INSTITUTE OF ENERGY
FOR SOUTH-EAST EUROPE

One Day IENE Workshop:

Electricity Storage and Grid Management for Maximum RES Penetration

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Pumped hydro storage: A prerequisite in the path towards a net-zero energy system

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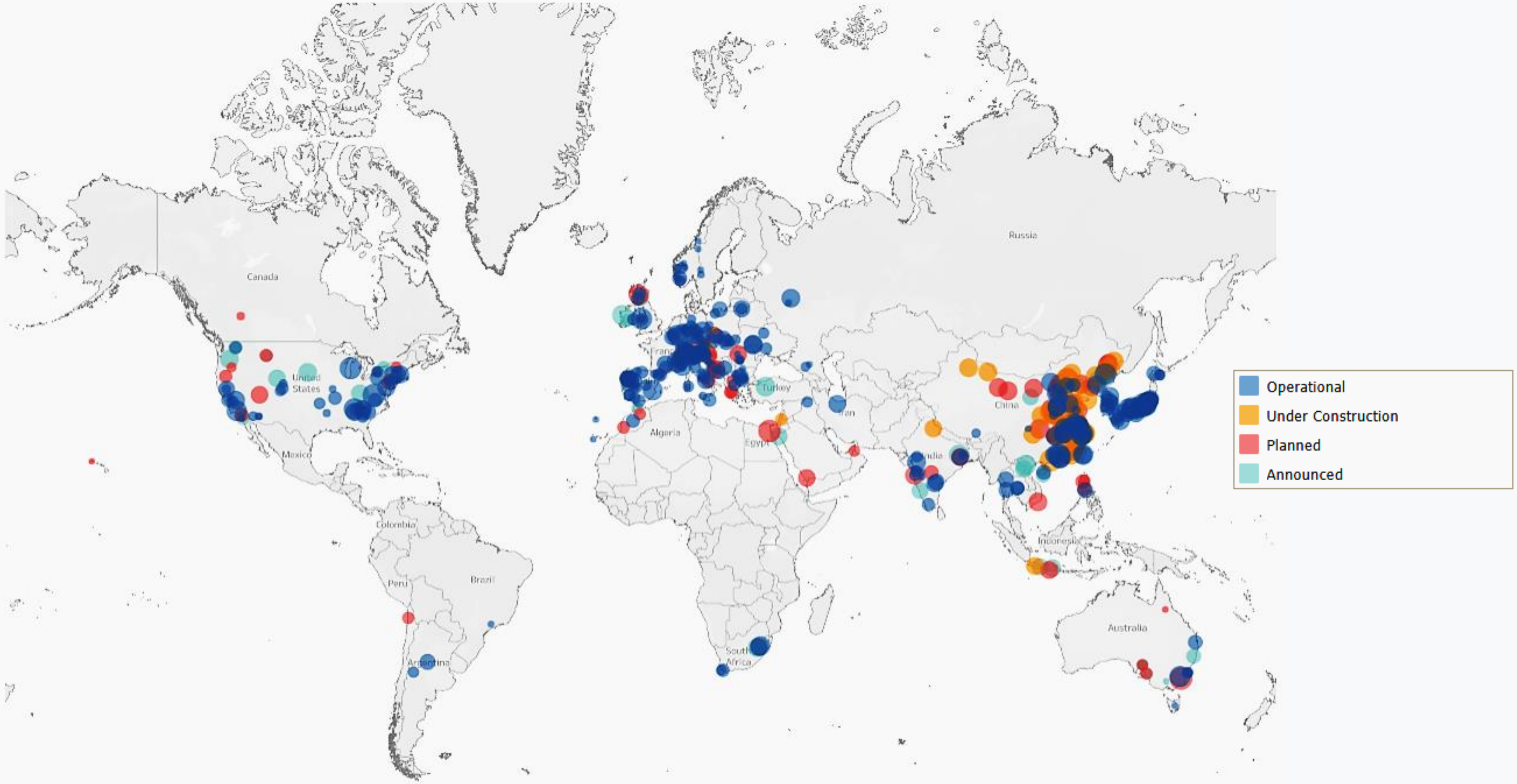
Topics to be discussed

- Pumped hydro storage (PHS): how indispensable is it in the pathway towards a fossil-free power system?
- Are Li-ion batteries a PHS substitute as long-duration storage alternatives?
- Can PHS contribute to capacity adequacy?

