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Comparison of Renewable Large-Scale Energy Storage Power Plants based on Technical and Economic Parameters

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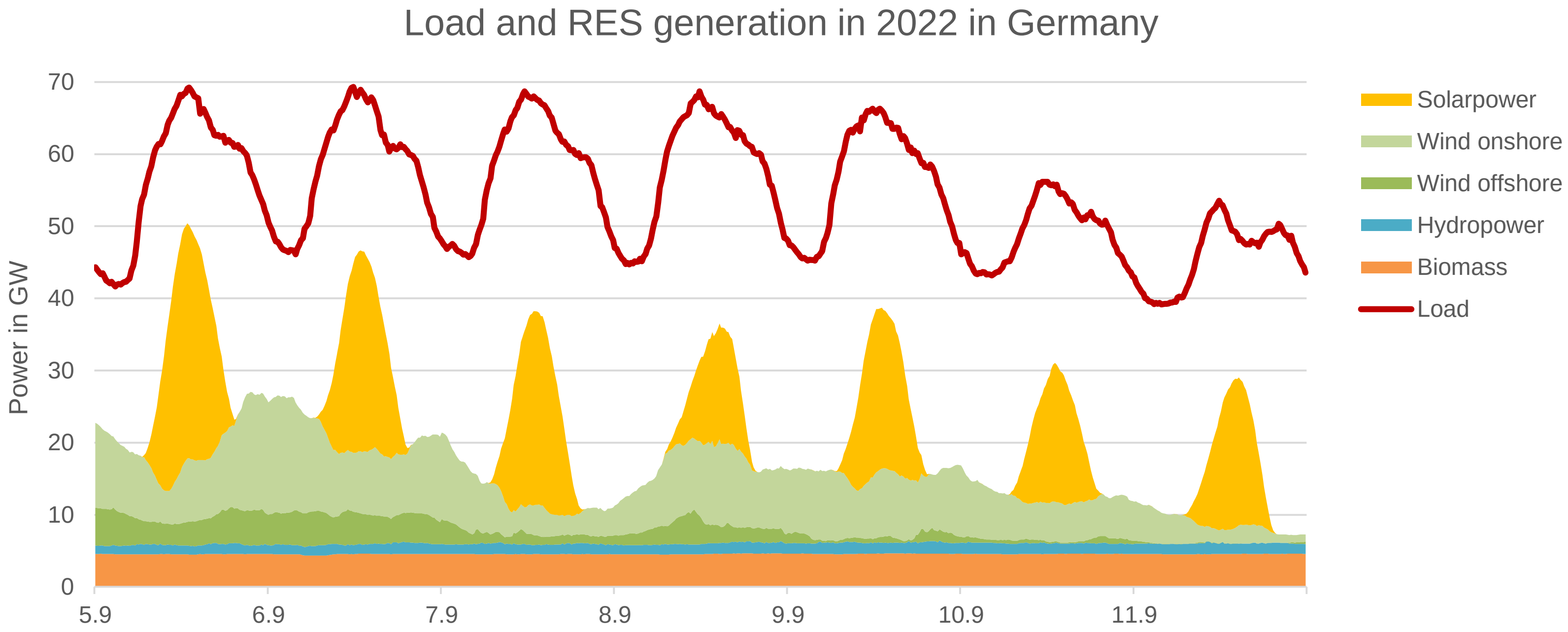
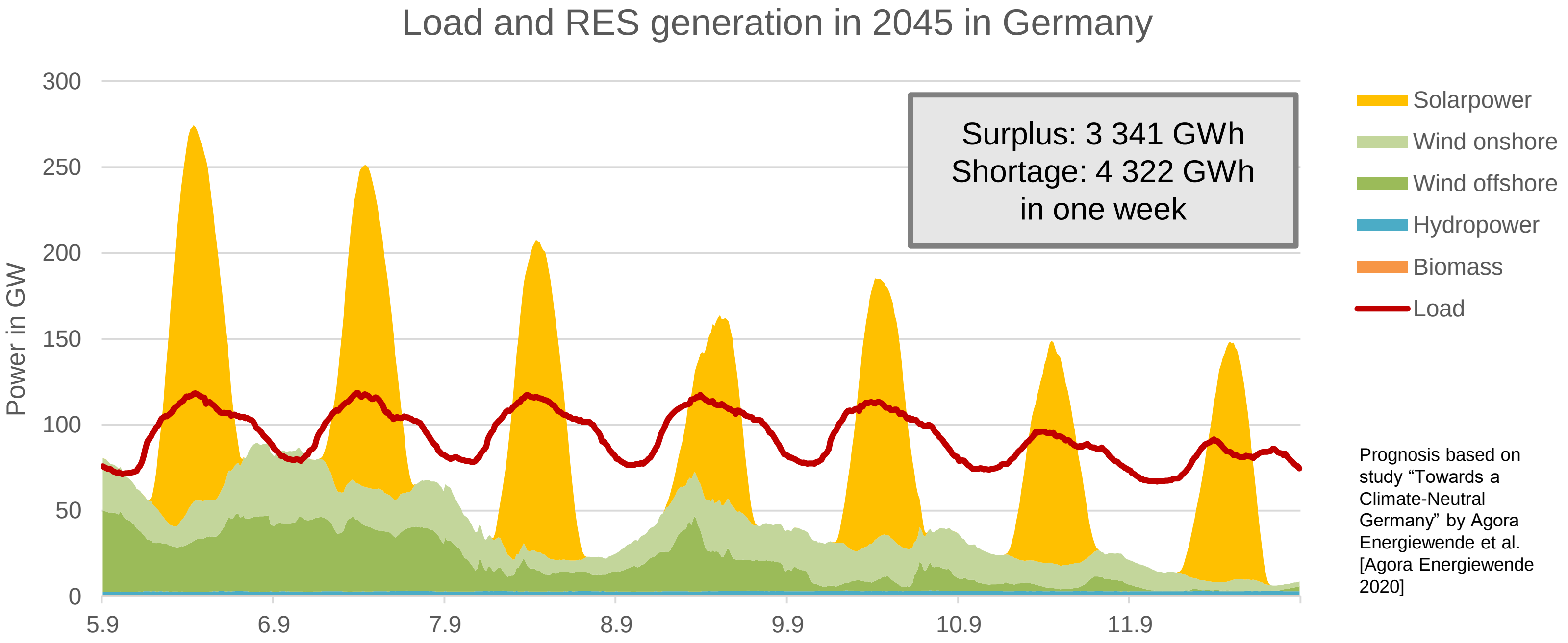
Need for energy storage



