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Which role will the pumped-storage hydro and the batteries play in the future Spanish system: a case study?

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1. **Introduction**
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Why flexibility will be needed in future electric systems?

1. Conventional generation is being phased out
2. VRES introduce additional flexibility requirements

Flexibility **mechanisms**:

- ESS (**Energy Storage Systems**) (PSH, batteries)
- Flexible electricity **generation** (CCGT, hydro)
- Flexible **demand** (DSM)
- **Grid** expansion

Operational flexibility

- **Ability of the system to withstand to the uncertainty and variability in generation and electricity demand**, while maintaining the desired **reliability** at an affordable **cost**
- Measure: **the contribution** of each dispatchable technology **to the variation of the (net) demand** at different time horizons (monthly, weekly, daily)

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Operation model openTEPES

https://pascua.iit.comillas.edu/aramos/openTEPES/index.html

Pumped-storage hydro (PSH) or batteries **operate shifting energy between different timeframes** and represent a **small modification of the variable operation cost →** a detailed system operation modeling is mandatory

- **Hourly operation**
- **Tight and compact UC formulation**
- **Natural scaling** of all the variables
- **Unit-based modelling of energy storage units**

Demand and operating reserves

- **Balance** of generation and demand [GW]
- **Upward and downward operating reserves** [GW] provided by controllable generators (CCGT, storage hydro) and ESS (pumped-storage hydro, batteries), **including activation** of these reserves [GWh]
- **Reserve activation**: a proportion (e.g., 25-30 %) of the power provided as operating reserves which is asked to be deployed as energy

Thermal subsystem

- Maximum and minimum output of the **second block** of a committed unit (all except the VRES units) [p.u.]
- Total output of a committed unit [GW]
- **Logical relation between commitment, startup and shutdown** status of a committed unit [p.u.]
- Maximum **ramp up and ramp down** for the second block of a thermal unit [p.u.]
- Minimum **up time and down time** of a thermal unit [h]

Hydro and storage subsystems

- Power plants: **hydro**, **open-loop pumped-storage hydro (PSH)** aggregated in management units, **closed-loop PSH** treated individually, and system **battery** storage
- ESS **energy inventory** (only for load levels multiple of 24, or 168 h depending on the ESS type) [TWh]
- Total charge of an ESS unit [GW]
- Maximum and minimum charge of an ESS [p.u.]
- **Incompatibility between charge and discharge** of an ESS [p.u.]

Variable renewable energy sources (VRES)

- Power plants: solar PV, solar thermal, onshore wind, biomass
- Distinction between existing onshore wind and new one
- **Maximum and minimum hourly variable generation**

