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How much storage do we need for the energy transition?

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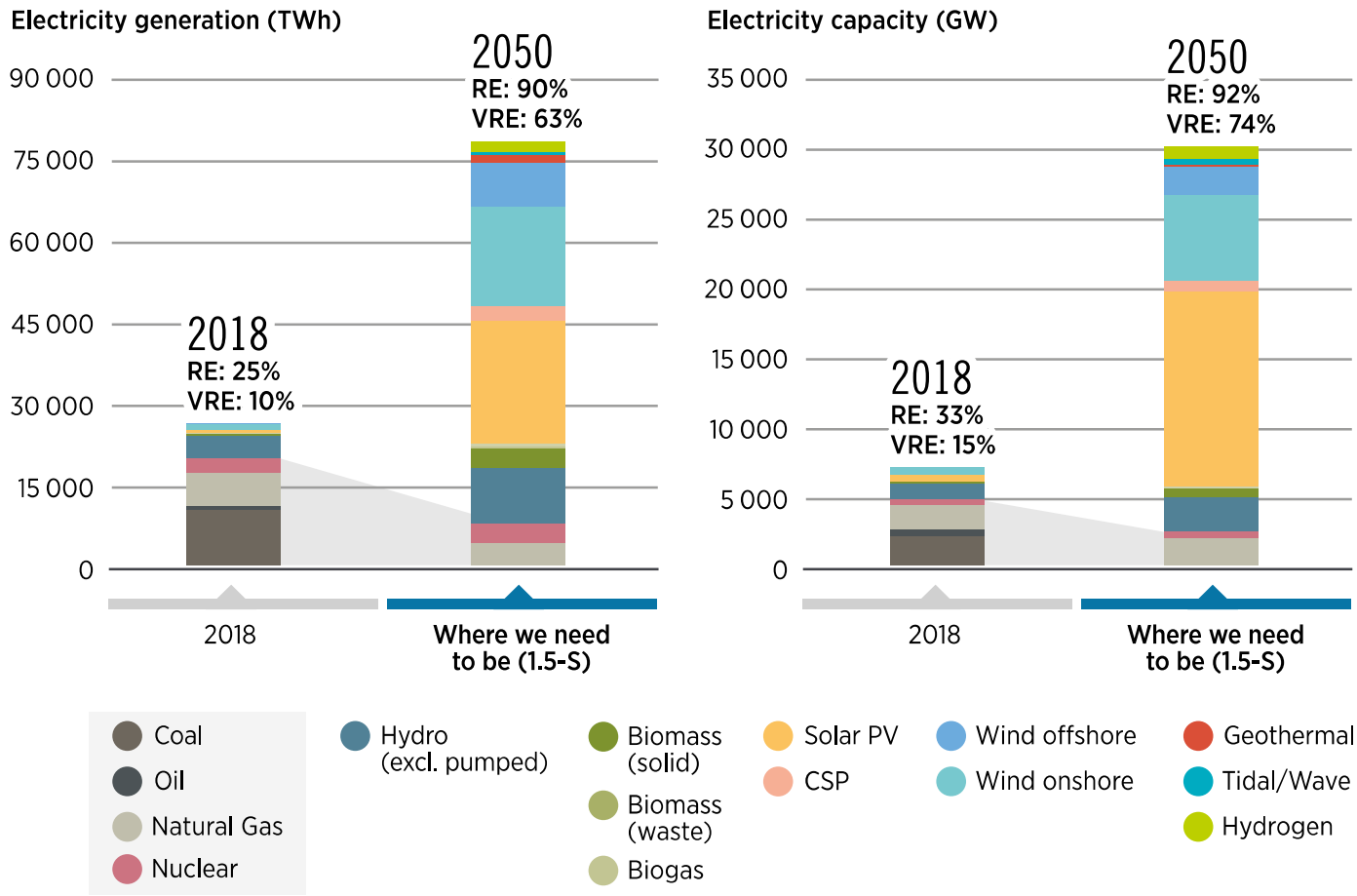
The energy transition requires a revolution in the power sector