Introduction

Pumped-Hydro Storage today



- ❖ PHS Installed Capacity worldwide (2022): **164.76 GW**
- ❖ Installed capacity may increase up to **240 GW** by **2030**

*https://www.hydropower.org/

Value of PHS

- A most effective energy/price arbitrage instrument
- System flexibility services
- Inertia, frequency regulation, voltage control
- Contribution to system adequacy (capacity value)

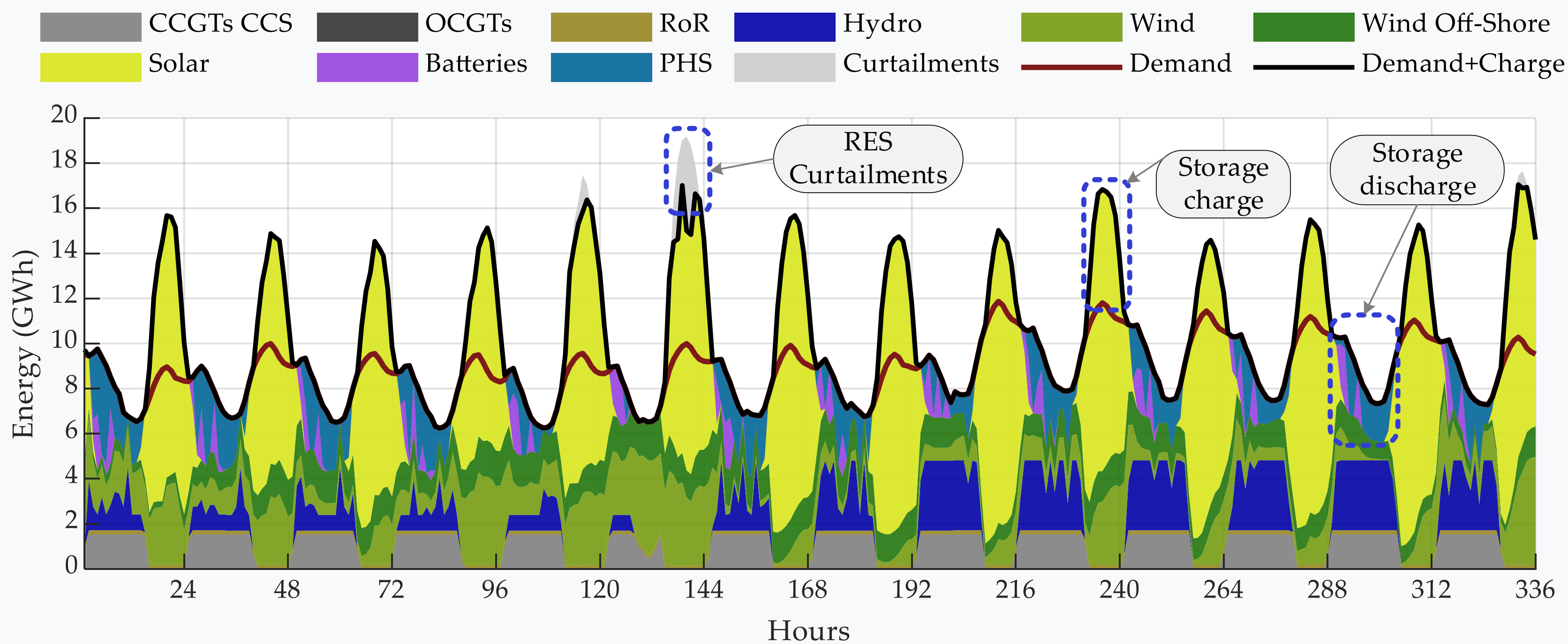
➢ **PHS a key enabler for the transition towards a low carbon energy system**

Significance of PHS to support the future development of the Greek power system

Capacity Expansion Planning (CEP) model employed

- CEP model allows to determine **optimal generation mix for a future fully decarbonized power system**, including storage
- Results shown for ideal **greenfield development scenario** (i.e. with no pre-existing thermal, RES and storage capacity)
  - Only **existing hydropower fleet** is taken as is and not optimized:
    - 12 large hydropower plants with large reservoirs and natural inflows
    - 2 open-loop PHS (Thisavros & Sfikia)
    - Small run-of-river installations
  - **Isolated system assumption** (no external interconnections)
  - **Optimization objective:** Minimize total cost (investment & variable)
- **High RES penetration levels** targeted, up to 100%