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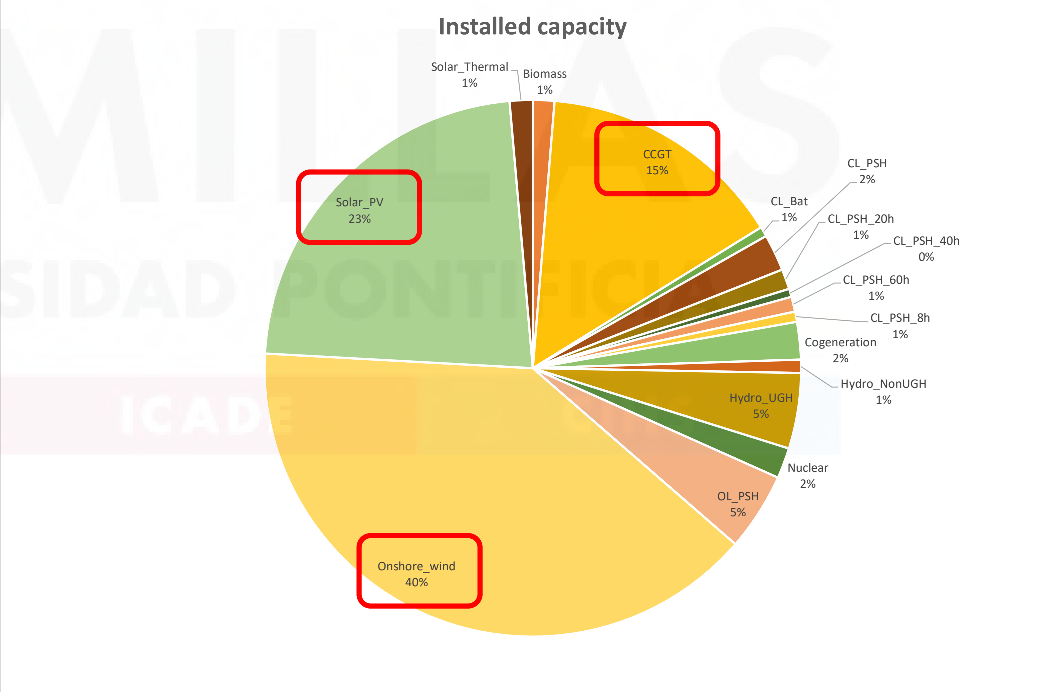
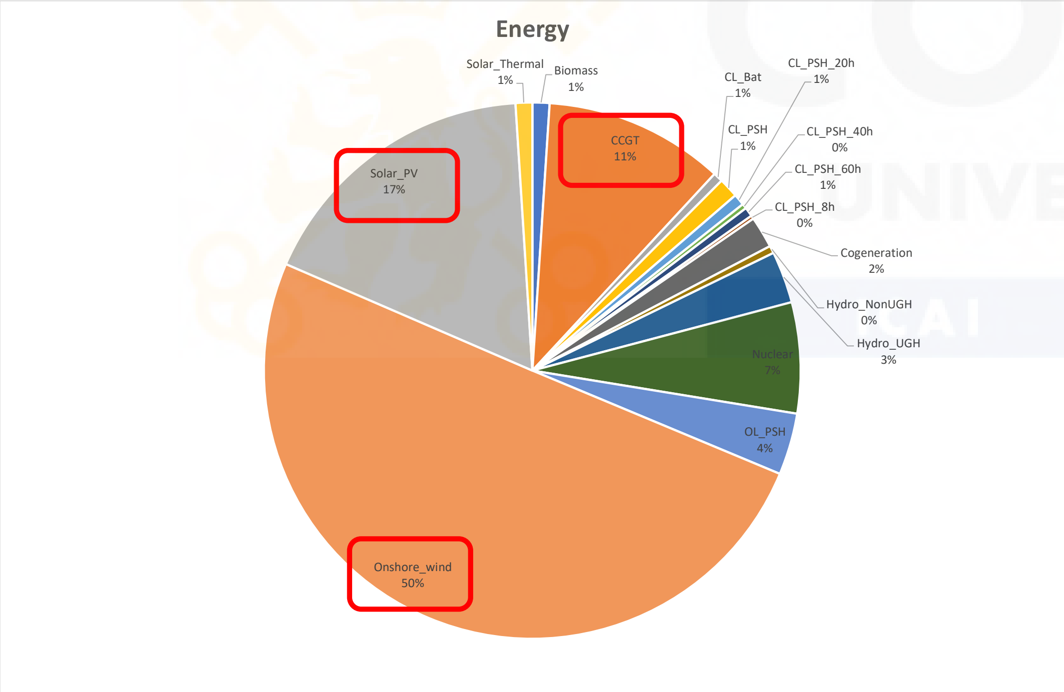
Case study: Spain 2030

- **10-year Integrated National Energy and Climate Plan (NECP)**
- Installed capacity: **165,000 MW**
- Half of the nuclear units phased out (**3,100 MW**), no coal units, existing CCGT (**24,500 MW**)
- Significant investments on solar PV (**37,500 MW**) and onshore wind (**65,200 MW**)
- Existing (**11,500 MW**) and additional pumped-storage hydro (**5,300 MW**)
- Batteries forced to be installed (**1,000 MW**)