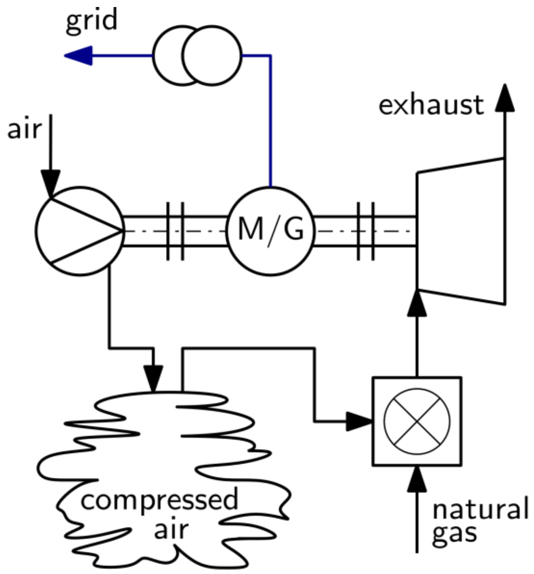
Need for energy storage



Prognosis based on study “Towards a Climate-Neutral Germany” by Agora Energiewende et al. [Agora Energiewende 2020]

Compressed Air Energy Storage

- Charging mode: compression of ambient air
- Storage in underground salt caverns
- Discharging mode: natural gas turbine
- Two existing plants in Huntorf (DE) and McIntosh (USA)

