

Opportunities for Power-to-Power Energy Storage based on H₂ & gas turbines (Case of Spain)

6th Thermal, Mechanical and Chemical Energy Storage Workshop
July 31st & August 1st 2024 - Charlotte, NC

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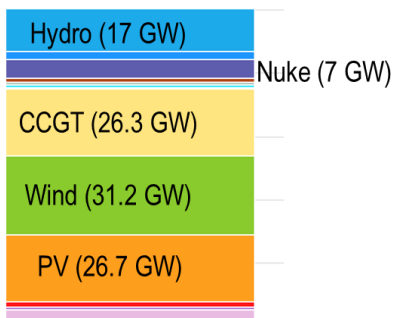
- Energy transition
- Role/limitations of the grid
- Impact on market of electricity
- Fundamentals of P2P based on H_2 +GT
- Economics of P2P based on H_2 +GT
- Foreseen operation of P2P based on H_2 +GT
- Is it an interesting business model?
- Final considerations

Energy transition – National Integrated Energy & Climate Plan

	Installed capacity (MW)					
	2015		2020		2030	
Wind	22925	21%	28033	25%	50333	31%
Solar PV	4854	5%	9081	8%	39181	24%
Solar CSP	2300	2%	2303	2%	7303	5%
Hydro	14104	13%	14109	13%	14609	9%
Pumped Hydro	6024	6%	6024	5%	9524	6%
Biogas	223	0%	211	0%	241	0%
Biomass	677	1%	613	1%	1408	1%
Coal	11311	11%	7897	7%	0	0%
Combined cycle GT	26612	25%	26612	24%	26612	17%
CHP	6143	6%	5239	5%	3670	2%
Fuel/Gas	3708	3%	3708	3%	1854	1%
Waste	893	1%	610	1%	341	0%
Nuclear	7399	7%	7399	7%	3181	2%
Storage	0	0%		0%	2500	2%
	107173	26%	111839	33%	160757	56%

	Generation (GWh)					
	2015		2020		2030	
Wind	49325	18%	60670	22%	119520	35%
Solar PV	8302	3%	16304	6%	70491	20%
Solar CSP	5557	2%	5608	2%	23170	7%
Hydro	28140	10%	28288	10%	28351	8%
Biogas	743	0%	813	0%	1505	0%
Biomass	3126	1%	4757	2%	10031	3%
Coal	52281	19%	33160	12%	0	0%
Combined cycle GT	28187	10%	29291	10%	32725	9%
CHP	29291	10%	28474	10%	18074	5%
Fuel/Gas	13783	5%	10141	4%	5071	1%
Waste	1344	0%	918	0%	355	0%
Nuclear	57196	20%	58039	21%	24952	7%
Storage	3228	1%	4594	2%	11960	3%
	280503	21%	281057	27%	346205	55%

125.8 GW

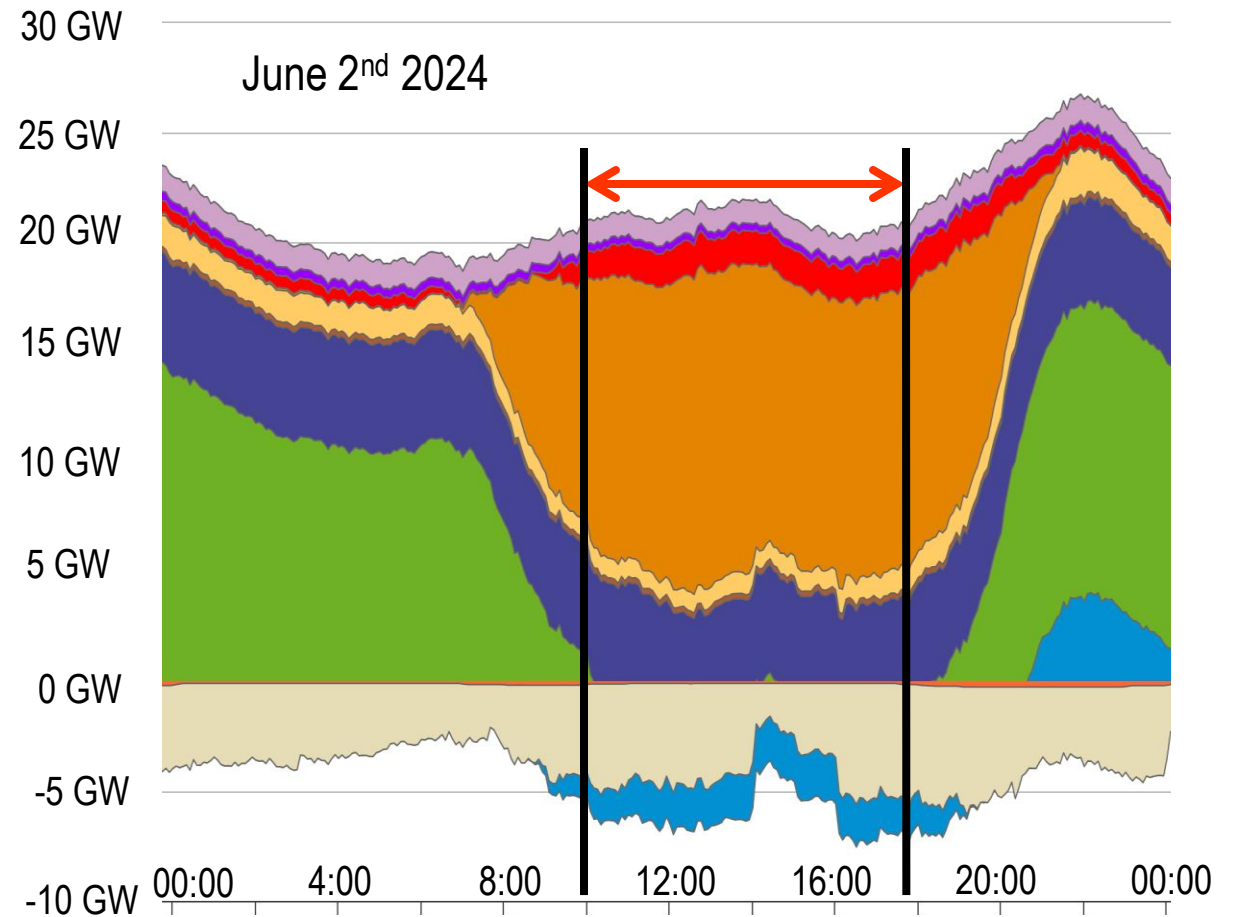
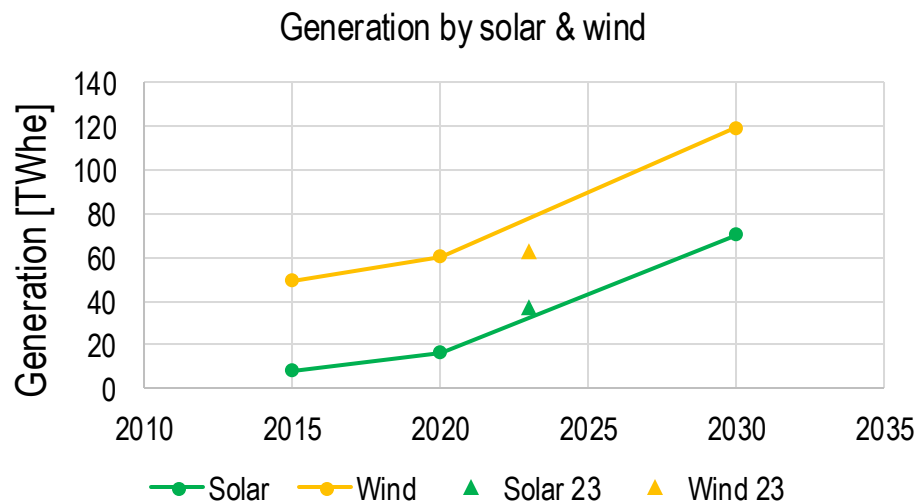
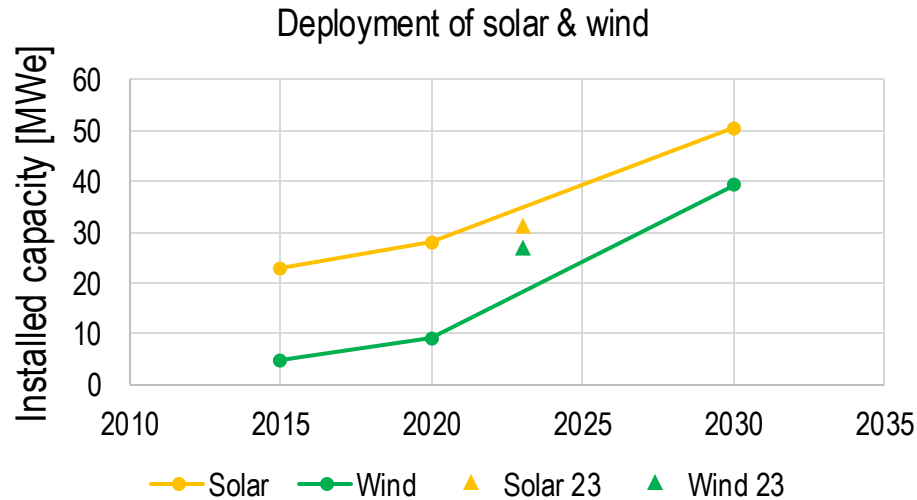