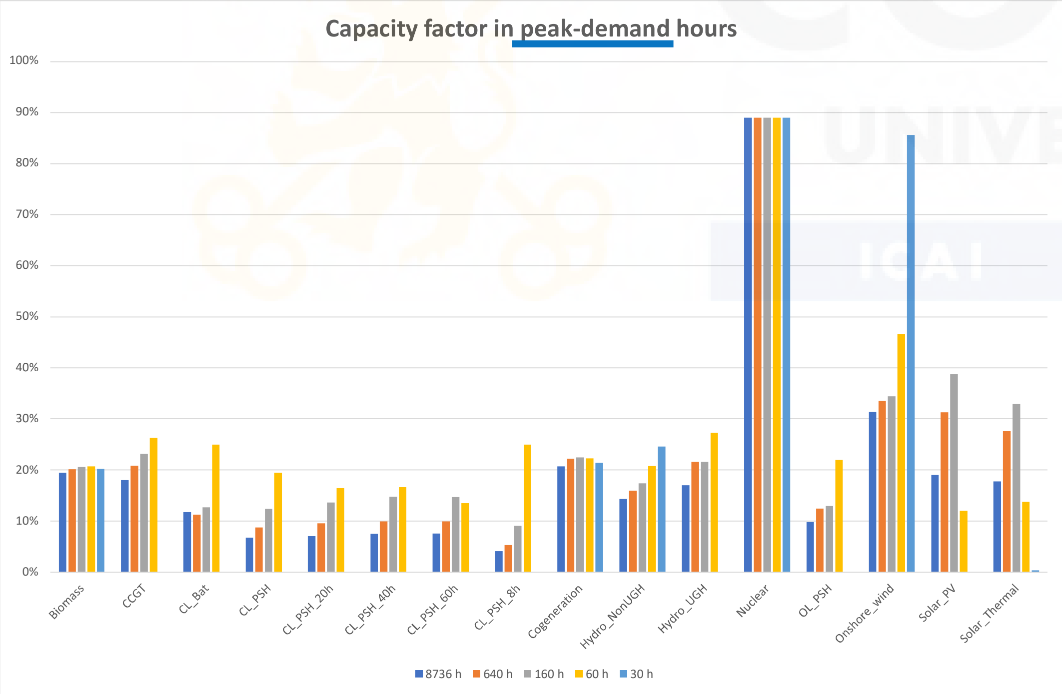
System operation

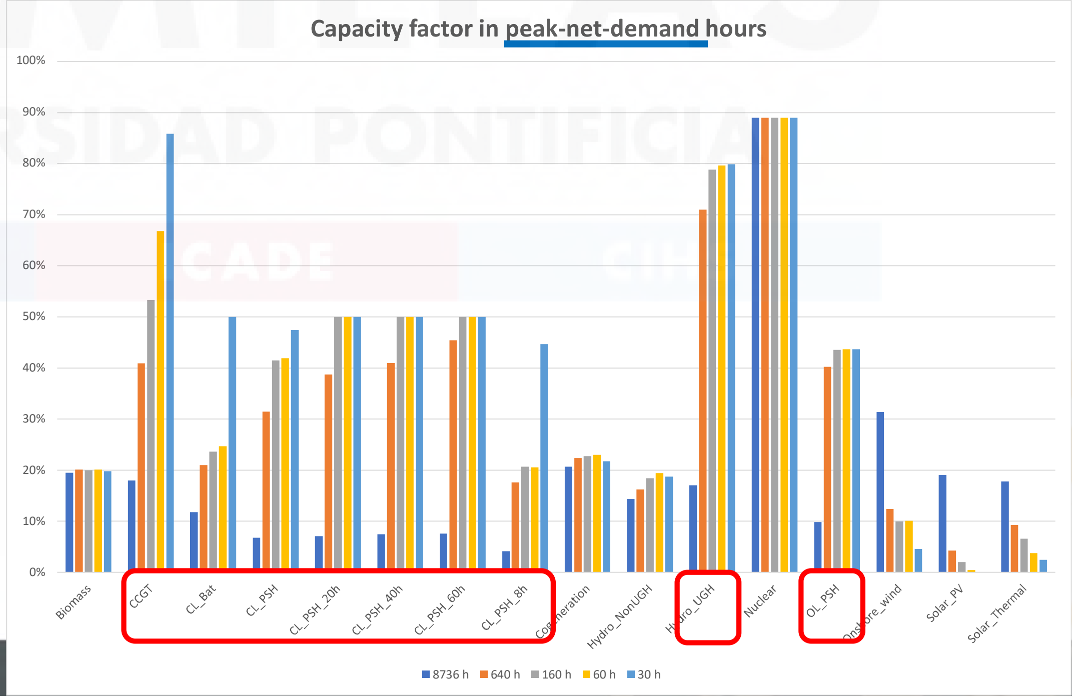
Energy demand: **334,270 GWh**



Firmness/Electric Load Carrying Capability (ELCC)

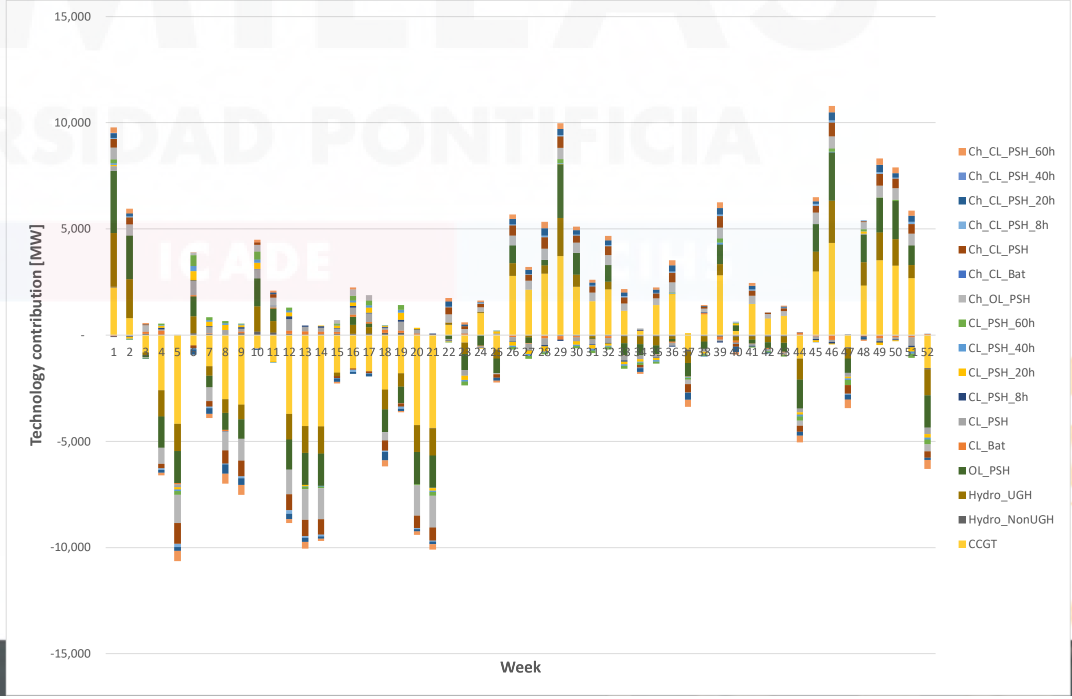
Capacity factors of the different technologies at **peak hours of demand and net demand**





Flexibility

Technology contribution to the monthly/weekly variation of the net demand (difference between the value and its mean)



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Conclusions

- Future electric system with a **high share of VRES will require flexible generation and ESS**
- A **detailed operation model** is mandatory and suitable for capturing operation of ESS
- At **peak net-demand hours, CCGT, hydro, open- and closed-loop PSH have larger capacity factors** while **VRES decrease their capacity factor**
- **Flexibility** provided by **CCGT, hydro, PSH, and batteries**
- **The higher storage capacity the more ESS is used** (PSH with large reservoirs preferred over smaller ones). **Batteries compete with the PSH with small size (8 h)**

Thanks for your attention

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