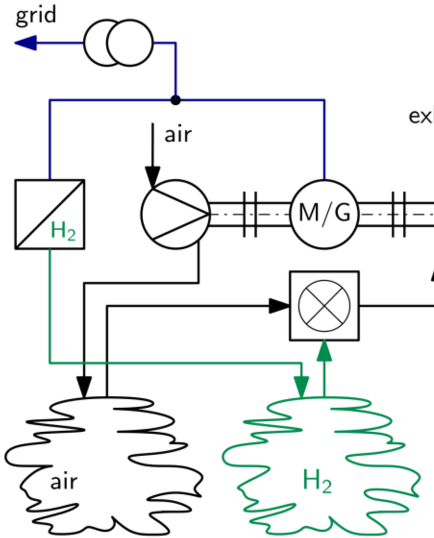


- Pros: High storage capacity, proven concept
- Cons: Carbon emissions

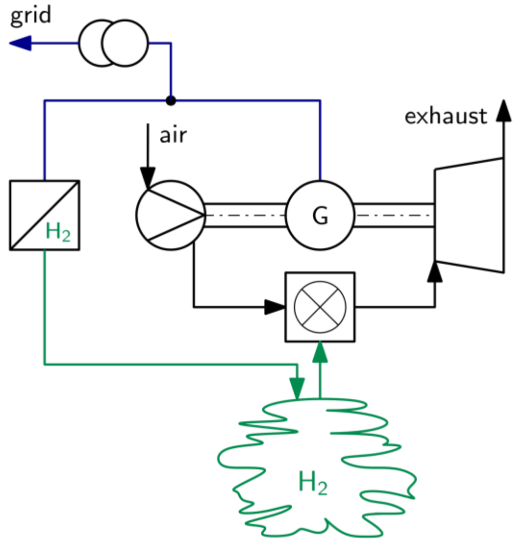
- Advancement: Adiabatic CAES with thermal energy storage

Advancements of CAES

Hydrogen Compressed Air Energy Storage (HCAES)



Hydrogen Energy Storage (HES)



Concepts of Large-Scale Energy Storage

Abbr.	Description	Storage medium	Reconversion
CAES	Compressed Air Energy Storage	Compressed air	Natural gas turbine
ACAES	Adiabatic Compressed Air Energy Storage	Compressed air and heat	Expansion turbine
HCAES	Hydrogen Compressed Air Energy Storage	Compressed air and Hydrogen	Hydrogen gas turbine
HES-GT	Hydrogen Energy Storage	Hydrogen	Hydrogen gas turbine
HES-FC	Hydrogen Energy Storage	Hydrogen	Fuel cell