System operation at 90% RES penetration

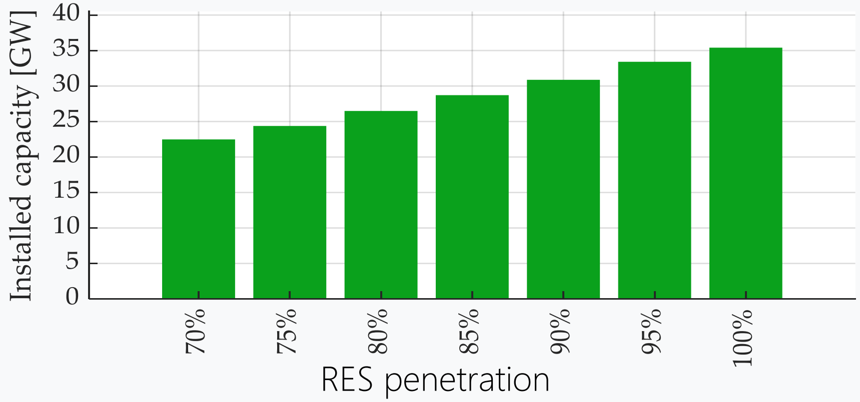


❖ PHS systematically do energy arbitrage between mid-day and evening/night hours

- Management of mid-day congestion due to PVs
- Mitigation of RES curtailments and cost reduction

RES & Storage needs escalation at increased RES penetration targets

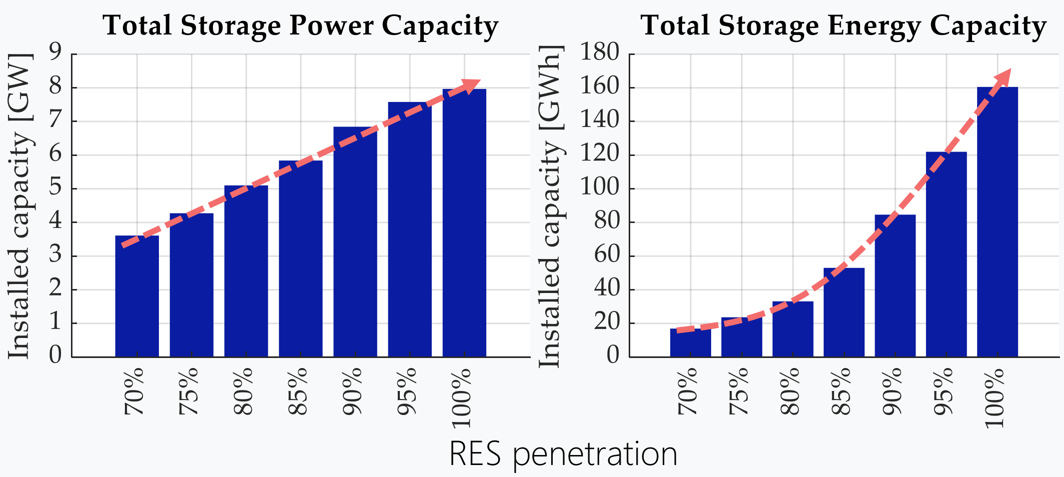
RES installed capacity (all RES technologies)



Total installed RES capacity increases **from ~22 GW to ~35 GW,** to achieve RES penetration target of 70% to ~100%

