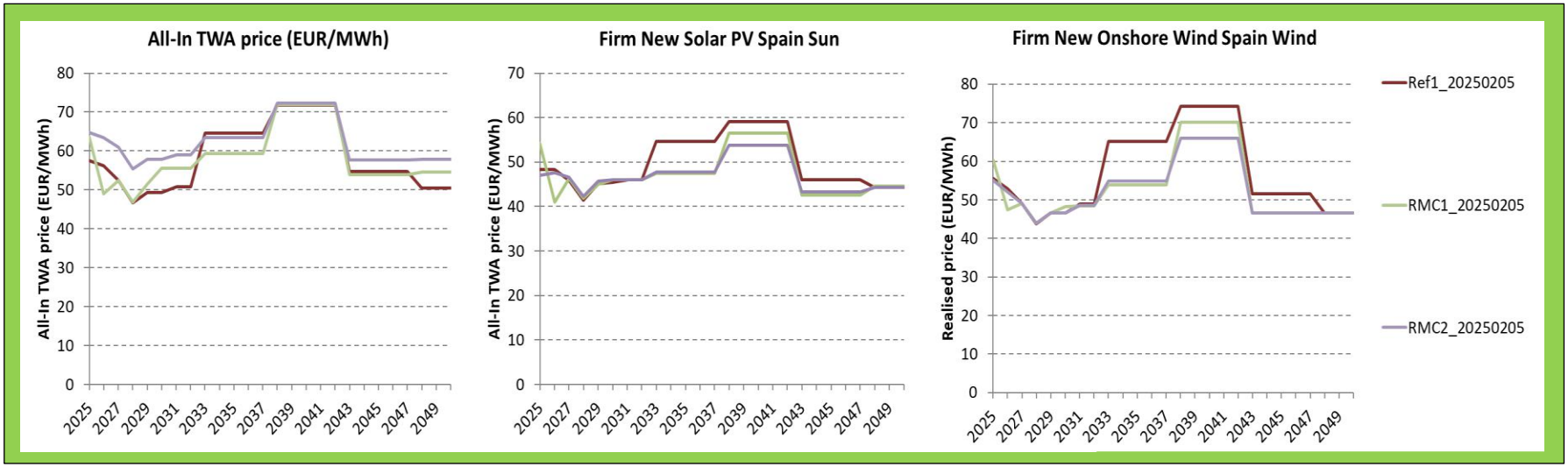
Defining modelling paths (9-10)



Sensitivity results (path 9-10)