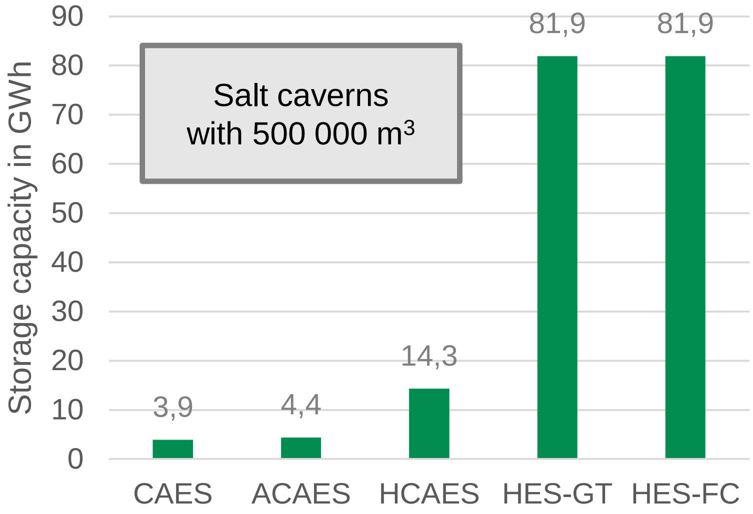
Criteria for comparison

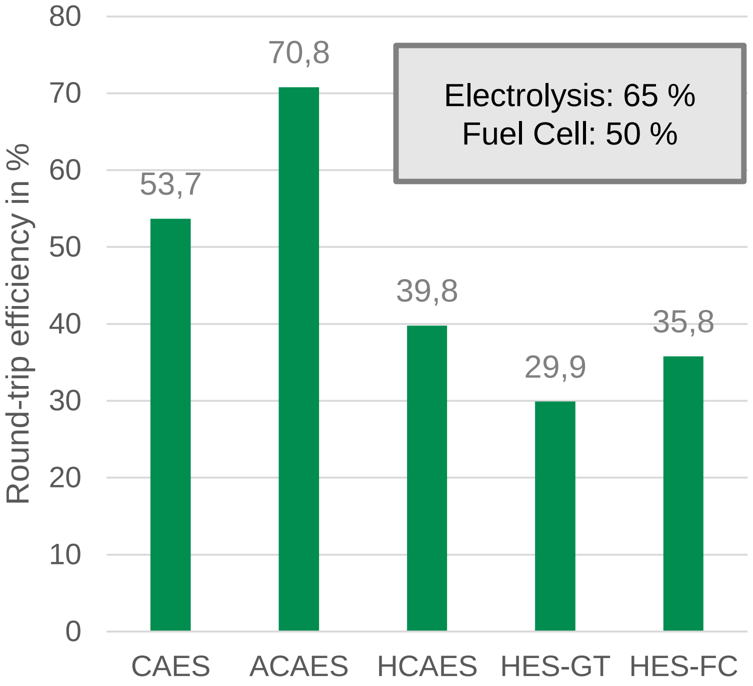
Calculated criteria
- Storage capacity
- Round-trip efficiency
- Specific investment costs

Qualitative criteria
- Technology Readiness Level
- Provision of ancillary services
- Emissions
- Storage losses

Comparison based on ranking for each criterion

Storage Capacity and Round-Trip Efficiency





- Pumped Hydropower: biggest plant in Germany with 3.5 GWh [European Commission 2020]
- Li-Ion Battery: biggest system in Europe with 0.1 GWh [European Commission 2020]

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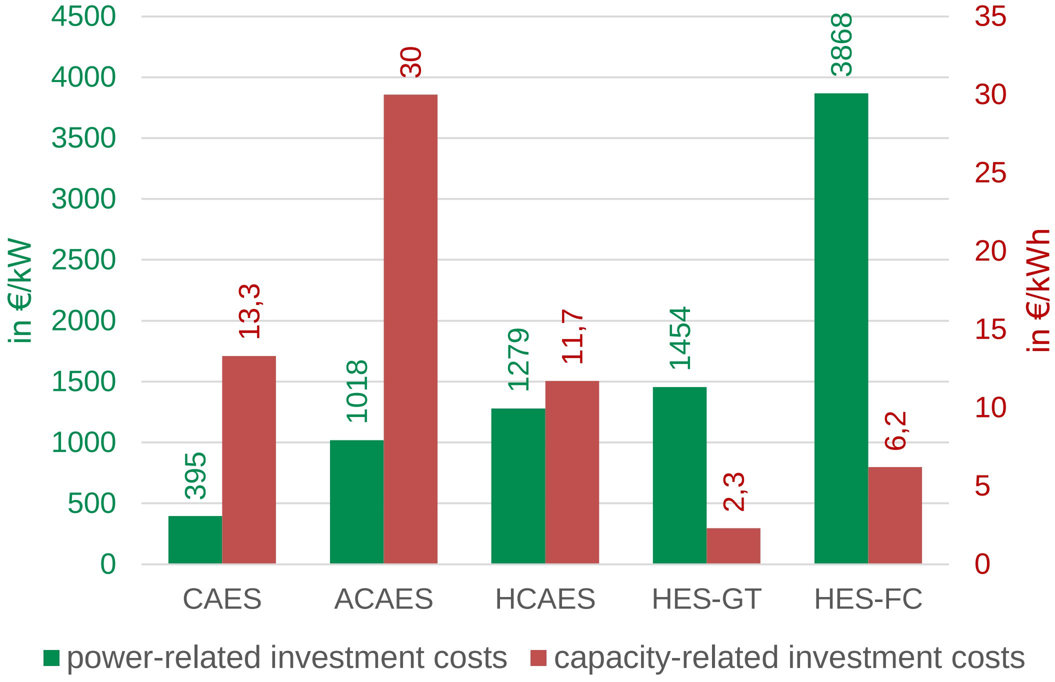
Power- and capacity-related investment costs