- National Energy & Climate Act (2021-2030):
 - 21% CO₂ footprint (1990) – all sectors
 - +39.6% energy efficiency – all sectors
 - 42% share of RREE (energy) – all sectors
 - 74% share of RREE (electricity)

- National Energy & Climate Act (2021-2030):
 - +50% installed capacity
 - +23.4% generation

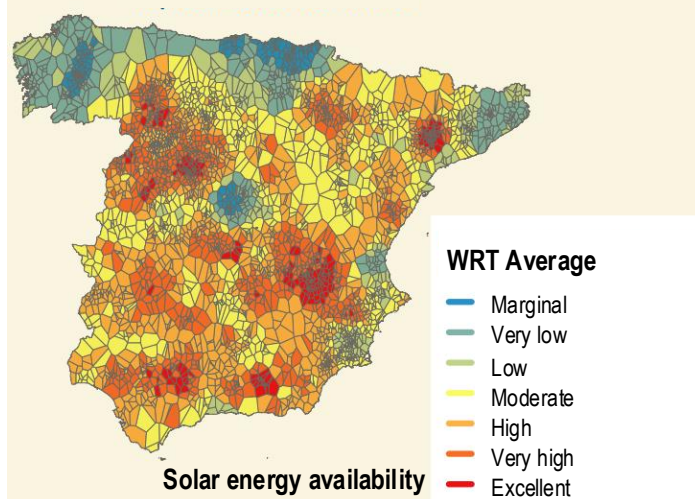
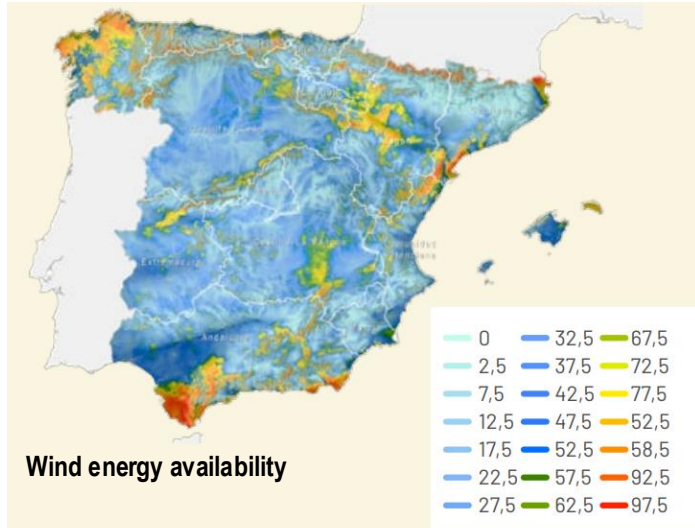
Global (0-D) energy balance does not reflect the actual technical challenge

Energy transition – National Integrated Energy & Climate Plan



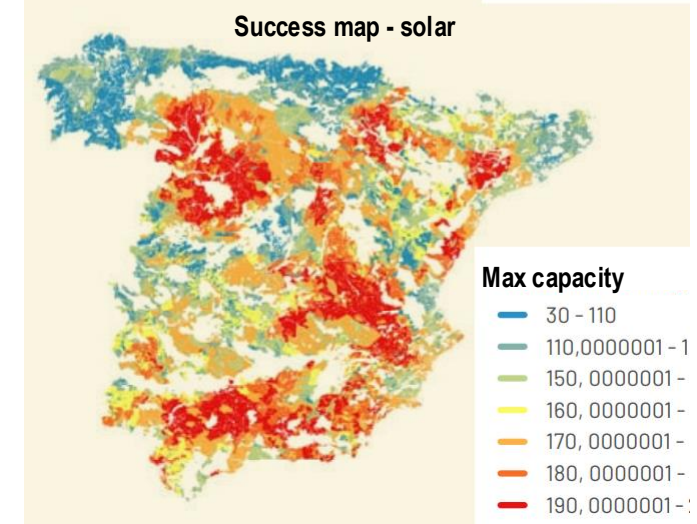
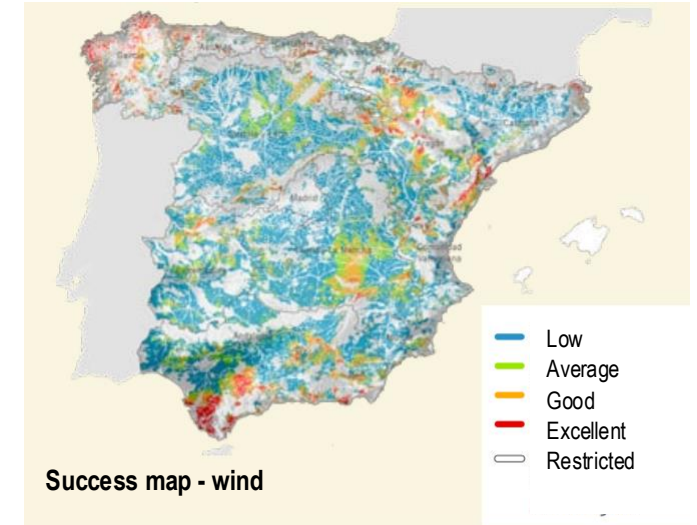
Duck curve already very visible

Energy transition – National Integrated Energy & Climate Plan

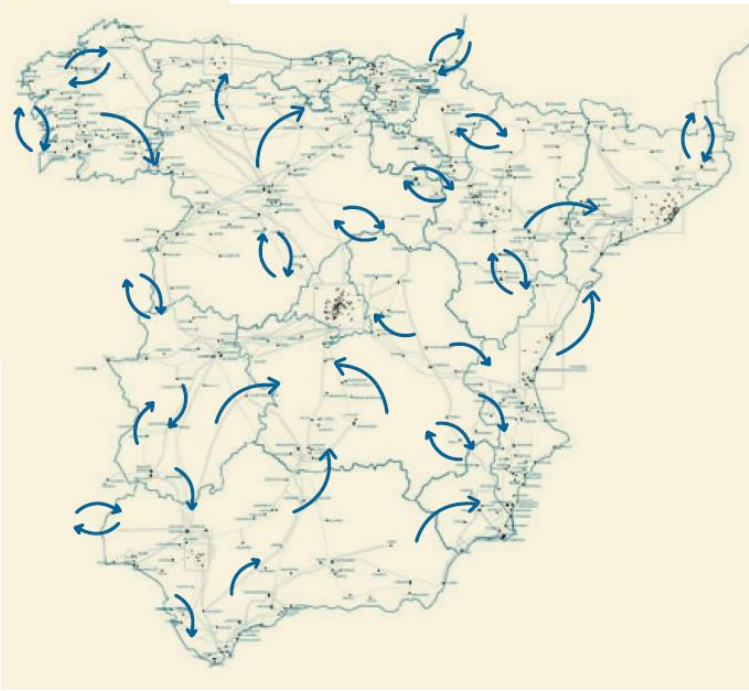
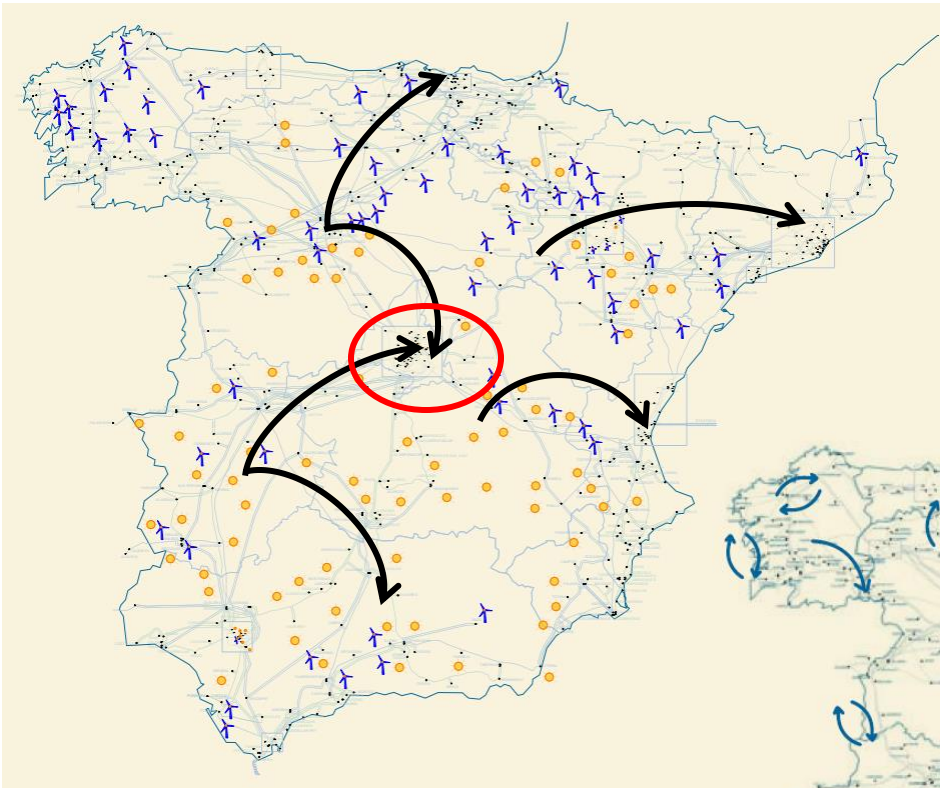