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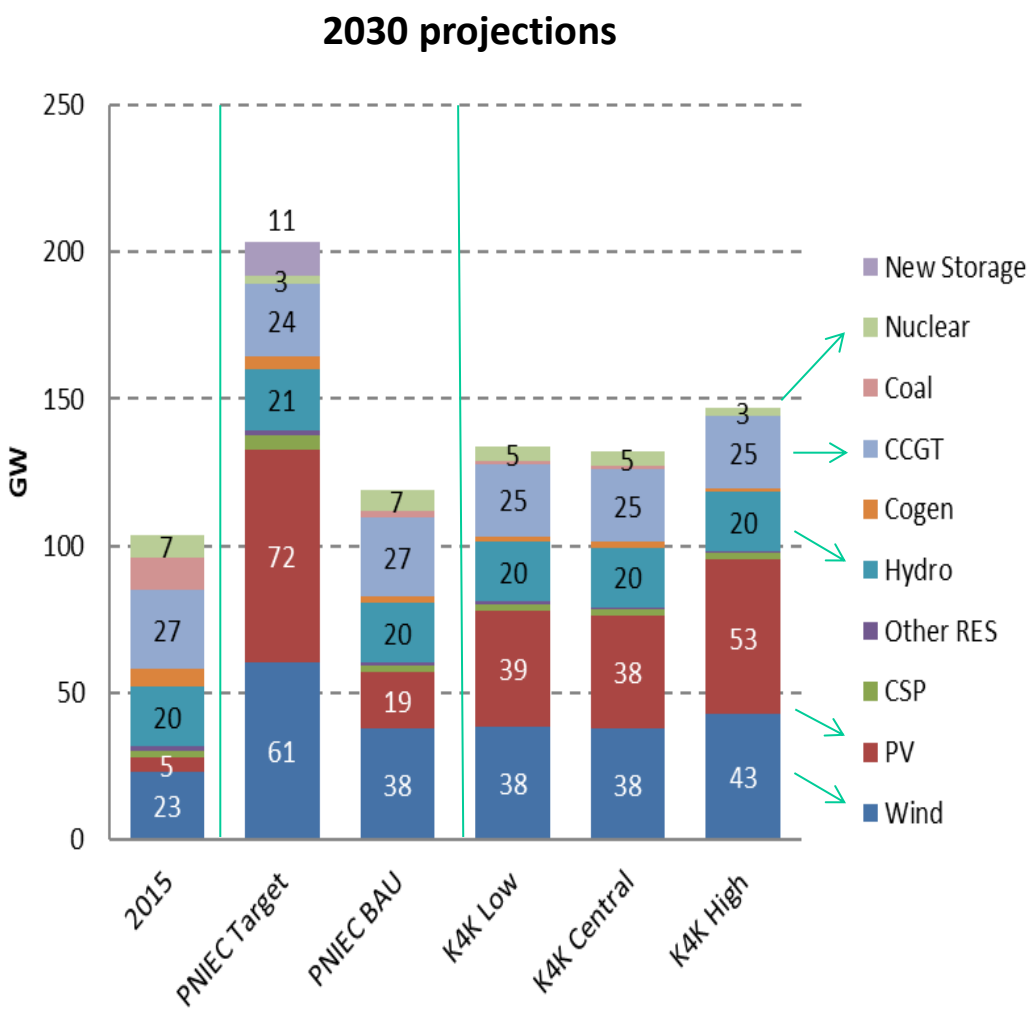
Achieving the NECP 2030 targets

- Share of renewable generation in K4K Central Case is 76.00% and 81.70% in the Low Case (compared to 81% target in new NECP).
- NECP capacity targets very aggressive since requires significant increase in demand, historical hours for renewables, and massive increase in exports.
- What if the government pursues aggressive targets that exceed saturation point?
  - Auctions for new capacity only will undermine merchant market and be open to legal challenge for discrimination.
  - Better to use market for green certificates with firm targets and open to all. (With bonus of no "missing money" problem even if one exceeds saturation points.)



Note : Hydro includes pumped storage.
Source: Plan Nacional Integrado de Energía y Clima 2023-2030 ("PNIEC") 2024, Mainland figures only, K4K 2024Q4.

And beware PNIEC assumptions

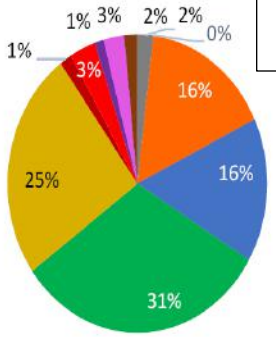
Figura D.7. Resultados Escenario Objetivo H2030

Escenario Objetivo H2030. Plan de Energía y Cambio Climático.

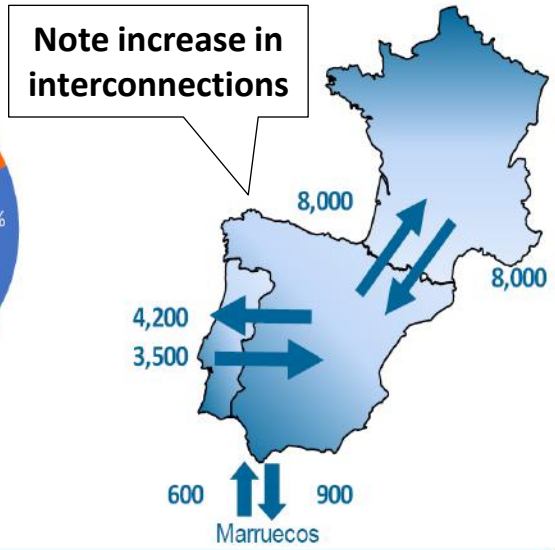
España Peninsular		Generacion mínima síncrona:	3N+7 Térmicas	*Cod 01_2030*
La demanda en ES (TWh):	263	Demanda punta (MW):	47,768	