Note: RES capacities for increased system demand of ~70 TWh

Aggregate power & energy capacity of required storage

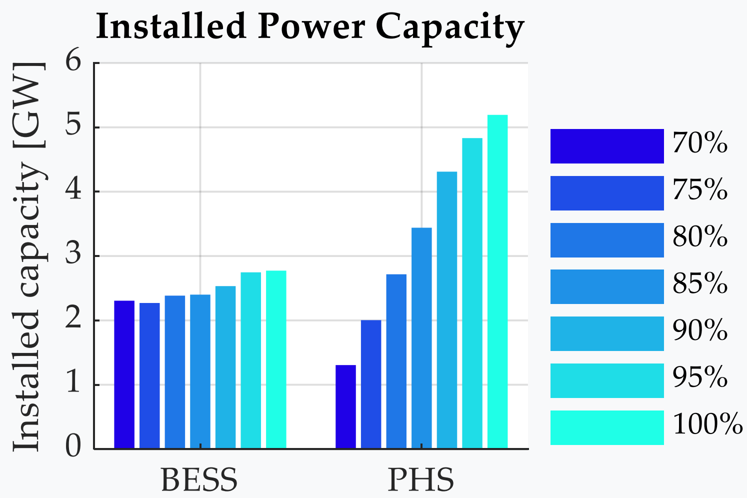


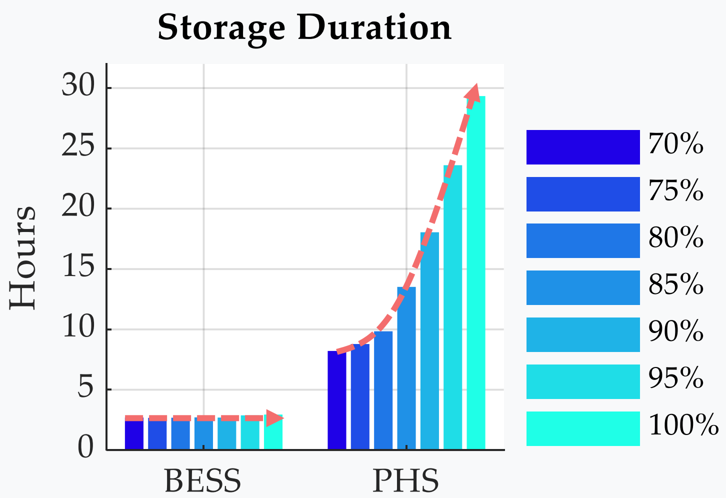
Storage capacity escalates fast at high RES penetrations:

- **Linear** increase of **power capacity**
- **Accelerated** increase of **energy needs**

Note: Storage needs amplified due to lack of external system interconnections

Allocation of storage needs to principal technologies

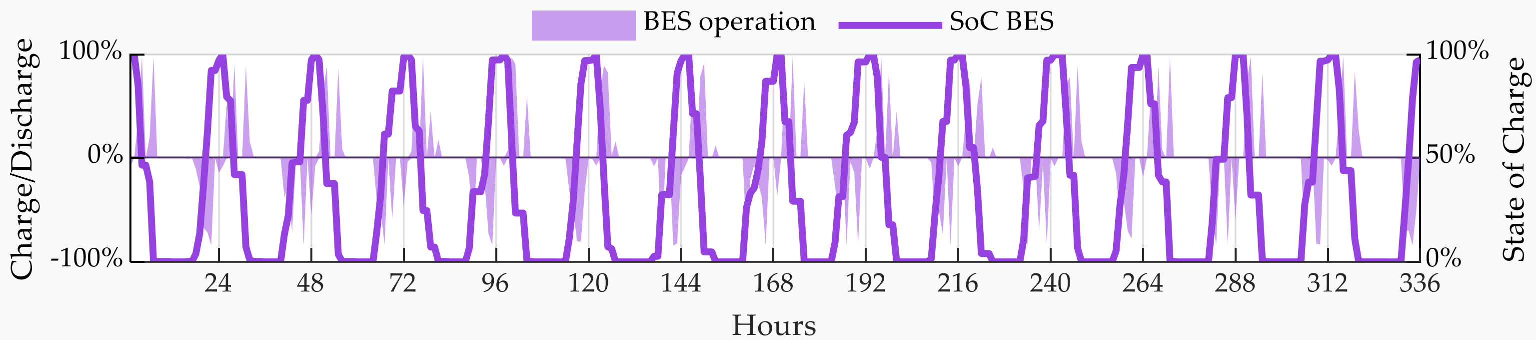




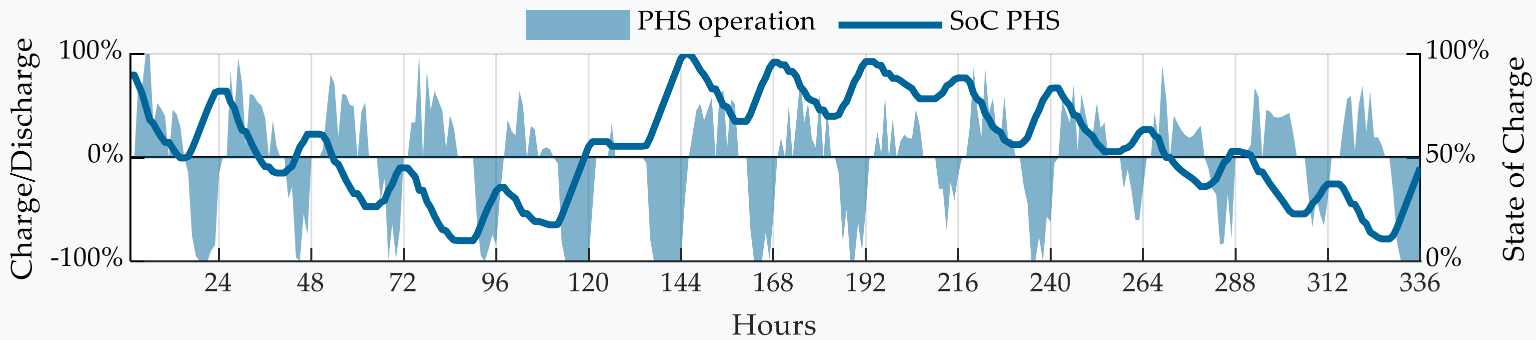
- **BESS needs remain constant,** regardless of RES penetration target:
  - 2 GW to 3 GW with a ~2-3 h duration
- Needs for PHS escalate fast to support increasing decarbonization targets:
  - From 1.3 GW to 5.1 GW
  - From 10 GWh to 160 GWh (7.5 h to 30 h average duration)