Environmental restrictions

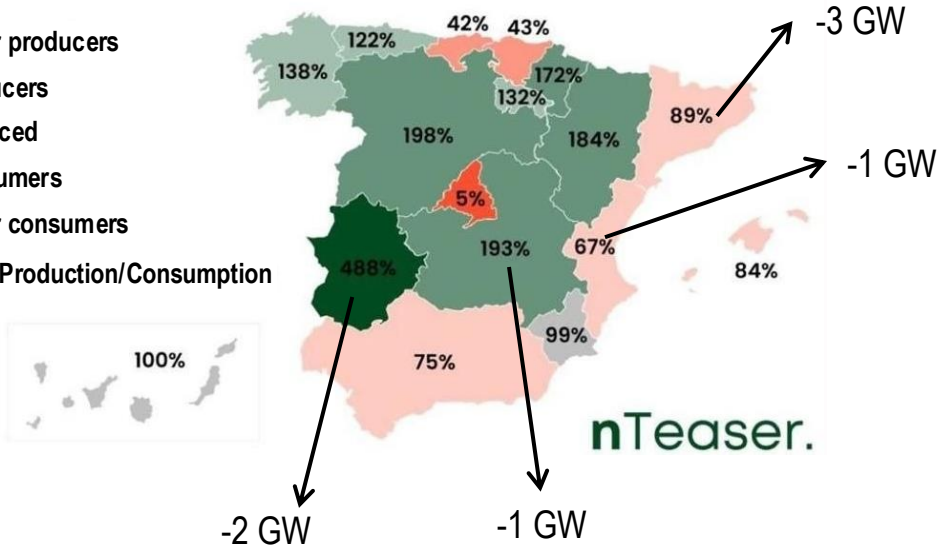
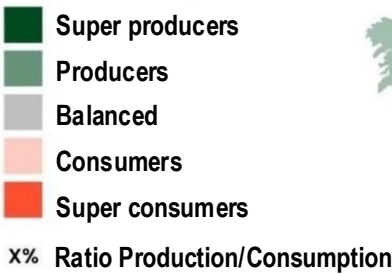
- Extreme
- Very high
- High
- Moderate
- Low



Energy transition – National Integrated Energy & Climate Plan



Source: Red Eléctrica de España, Plan de desarrollo de la red de transporte de energía eléctrica 2012-2026



Energy transition – National Integrated Energy & Climate Plan

- Simplistic 0-D approach: replacement of 2.5 TWh/y carbon-laden energy

Technology	EOH	CF	Capacity (2.5 TWh)
PV	1750 h	20%	1.5 GW
CCGT	5250 h	60%	0.5 GW
Coal	6500 h	75%	0.4 GW

Now we pretend to swallow this
(plus we need ES)

Grid sized to take this

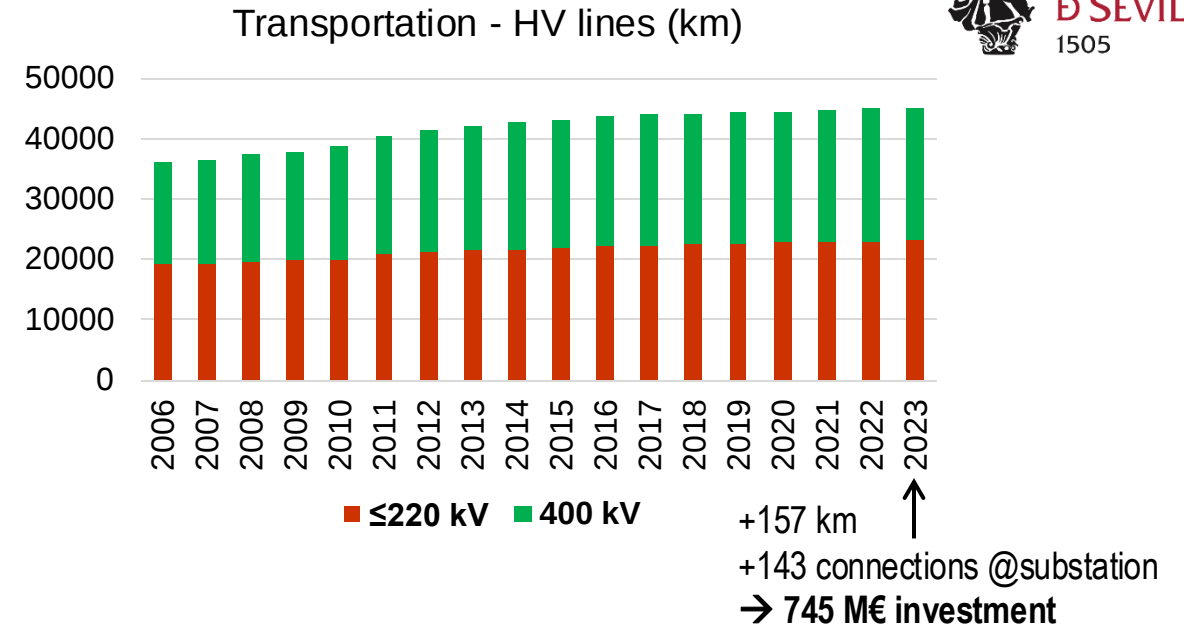
- **FACT: curtailments are increasing**
 - **Technical (congestion): PV & Wind**
 - **Economic: CSP**

Year	Curtailment	Cost
2021	0.067 TWh	910 M€
2022	1.08 TWh	1270 M€
2023	1.2 TWh	>2000 M€

Added cost because other, more
expensive technologies than PV
and Wind must come online

Grid of electricity – Spain

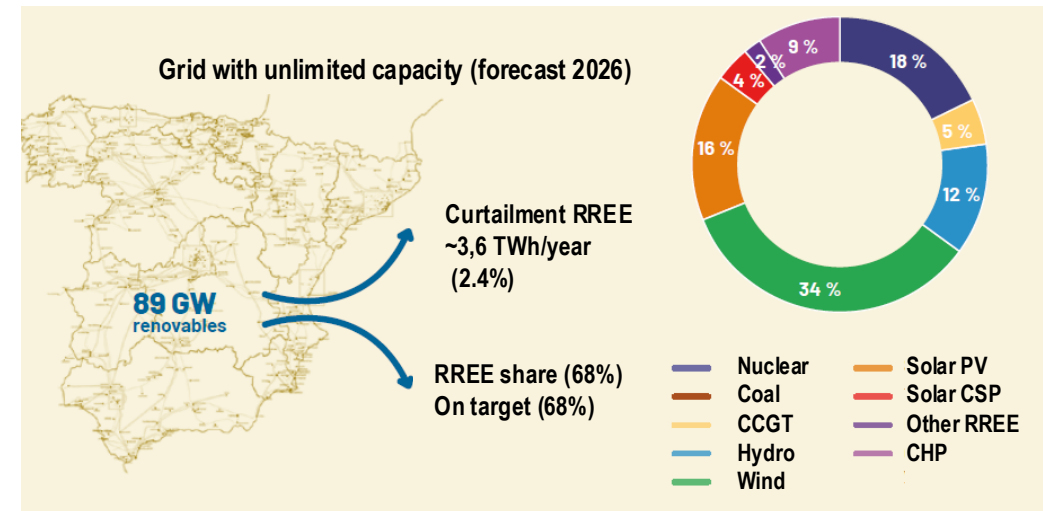
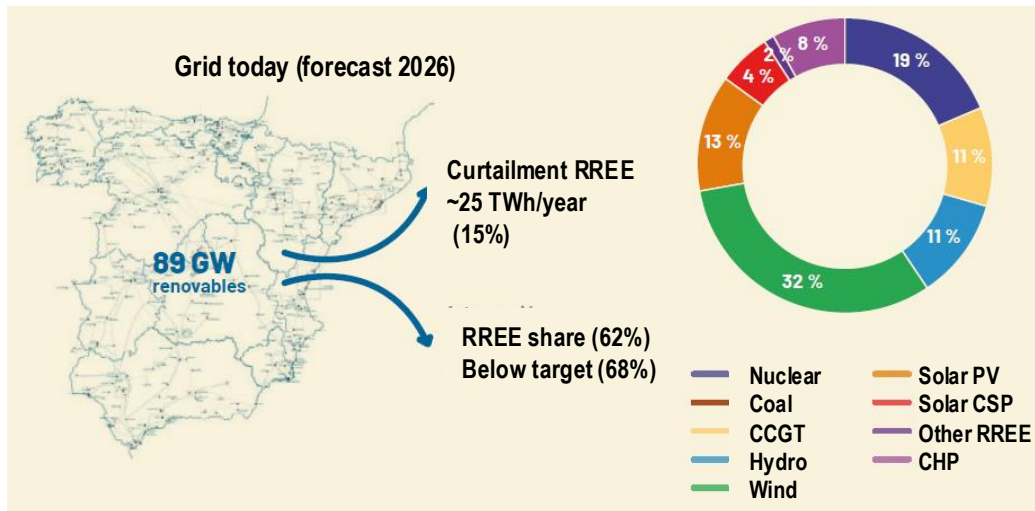
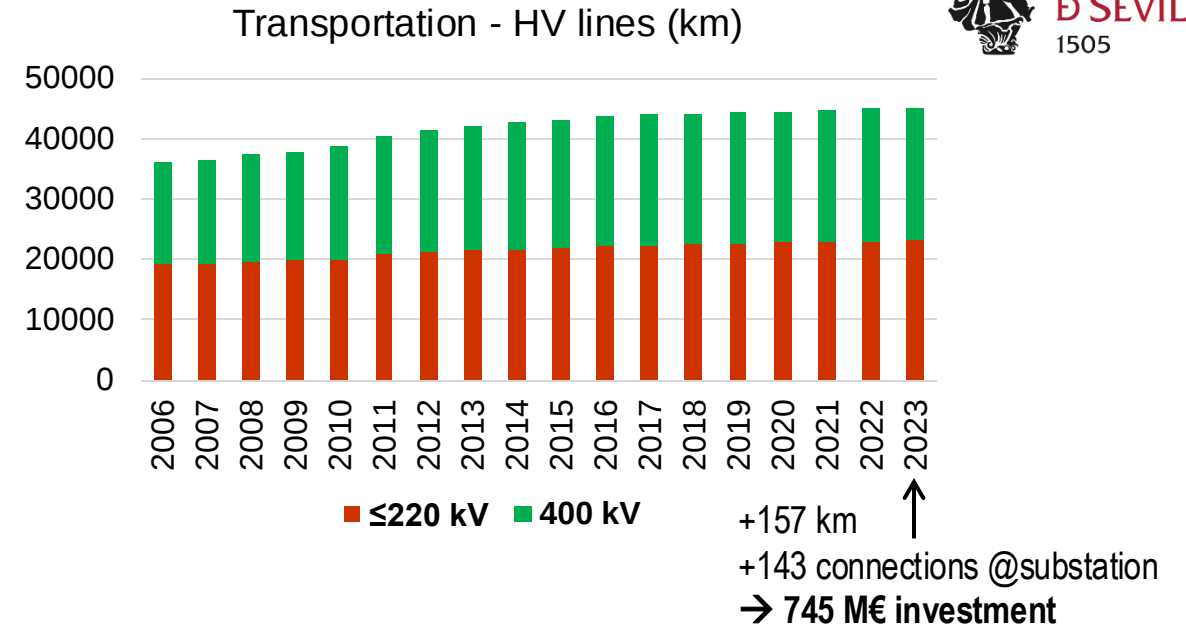
- Grid of electricity:
 - 45,223 km HV lines (42,713 km in 2014)
 - 6,000 connections @substations
 - 94,981 MVA transformation capacity