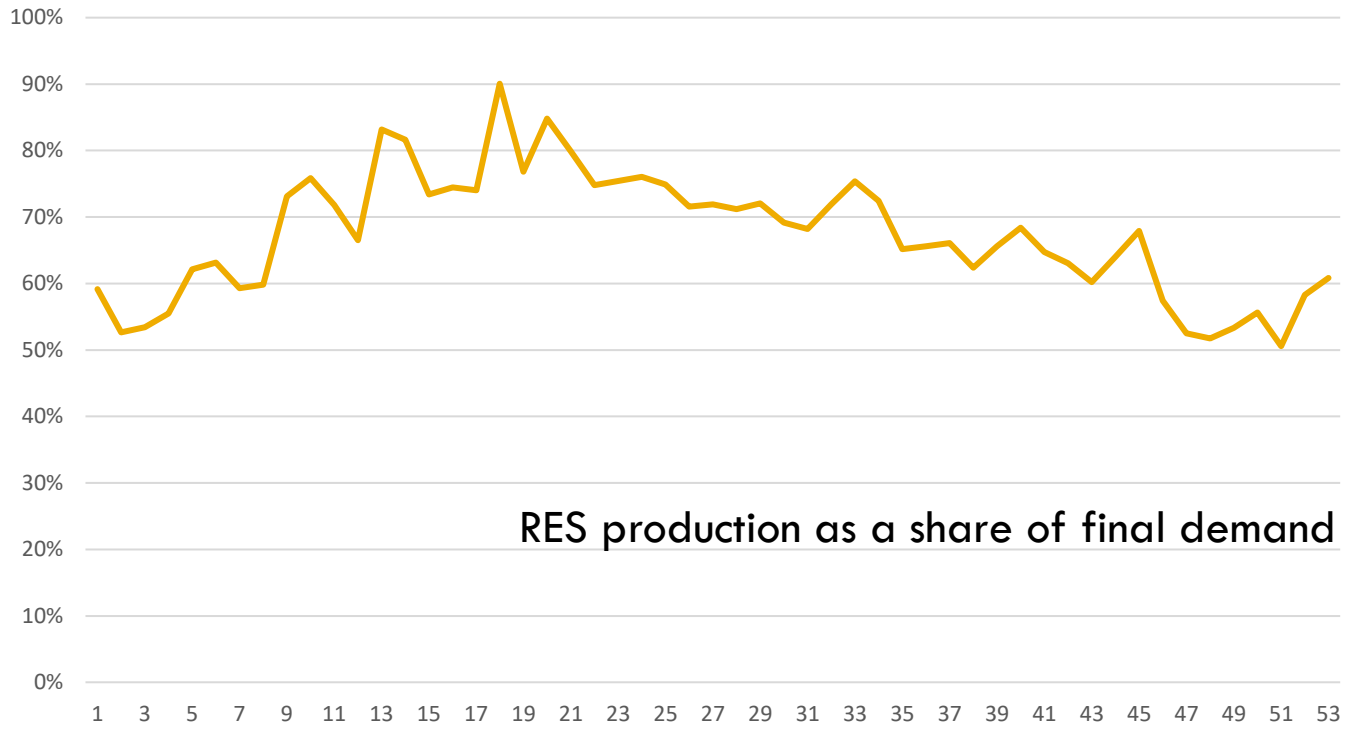
FIGURE 5 **Renewables will dominate the power generation mix**

Electricity generation and capacity by source, 2018, 2050 (TWh/yr and GW/yr) in the 1.5°C Scenario



Source: IRENA World Energy Transitions Outlook 2021

But renewables cannot follow demand



So we need storage:

- How much?
- How do we pay for it?