Capacidad instalada en España (MW)

	MW	%
Nuclear	3,050	2%
Carbón	0	0%
Ciclos	24,560	16%
Hidráulica (+ bombeo)	24,140	16%
Eólica	48,550	31%
Solar FV	38,404	25%
Termosolar	2,300	1%
Termosolar almacen. 9h	5,000	3%
Resto RES	1,730	1%
Cogeneración y otros	3,980	3%
Baterías	2,500	2%
Total sistema eléctrico	**154,214**	**100%**



Capacidad de intercambio (MW)



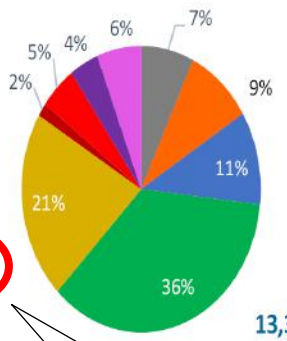
Source: PNIEC (Jan 2020) Annex D.

Capacity may not need to be that high

Balance de generación (GWh). España peninsular

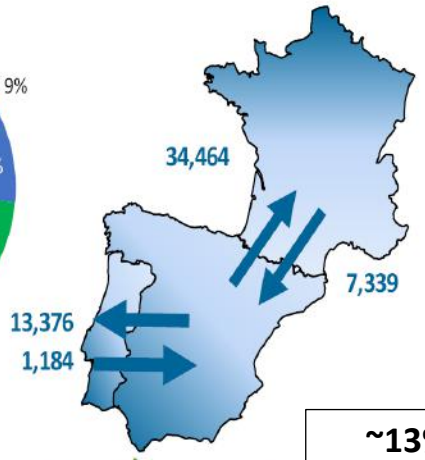
	GWh	%	Horas utilización
Nuclear	22,034	7%	7,224
Carbón	0	0%	0
Ciclos	27,617	9%	1,124
Hidráulica	32,376	11%	1,341
Eólica	109,464	36%	2,255
Solar FV	65,180	21%	1,697
Termosolar	4,629	2%	2,013
Termosolar almacen. 9h	15,156	5%	3,031
Resto RES	12,088	4%	6,987
Cogeneración y otros	18,399	6%	4,623
Generación	**306,943**	**100%**	

Balance almacenamiento	**-4,964**
Consumo almacenamiento	*22,042*
Producción bombeo	*13,782*
Producción baterías	*3,296*



Historical hours

Saldo de intercambios anual (GWh)



Perfil exportador con Marruecos: 0		
Saldo ES-FR	*27,125*	
Saldo ES-PT:	*12,192*	
Saldo Neto + Marruecos:	***39,317***	***ES EXPORT***
CONGESTIONES (% horas)	→	←
ES-FR	53.2%	8.6%
ES-PT	8.0%	0.7%
Spread ES-FR (€/MWh):	***23.4***	

~13% of generation for export?

Source: PNIEC (Jan 2020) Annex D.

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Draft PNIEC even more unlikely

Escenario Objetivo H2030. Plan de Energía y Cambio Climático.

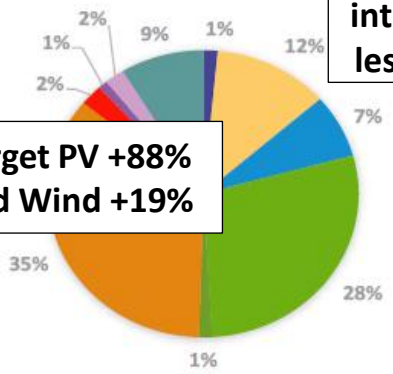
España Peninsular	*Generacion mínima síncrona:*	7 CC + 3 NUC	*Cod 2030_600*
Demanda (TWh):	**344.0**		
Punta horaria de demanda (MW):	**53794**		

+31% and +13% respectively

Capacidad instalada (MW)