- If the grid is to take 35 GW added capacity for PV+Wind (National Plan)...
- The investment needed in 2023-2030 is **>20000 M€**
 - Transportation (75-100 k€ / MW RREE – REE TSO): 2650 – 3500 M€
 - Distribution (500 k€ / MW RREE – Deloitte): 17500 M€

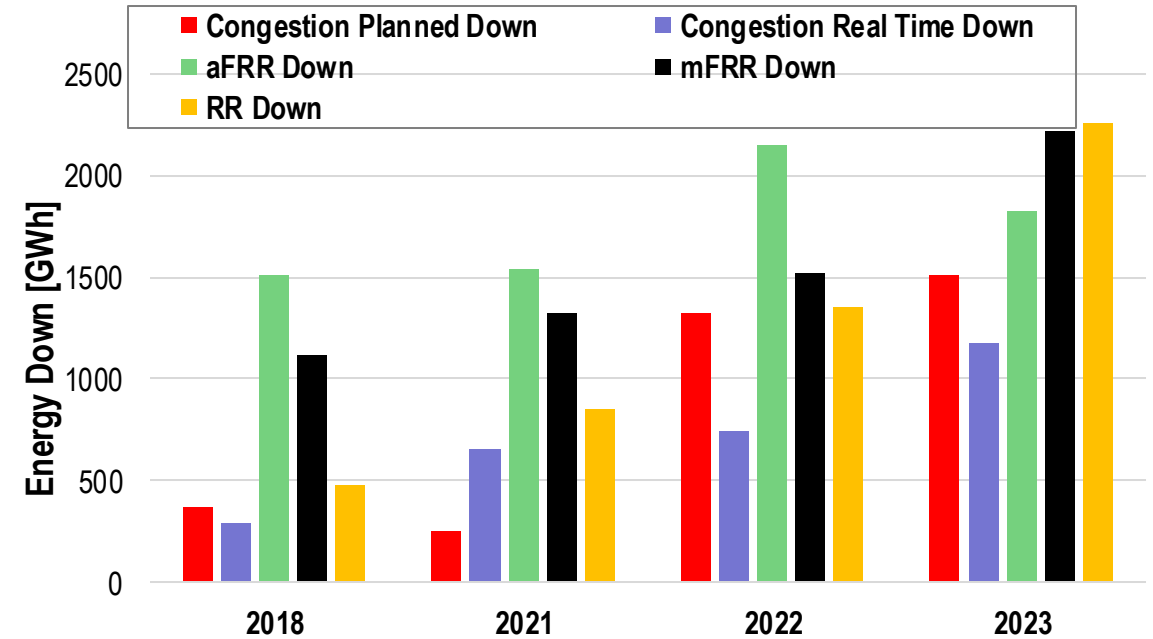
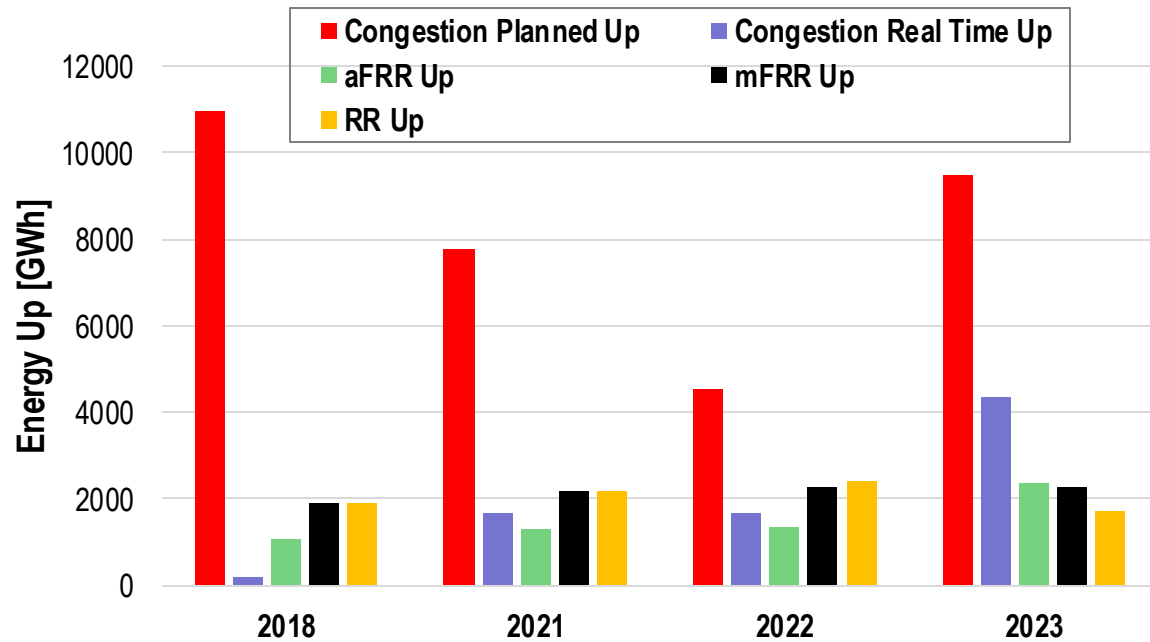
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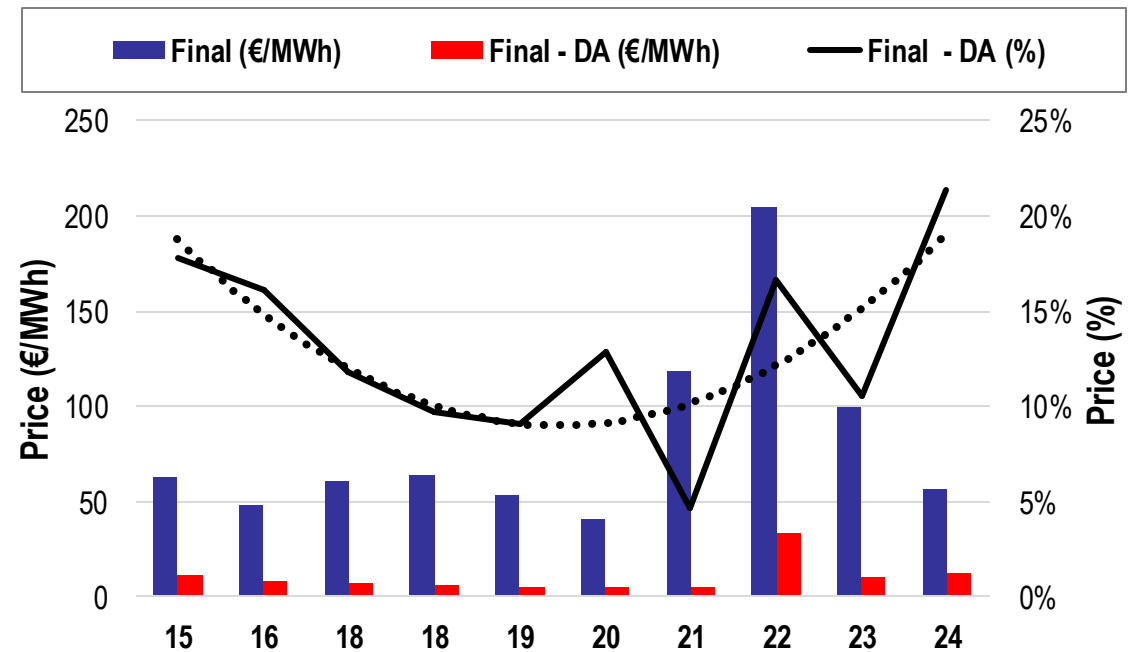
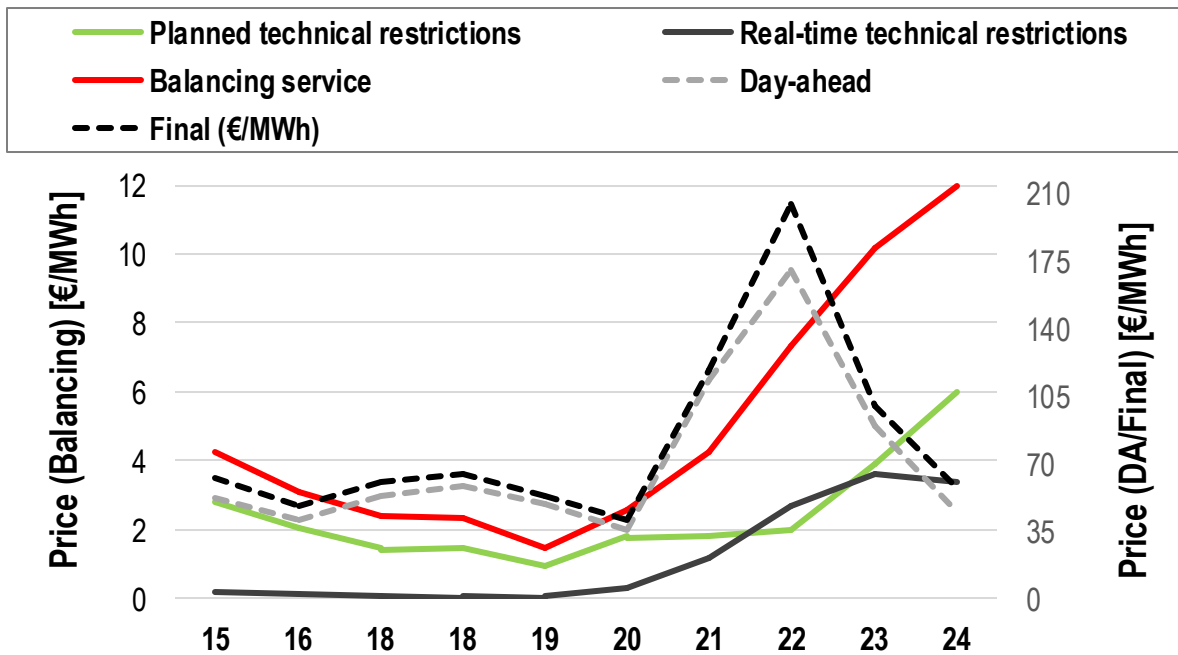
Grid of electricity – Spain