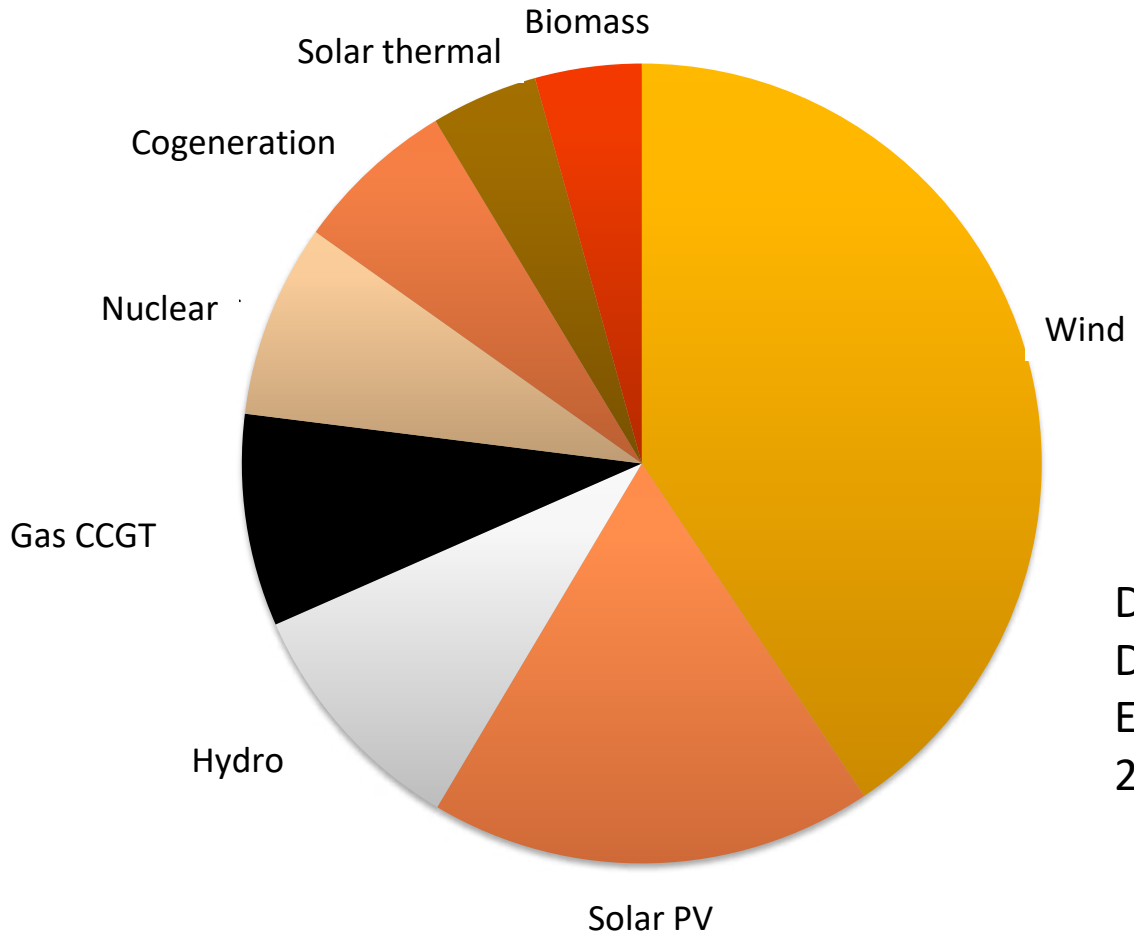
Previous assessments of storage needs

- MIT The Future of Energy Storage (2022)
- Junge et al (2022): Optimal storage
- Barbar et al (2022): Energy storage in India
- Dimanchev et al (2021): The role of hydro
- McPherson et al (2018): Global approach