BESS vs. PHS operation at 90% RES penetration

BESS



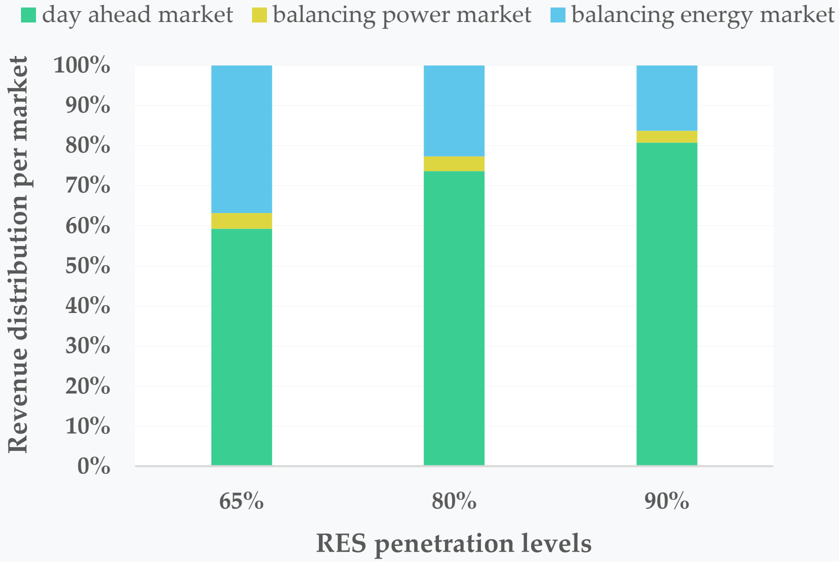
PHS



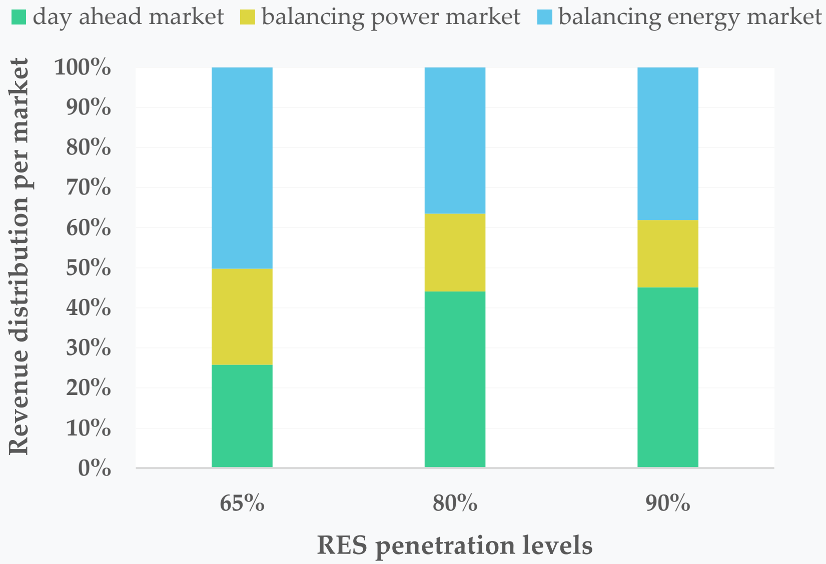
- Short duration storages (BESS): daily cycles
- Long duration storages (PHS): both daily & multi-day cycling