- Implications of the limited capacity of the grid and increased share of RREE:
 - More energy traded for ancillary services

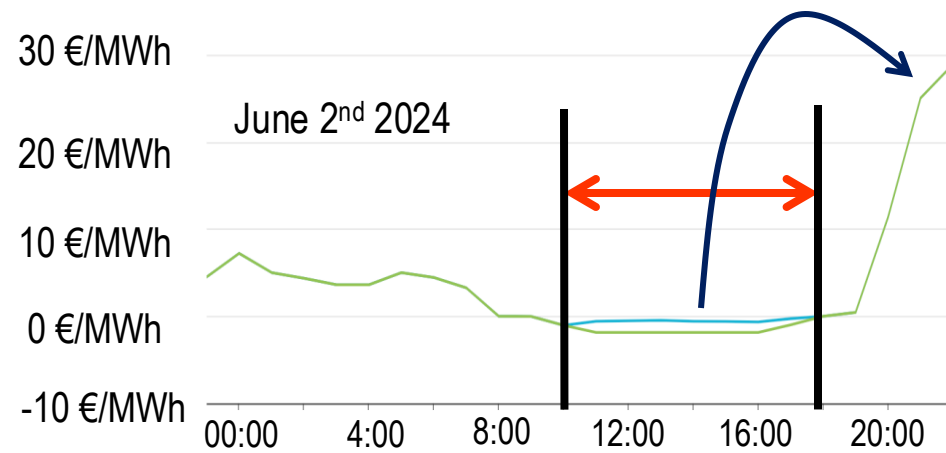
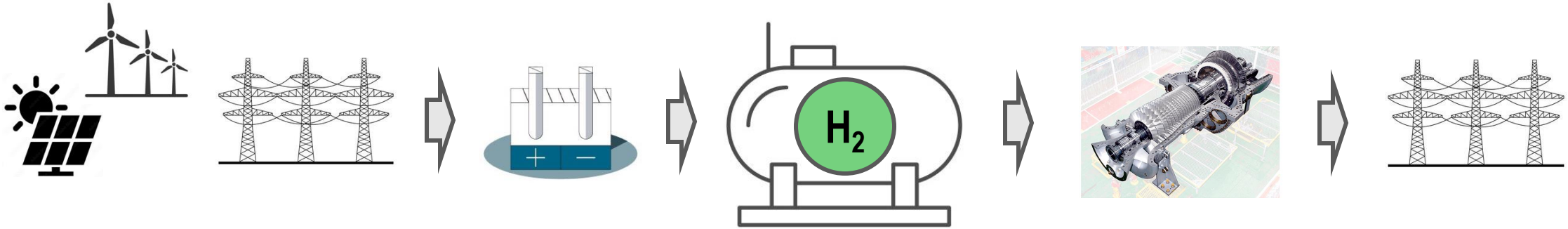


Grid of electricity – Spain

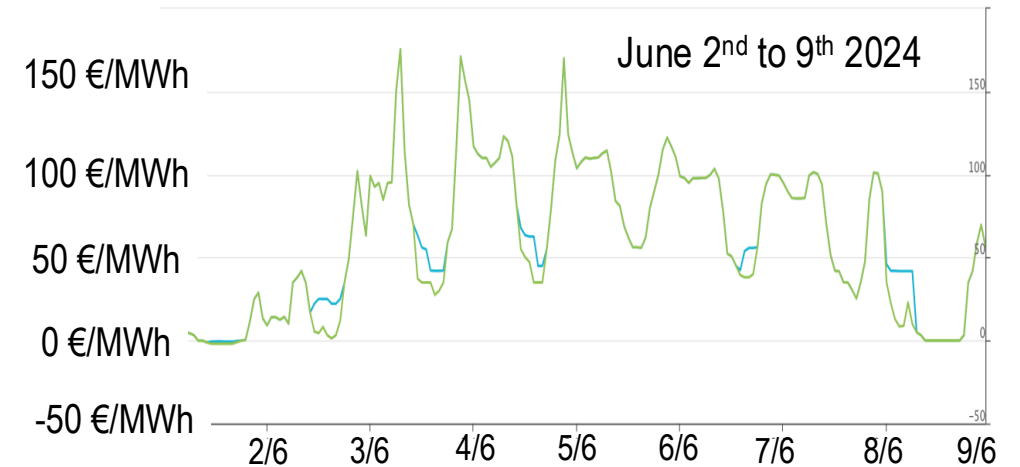
- Implications of the limited capacity of the grid and increased share of RREE:
 - More energy traded for ancillary services
 - Added cost to the system due to larger share of non-dispatchable renewable energy