Our approach

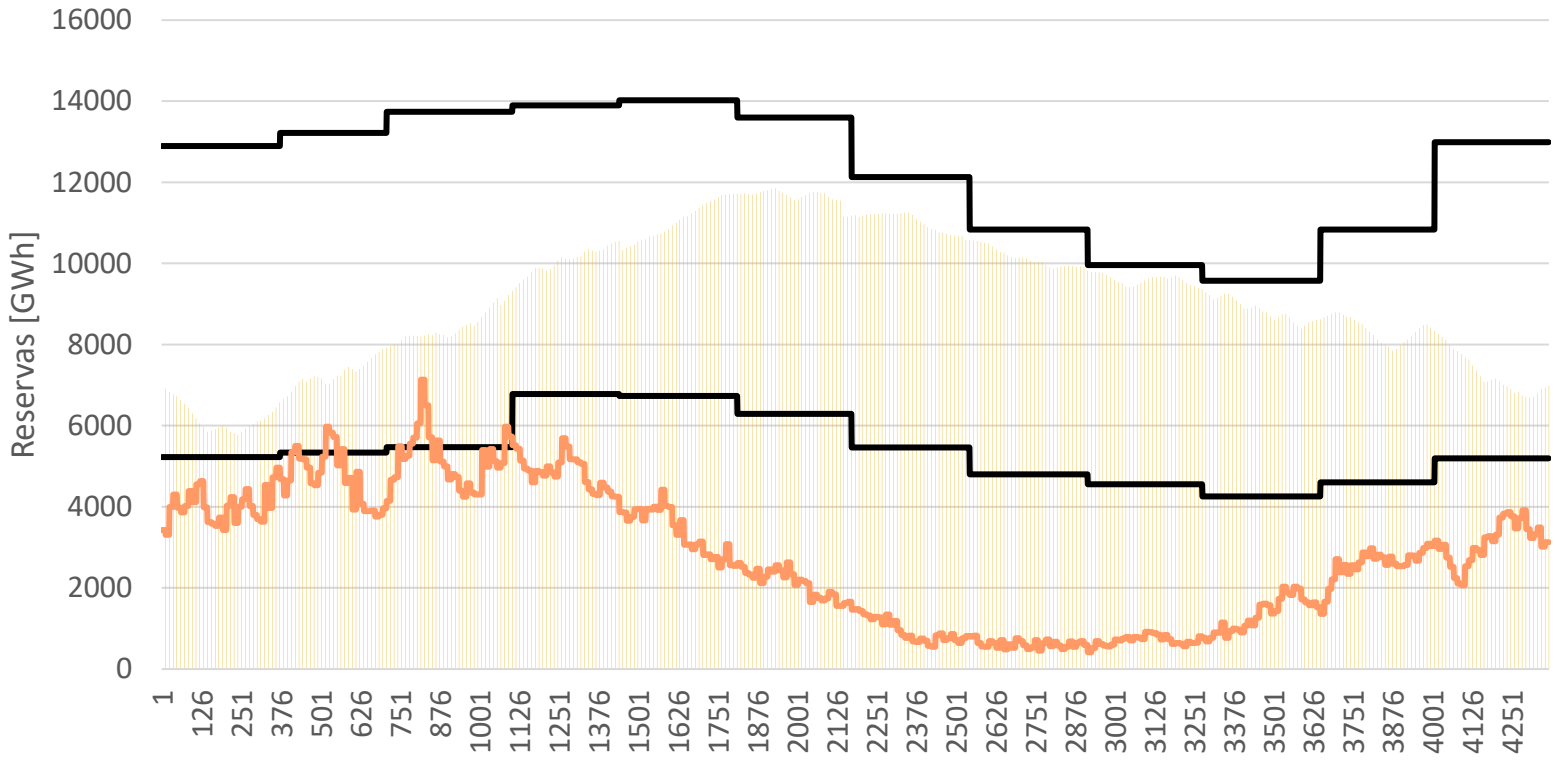
- Worst-case scenario for investments
  - Revenue gap for storage
- Realistic flexibility in hydro
- Sophisticated electricity model (OpenTEPES) with hourly detail

Spain as a case study - 2030



Demand: 263 TWh
DSM: 11 TWh
Exports: 39 TWh
27 GW CCGT

Hydro management



Results: Investment and Operation

	Installed Power [MW]		Installed capacity [GWh]	CCGT [GWh]	RES Spillage [GWh]
	Batteries	Pump Hydro			
Base Case	494	648	25.09	24144	35482
No DSM	347	1497	36.65	24506	35501
Exports	556	1881	44.67	27054	7891
Non-flexible hydro	231	929	28.17	26715	38376
Dunkelflaute	184	912	27.13	27353	32629

Results :Costs

	Total cost [M€]	Investment cost [M€]	Average marginal cost [€/MWh]
Base Case	3985	49.4	63.03
No DSM	4064	75.0	62.67
Exports	4604	110.6	92.12
Non-flexible hydro	4254	53.6	62.29
Dunkelflaute	4339	50.2	65.68