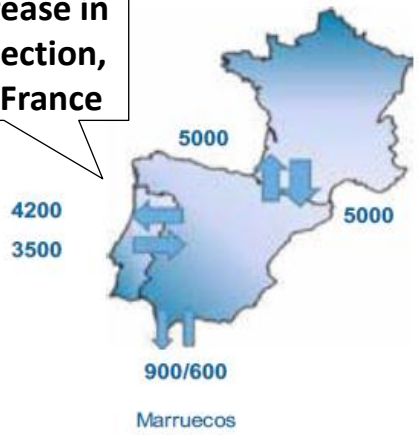
	MW	%
Nuclear	3041	1%
Carbón	0	0%
Ciclos	24499	12%
Hidráulica (sin bombeo)	14562	7%
Eólica terrestre	57737	28%
Eólica offshore	2800	1%
Solar FV	72130	35%
Termosolar	4804	2%
Resto RES	1964	1%
Cogeneración y otros	4205	2%
Almacenamiento	17612	9%
Total sistema	**203353**	**100%**
Electrolizadores	**11980**	

Target PV +88% and Wind +19%



Capacidad de intercambio (MW)

Same increase in interconnection, less with France



Información adicional:

Potencia renovable en España peninsular (MW)	***153997***	*76%*	*del Total sistema*

Source: Updated PNIEC (2024) Annex D.

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Generation and capacity probably too high

Balance de generación (GWh)

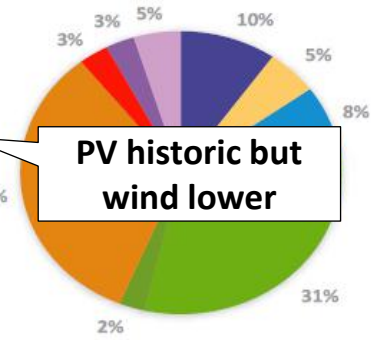
	GWh	%	Horas utilización
Nuclear	36881	10%	7224
Carbón	0	0%	0
Ciclos	19750	5%	806
Hidráulica (sin bombeo)	28932	8%	1987
Eólica terrestre	117450	31%	2034
Eólica offshore	9695	3%	3463
Solar FV	125377	33%	1738
Termosolar	11426	3%	2378
Resto RES	10993	3%	5597
Cogeneración y otros	17859	5%	4247
Generación [1]	**378362**	**100%**	

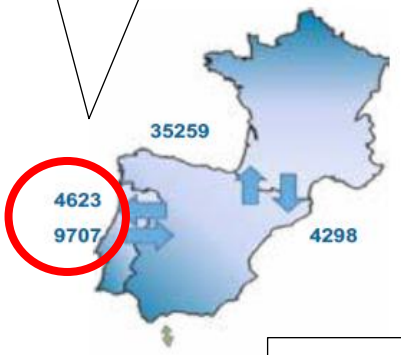
[1] *Sin almacenamiento*

Balance almacenamiento	**-7185**	GWh
Consumo	*35447*	
Producción	*28262*	

Reversal of flows with PT but FR takes up the slack

PV historic but wind lower





Perfil Marruecos

More reasonable 7% of generation?

	GWh
Saldo ES-FR	*-30961*
Saldo ES-PT:	*5083*
Saldo neto internacional (FR, PT, MA)	*-27243*

Positivo: saldo importador. Negativo: saldo exportador.

CONGESTIONES (% horas)	→	←
ES-FR	76.7%	7.5%
ES-PT	3%	19%

Spread ES-FR (€/MWh) [3] **:**	**27.4**

[3] *Media horaria de la diferencia de precios en cada hora en valor absoluto*

Source: Updated PNIEC (2024) Annex D.

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Final comments

- What if government targets capacity that exceeds saturation points? Let's hope they don't discriminate between different cohorts of assets! Setting an aggressive green energy target (GWh) and backing this up with tradable green certificates would ensure that all investors - old and new - are protected from the inevitable electricity price crash.
- So get informed and if you want to take a view on realised prices for PV or wind, think about these:
  - Demand growth ← **Re saturation point**
  - Fuel prices
  - EUA prices ← **Short-term impact**
  - Taxes (Generation Tax, Green Cent Tax)
  - Lifetime limit for existing plants (cogeneration and renewables included)
  - Hydrology
  - Operational hours for New Wind and PV
  - Capex, leverage and cost of capital of New Wind and PV
  - Rate of deployment of New Wind and PV (including rooftop)
  - Measures to meet PNIEC targets (including auctions) ← **Especially important**