Allocation & evolution of market revenues

PHS @ 12-h



BESS @ 2-h



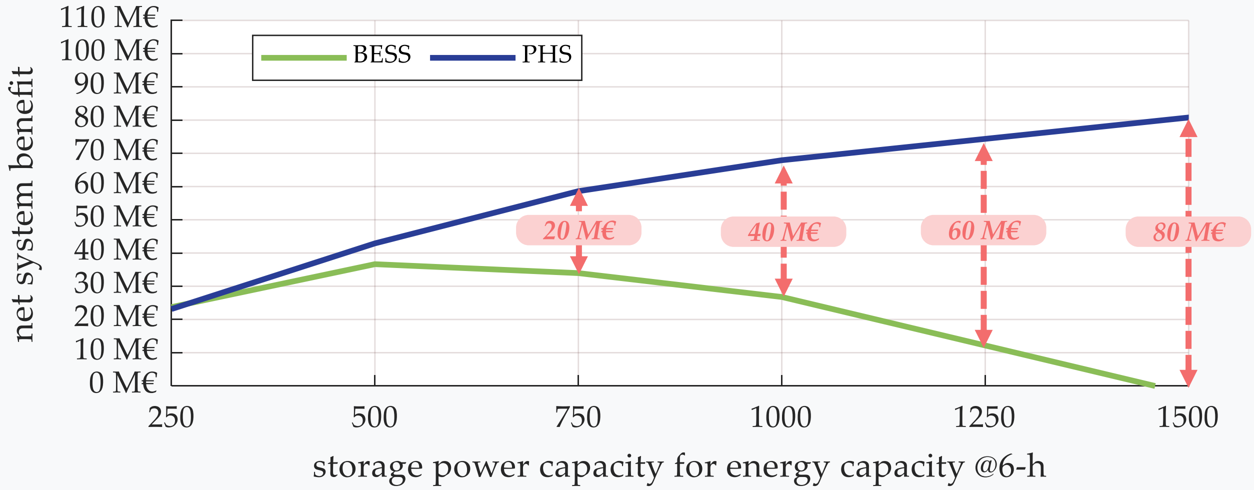
- ❖ DAM revenues gradually increase at higher RES penetration levels
- ❖ Long duration storages (PHS) obtain their revenue primarily from the spot energy market; income from balancing power market very limited
- ❖ Short duration storage (BESS) earnings primarily come from the balancing market (power and energy); energy arbitrage remains insignificant

Are Li-ion batteries a PHS substitute as long-duration storage alternatives?

A comparison between PHS & BESS from a system perspective

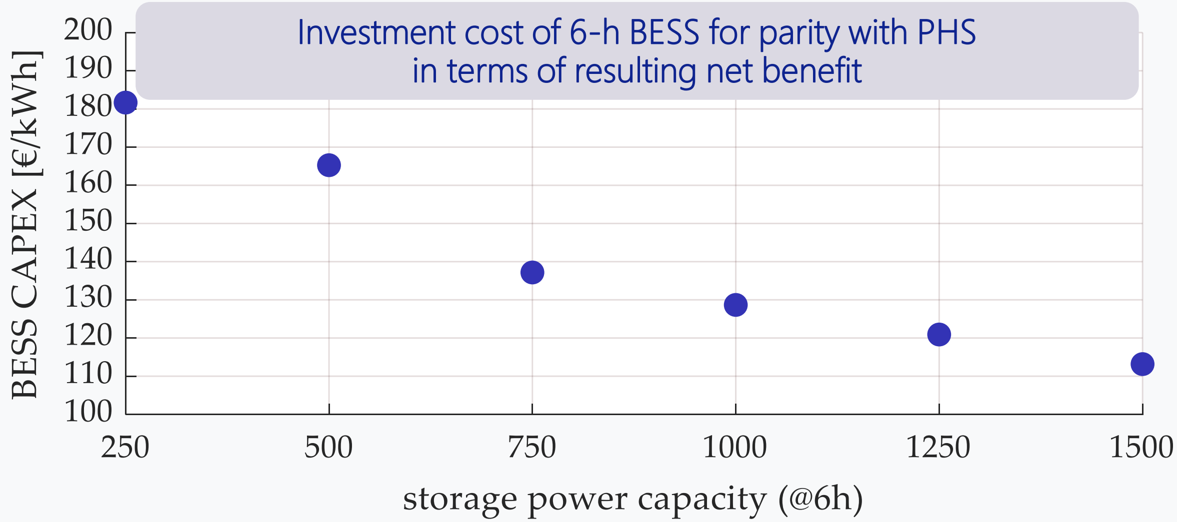
- Cost-Benefit Analysis to comparatively evaluate PHS and BESS solutions
  - **Net economic benefit of system** through the introduction of storage: calculated against baseline scenario without storage, taking account of savings in system variable generation cost, while considering the fixed cost of storage
- Case study considered:
  - PHS and BESS configurations of 6-h duration, ranging from 250 MW to 1500 MW
    - 6-h lies close to the lower boundary of PHS capacities, while it exceeds the upper boundary of commercially available Li-ion batteries today (typically 4 h)

PHS vs. BESS: net economic benefit



- Long duration (6 h) BES systems achieve substantially lower net system benefit compared to PHS, for any storage capacity above 500 MW
  - ❖ Gap in net benefit increases in favor of PHS at higher power capacities

BESS CAPEX to achieve the same net benefit as PHS



Parity achieved for BES cost 100-150 €/kWh. Substantially lower than today's costs, possible in the long run.