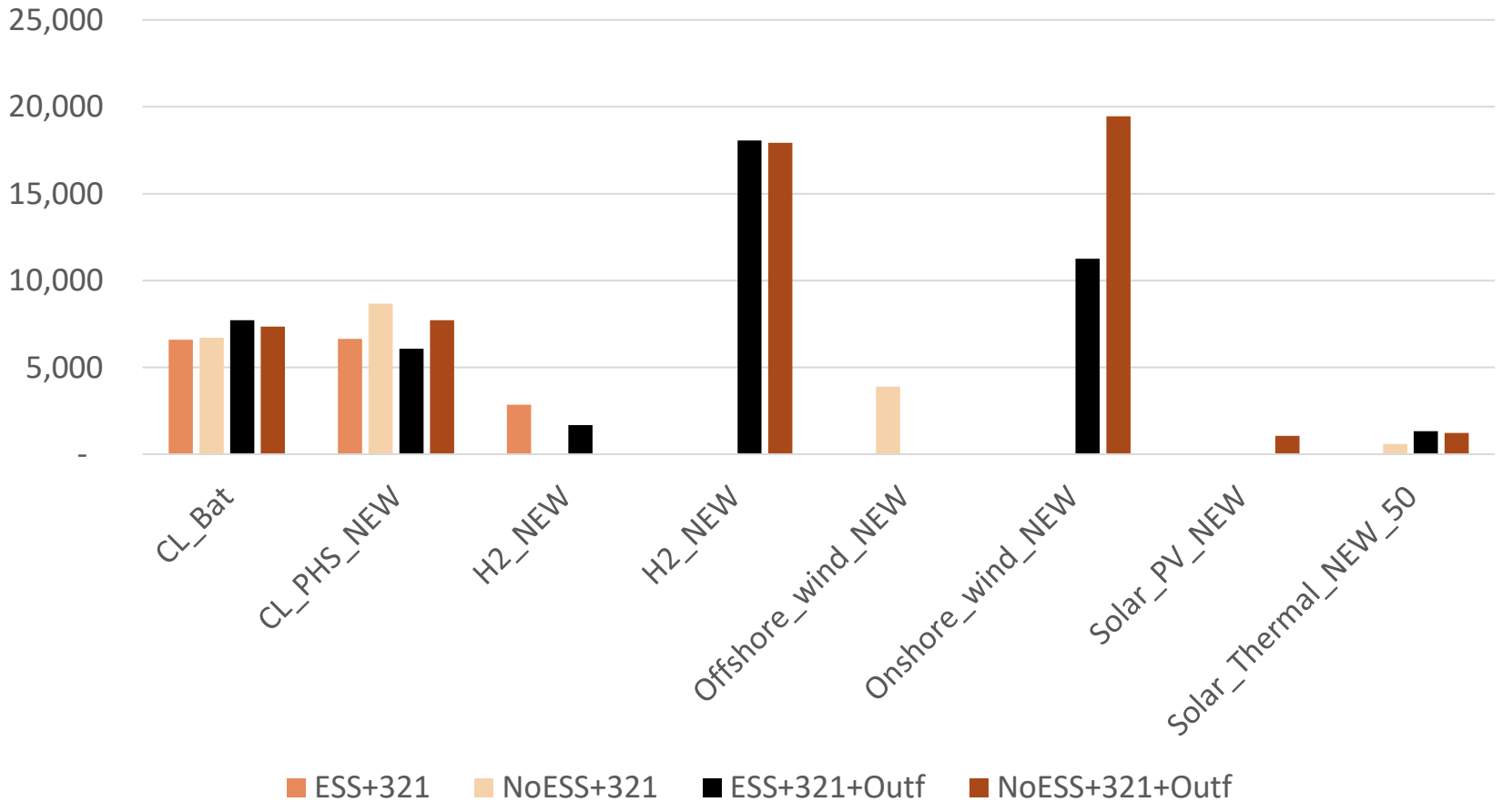
Results: Storage Revenues

	Base Case		No DSM		Exports		Non-flexible Hydro		Dunkelflaute	
	Batteries	PHS	Batteries	PHS	Batteries	PHS	Batteries	PHS	Batteries	PHS
Generation [M€]	6.30	22.92	5.38	47.53	14.28	95.85	2.98	29.70	2.36	29.62
Consumption [M€]	-3.06	-5.85	-2.39	-13.43	-9.64	-48.48	-1.57	-7.75	-1.22	-8.17
Down reserve[M€]	4.14	0.11	3.34	0.69	8.69	1.52	2.77	0.95	2.10	0.65
Up reserve[M€]	3.74	1.01	2.88	3.45	6.75	7.69	2.03	2.87	1.55	2.65
Annualized investment [M€]	-20.92	-22.82	-14.69	-56.13	-23.51	-82.91	-9.77	-39.61	-7.79	-38.23
Profit [M€]	-9.80	-4.63	-5.48	-17.89	-3.43	-26.33	-3.56	-13.84	-3.00	-13.48
Prof it[M€/GW]	-19.84	-7.15	-15.79	-11.95	-6.17	-14.00	-15.41	-14.90	-16.30	-14.78
Profit [€/MWh]	-12.01	-7.08	-9.22	-12.94	-6.66	-11.26	-9.37	-18.73	-10.22	-15.76