Power-to-H₂-to-Power based on gas turbines for the avoidance of curtailment

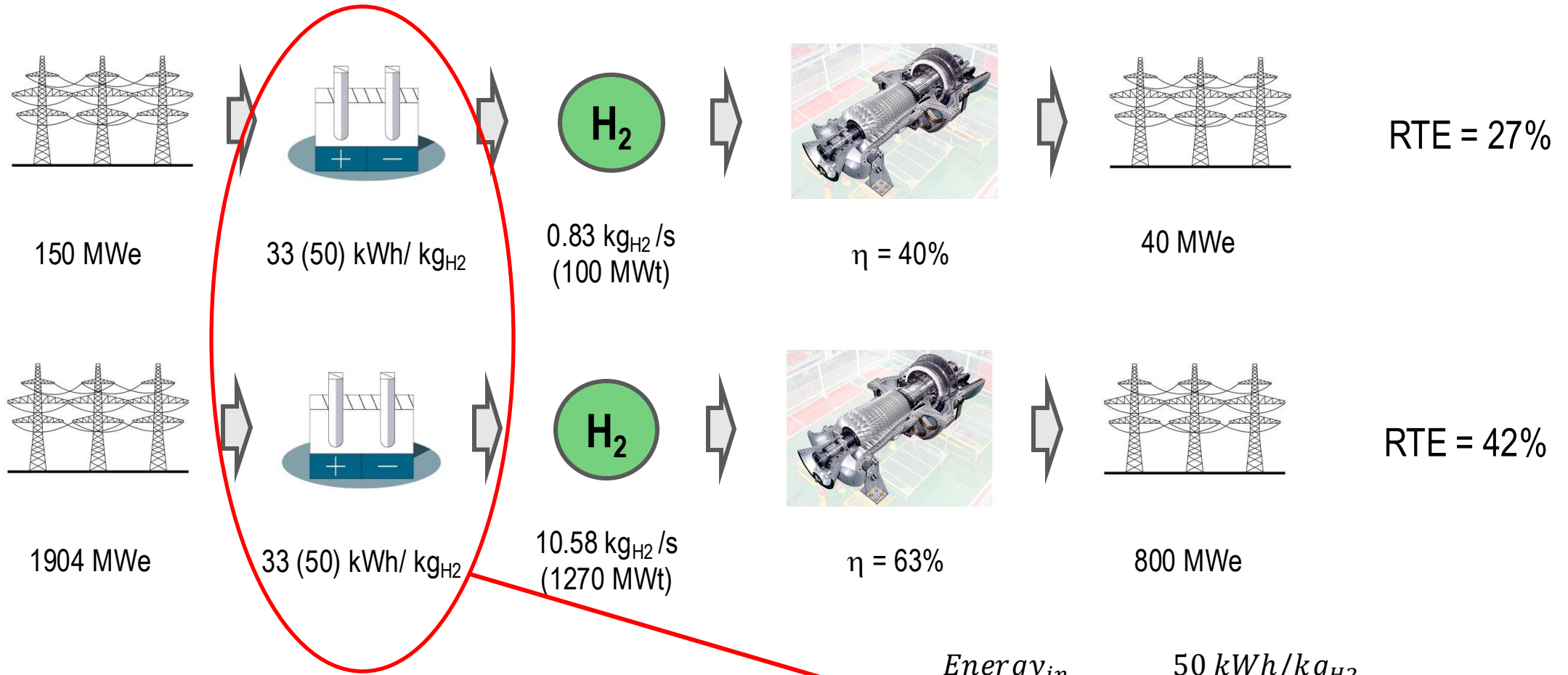


Business model: buy cheap / sell expensive



Model relies on volatility of market

Disclaimer: thermodynamic nonsense of Power-to-H₂-to-Power



$$\frac{Energy_{in}}{Energy_{out}(LHV)} = \frac{50 \text{ kWh/kg}_{H2}}{33.3 \text{ kWh/kg}_{H2}} = 1.5$$

Power-to-H₂-to-Power based on gas turbines for curtailment avoidance: is it a business opportunity?

- Is it a business opportunity?
 - Market volume?
 - Specific return on investment

Grid	Curtailment	40 MWe OCGT			800 (500) MWe CCGT		NG-GW Grid
		AOH	CF	GTs @ ~25%CF	AOH	CF	
Spain 2022	1.5 TWh	12500 h	1.15	4	1200 h	0.14	26.6
Spain 2026 (foreseen)	25 TWh	~170 kh	20	75	20000 h	2.28	26.6
Spain 2035 (foreseen)	125 TWh	~845 kh	95	385	100 kh	11.4	26.6
CAISO (2022)	2.5 TWh	16875 h	2	8	2000 h	0.23	30
ERCOT(2022)	7 TWh	47250 h	5.4	22	5600 h	0.64	70
SPP (2022)	11 TWh	74250 h	8.5	34	8800 h	1.0	37.6

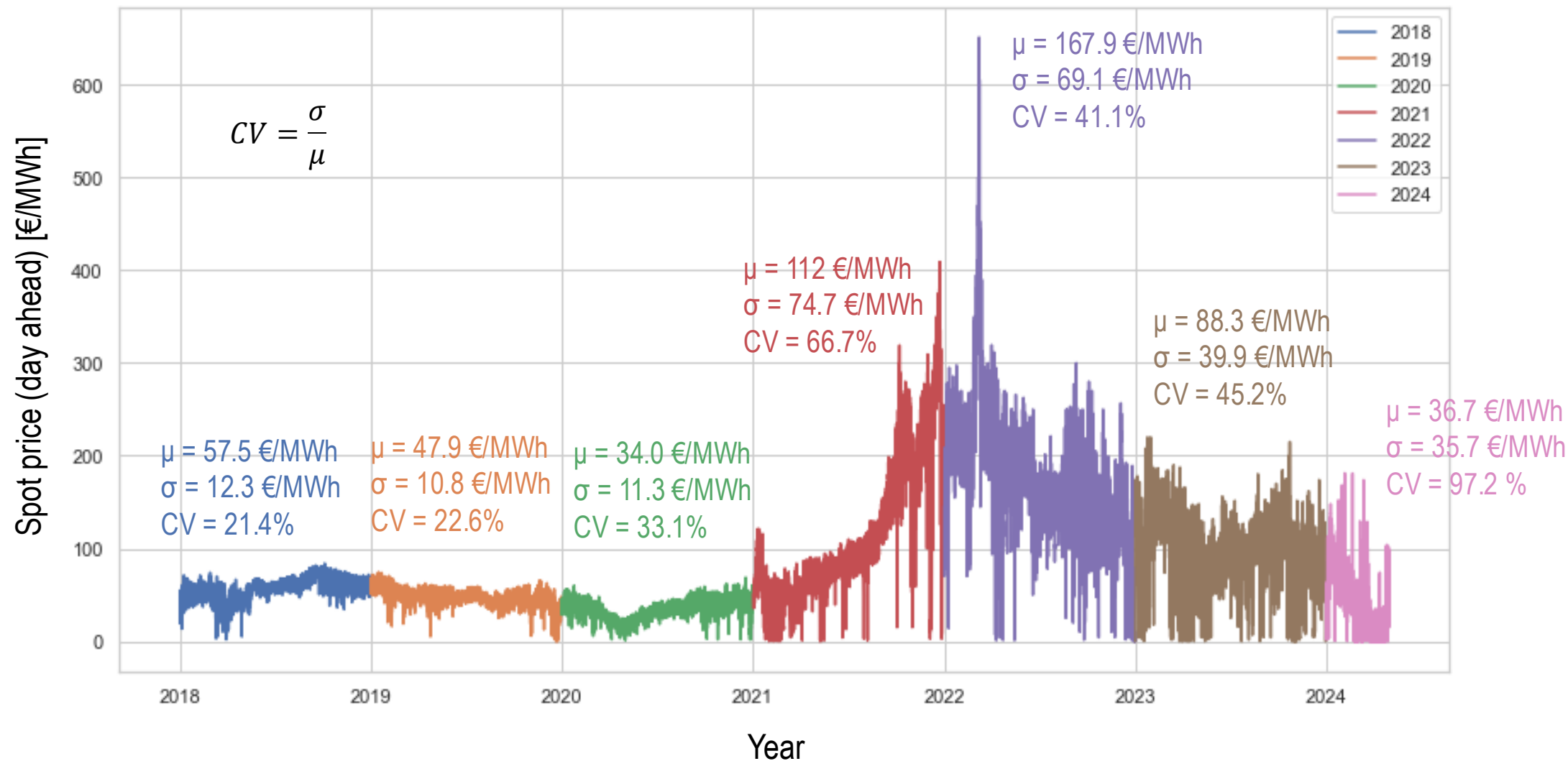
CAISO: California Independent System Operator

ERCOT: Electric Reliability Council of Texas

SPP: Southwest Power Pool

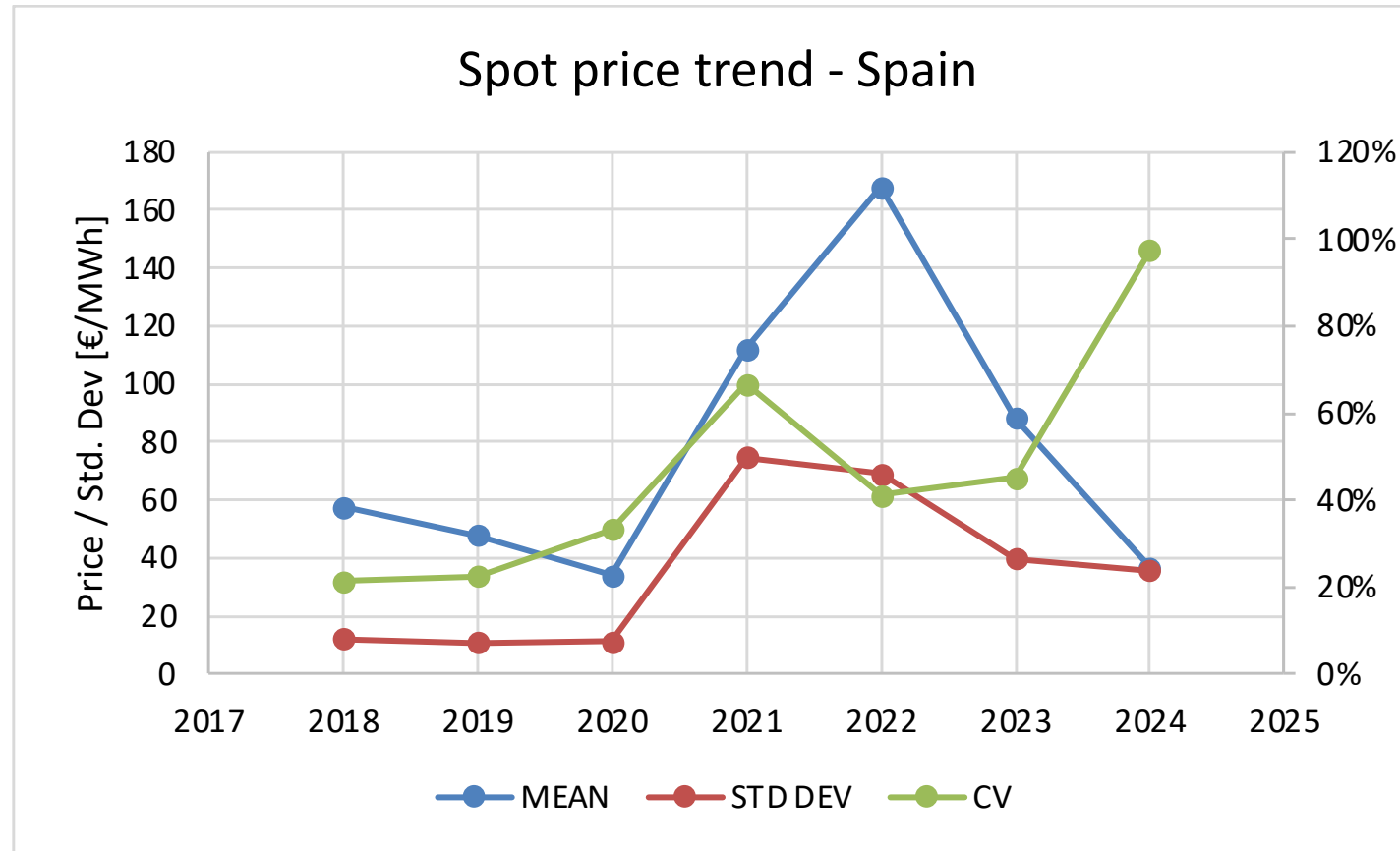
Market of electricity: does it fit this business model?