- ✓ **PHS is the technology of choice for long duration storage,** today and in the foreseeable future
- ✓ **BES maintain substantial advantages at shorter durations (2-4 h):**
  - ✓ Provision of balancing services and flexibility
  - ✓ Ease of deployment
  - ✓ Collocation with RES and consumer facilities

PHS contribution to capacity adequacy: Capacity value estimation

Value of PHS for capacity adequacy purposes

- Capacity adequacy: capability of the generation system to satisfy load demand without curtailments (loss of load events).

- System adequacy has historically relied on **conventional (thermal) generation.**

- Substitution of thermal generation assets by intermittent RES renders capacity adequacy a **major challenge for decarbonized power systems.**

- **Long duration storage** with high energy-to-power ratios **can contribute substantially to the adequacy of systems dominated by renewables**.

Capacity value of storage & participation in Capacity Remuneration Mechanisms (CRMs)

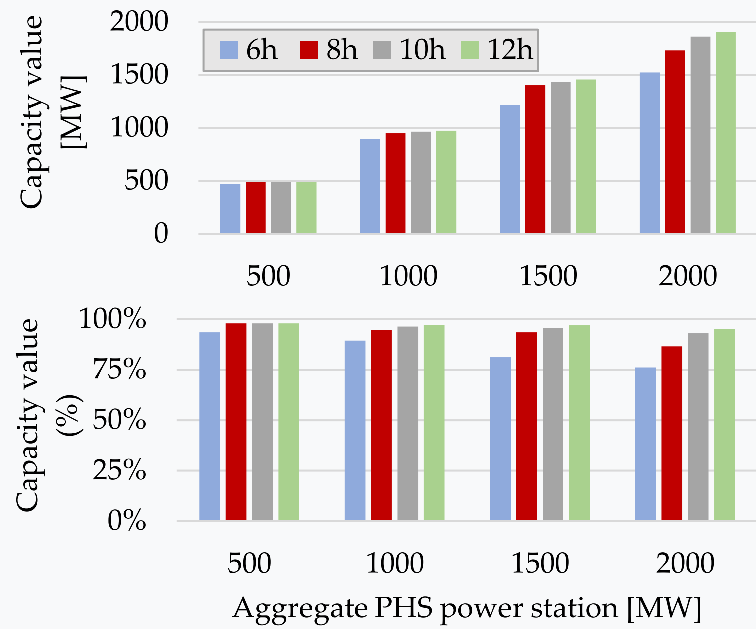
- Recognizing and quantifying the **capacity value of storage** a prerequisite for participation in CRM
- **Capacity value strongly depends on storage duration**
- **De-rating factors** apply for participation in capacity auctions

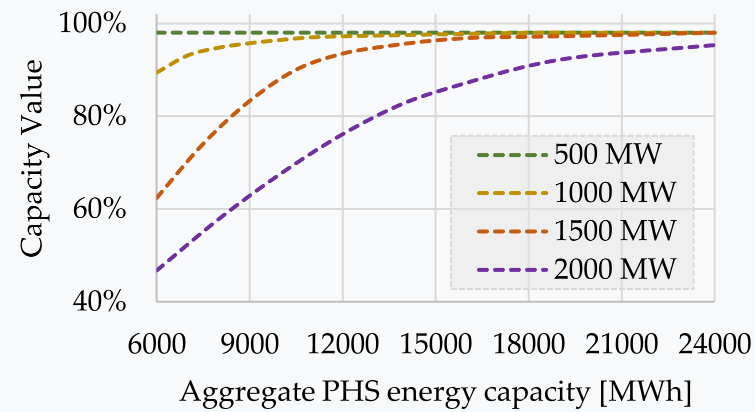
Country	TSO	Storage energy capacity		
		2-h	4-h	>6-h
Great Britain	nationalgridESO	40% - 49%	65% - 71%	~95%
Ireland	EIRGRID	34% - 40%	54%-61%	68%-77%
Belgium	elia	56%	79%	>80%