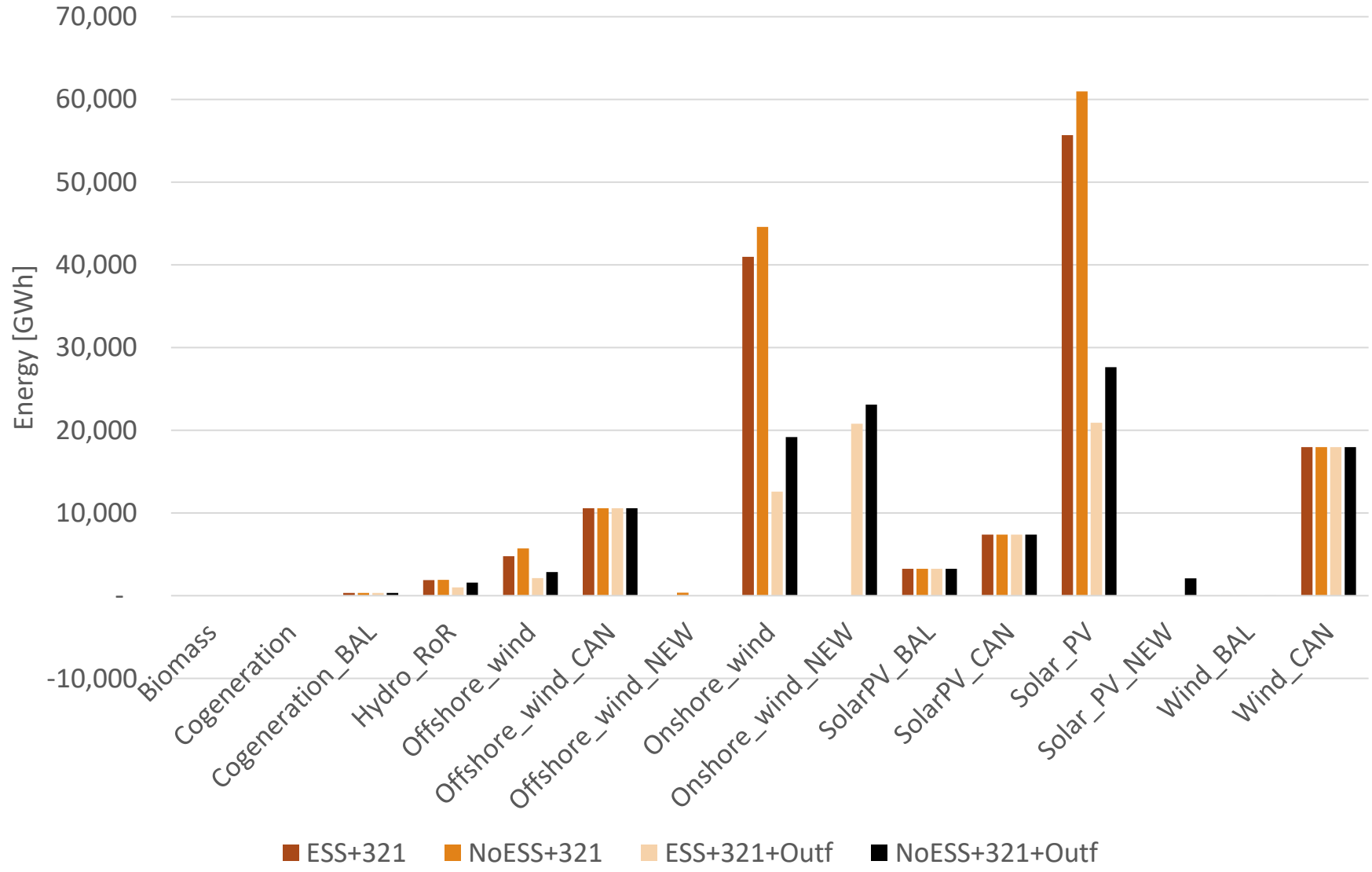
The 2050 case

- Fully-decarbonized power system
- 417 TWh demand:
  - 321 TWh final demand
  - 96 TWh hydrogen production (flexible or not)

Results: Installed capacity



Results: RES Spillage



Conclusions

- 2030
  - Storage needs: 0.01% of demand
    - But needs additional markets/support
  - Hydro key for flexibility
  - DSM competes with batteries
  - Gas comes to help if needed
- 2050
  - Storage needs: 0.07% of demand (still needs support)
  - Seasonal storage needed (H2?)
  - Sector coupling helps much

Thanks for your attention

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