Recent trends in Spain



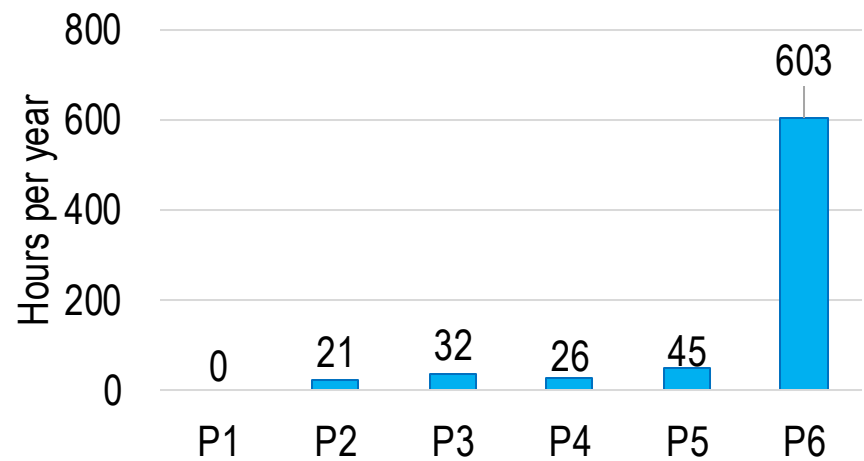
Market of electricity: does it fit this business model?

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Market of electricity – Spain: Operating costs (electricity)

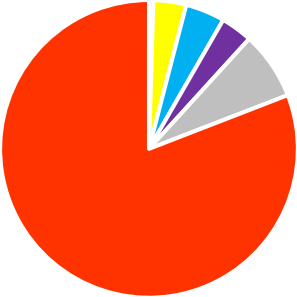
Example for a 40 MWe GT and 1.25:1 charging ratio (2023)



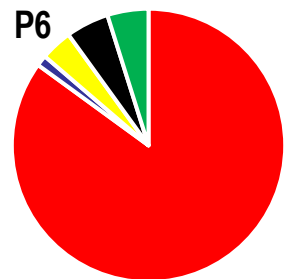
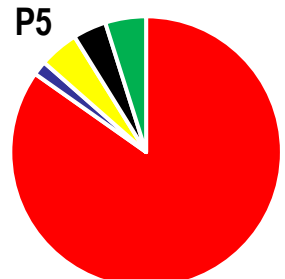
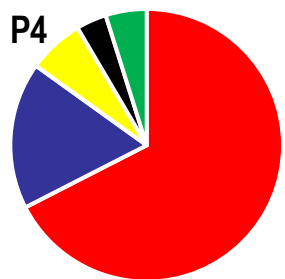
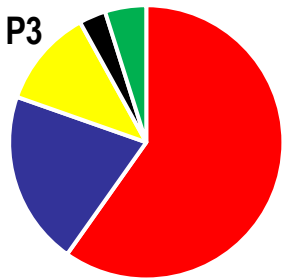
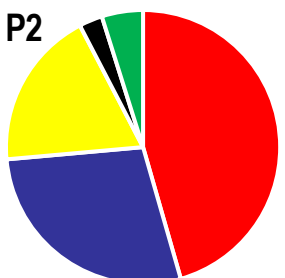
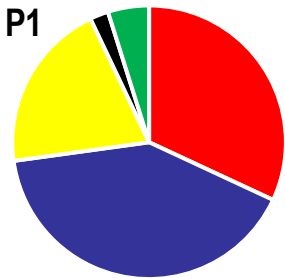
Annual distribution (regulator)



Operation of electrolyzers



■ P1 ■ P2 ■ P3 ■ P4 ■ P5 ■ P6 ■ P1 ■ P2 ■ P3 ■ P4 ■ P5 ■ P6

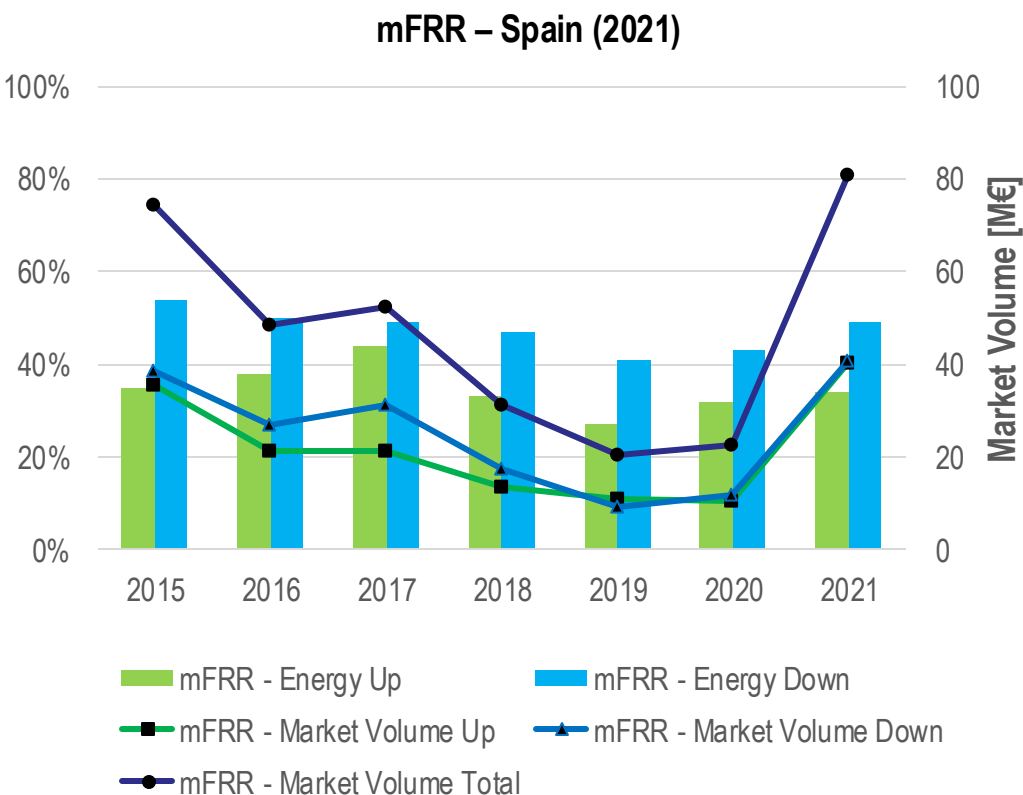
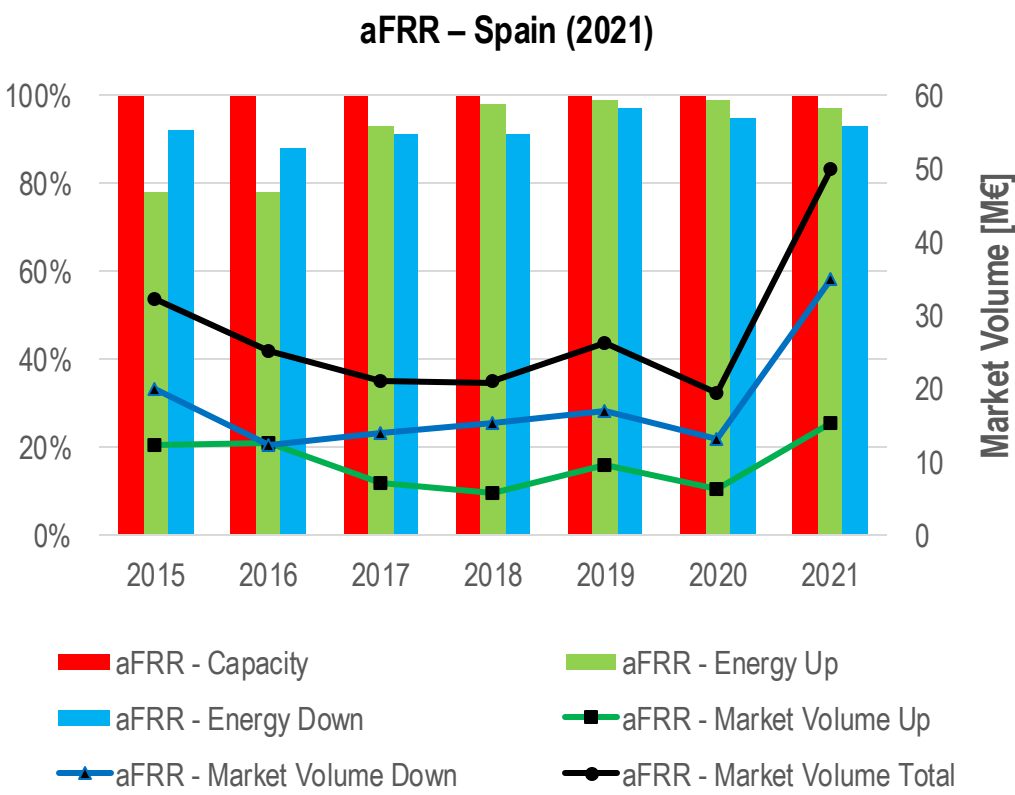