- Large differences noted due to the methodologies applied and the multitude of factors impacting capacity value in different systems

Quantified contribution to system adequacy – Application to the Greek system

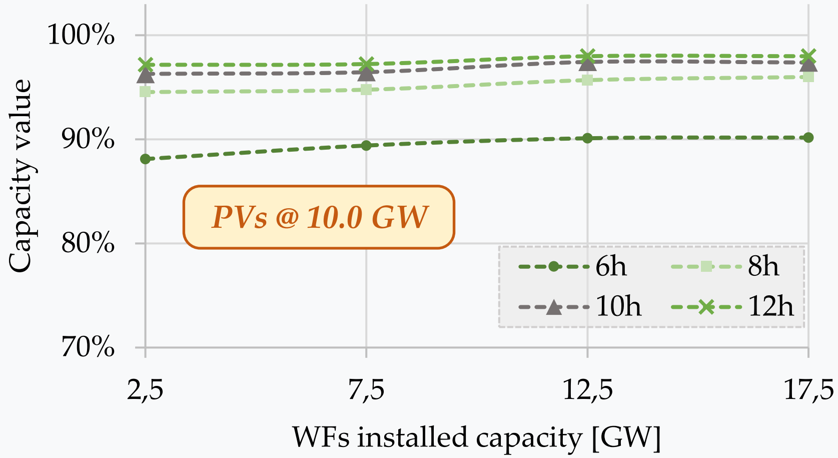
- ❖ PHS can contribute substantially to the adequacy of the Greek system
  - Aggregate PHS capacities up to 2 GW, with a duration of 6 h or more, present capacity values in excess of 75%
- ❖ Capacity value strongly dependent on <u>duration</u> and <u>overall storage capacity</u> of the system
  - Higher durations required at increased aggregate power capacities to reach maximum capacity value

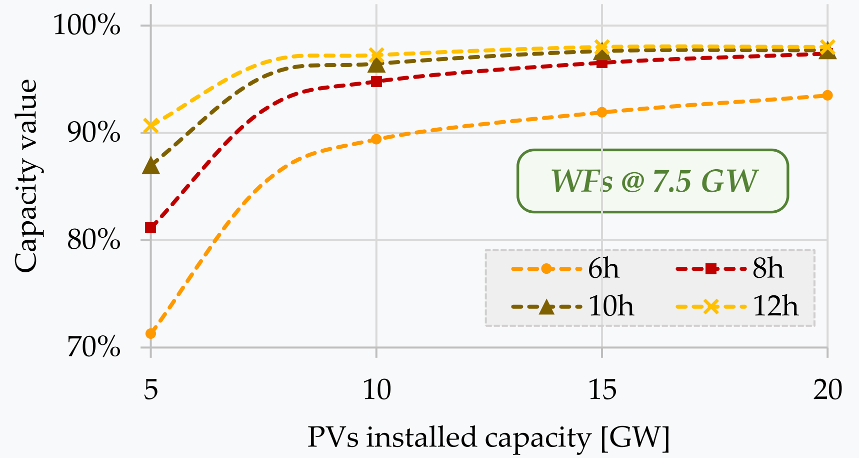




Impact of RES mix on the capacity value of PHS

The share of PV power in the energy mix may impact the capacity value of storage





- PHS capacity value relatively stable, regardless of installed wind capacity:
  - ~90% for 6-h PHS
  - >95% for 12-h PHS
- Strong impact of installed PV power on the capacity value of PHS:
  - PVs impose systematic arbitrage and peak shaving functionality, thus favoring the capacity contribution of storages
  - Capacity value reduced at low PV shares; tends to stabilize above 10 GW of PVs

Main conclusions

PHS essential to support transition to net-zero

- **Long duration storage a key enabler towards net-zero energy systems**
  - Over 5 GW/160 GWh of long duration storage may be required for 100% RES penetration
  - BESS of lower E-to-P ratios (2-4 h) still needed to provide flexibility and collocate with RES and demand
- **Li-ion BESS cannot effectively substitute PHS as long duration storage assets**
  - High investment cost (energy component) does not favor deployment at high durations
  - Decline of BESS cost may close the gap in the long run; still, BESS technologies known today not a viable substitute for PHS in the foreseeable future
- **PHS contribute significantly to capacity adequacy**
  - Can replace thermal units as system adequacy providers, delivering capacity values in excess of 75%
  - Capacity value depends on RES mix
    - High PV shares tend to amplify capacity value; impact of wind not as marked

Thank you

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