■ Spot price ■ Tolls ■ Charges ■ Margin ■ Tax

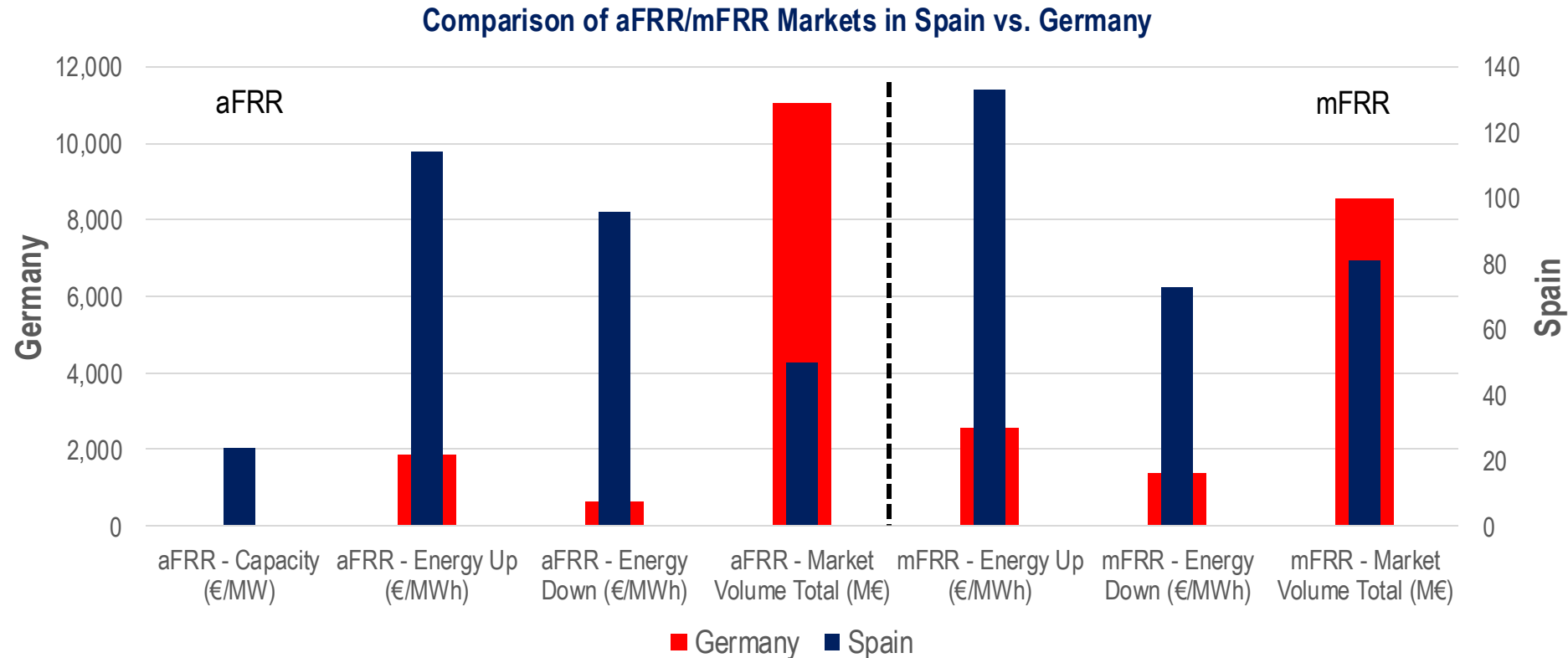
Economics – results

- 40+ cases studied
 - Past and foreseen markets
 - Various volatilities, with and w/o negative prices
 - Potential CapEx & OpEx reductions
 - Technical specs and layouts
 - ...
- Operating on the day-ahead (wholesale) market not profitable today
- Subsidies needed to break even (NPV=0):
 - Wild variability
 - Values ranging from 1 to 30+ times the average spot price

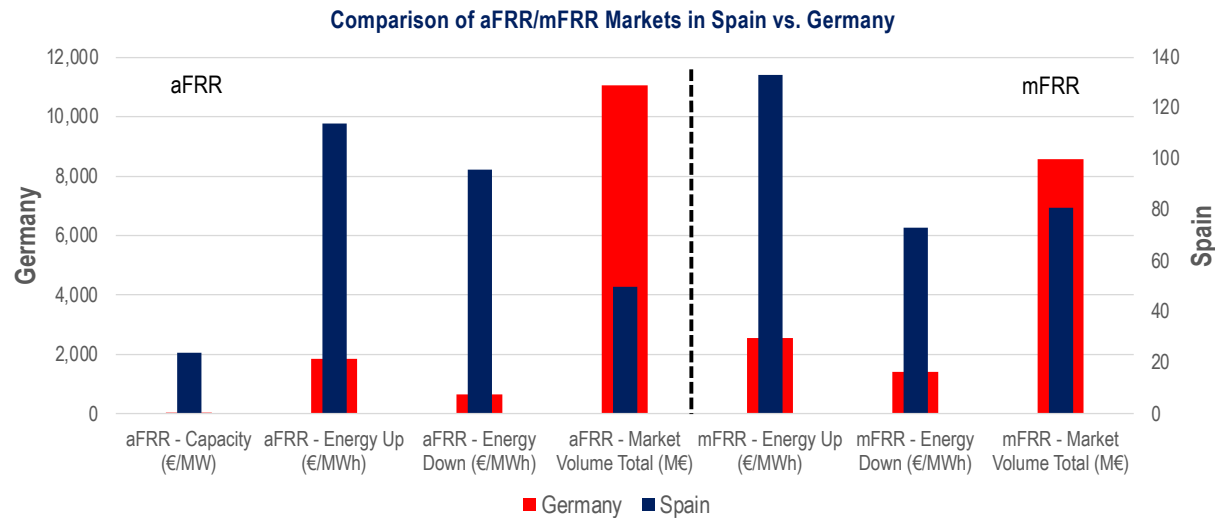
- Operating on secondary (ancillary) markets could turn the coin:



- Operating on secondary (ancillary) markets could turn the coin:
- Case-specific to each market – not a universal business model

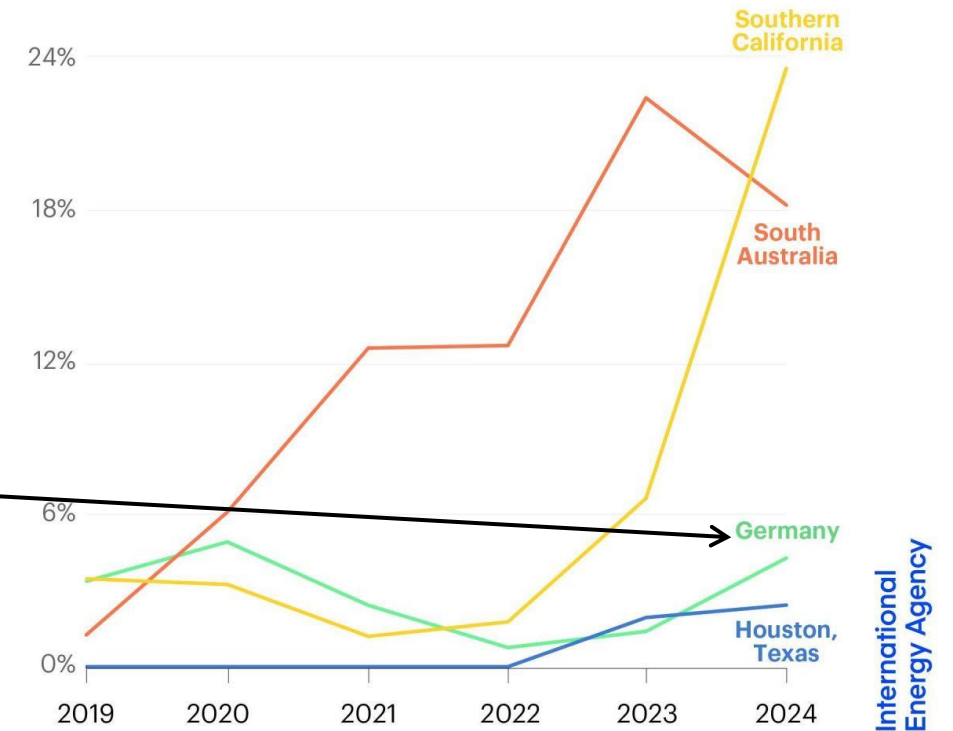


- Operating on secondary (ancillary) markets could turn the coin:
- Case-specific for each market – not a universal business model



Negative electricity prices are becoming increasingly common in some regions

Fraction of hourly wholesale electricity prices which were negative in select regions in the first half of the year, 2019-2024



Source: International Energy Agency

Conclusions

- Power-to-power (GTs running on green H_2) is thermodynamic nonsense, when considered in isolation
- Nevertheless, GTs running on H_2 are part of a larger system and they can:
 - Expedite full decarbonisation of the grid (more RREE more quickly)
 - Compensate for imbalances brought about by massive deployment of RREE (aFRR / mFRR)
 - Contribute to long-time energy storage
- Market volatility contributes to cost-effectiveness of the solution proposed
- Business model cannot rely on day-ahead spot market only
- Being able to provide ancillary services seems mandatory
- Even in the latter case → strongly market-dependent

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