Nominal power: 130 MW_{el}
in charging and discharging

Most expensive components:

- Thermal storage: 20 $€/kWh_{th}$
  - 63 % of ACAES
- Electrolysis: 1074 $€/kW_{el}$
  - 61 % of HCAES
  - 73 % of HES-GT
- Fuel cell: 2500 $€/kW_{el}$
  - 65 % of HES-FC

Comparison [Schmidt 2019]:

- PHS: 960 €/kW, 70 €/kWh
- Li-Ion: 570 €/kW, 680 €/kWh

Technology Readiness Level

Components

- Thermal energy storage: **3-4** [Barbour 2021]
- Electrolysis: **6-8** [Pinsky 2020]
- Hydrogen salt cavern: **8**
- Hydrogen gas turbines: **7** [IEA 2015]
- Fuel cells: **6** [IEA 2021]

→

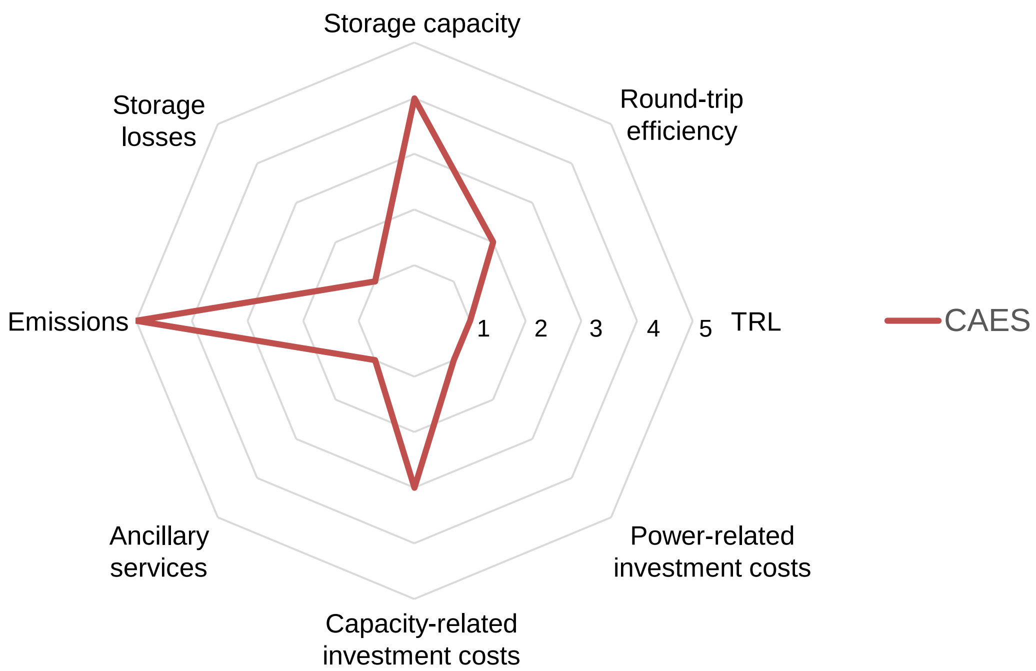
Concepts

- CAES: **8**
- ACAES: **4**
- HCAES: **7**
- HES-GT: **7**
- HES-FC: **6**

TRL	Description
1	basic principles observed
2	technology concept formulated
3	experimental proof of concept
4	technology validated in lab
5	technology validated in relevant environment
6	technology demonstrated in relevant environment
7	system prototype demonstration in operational environment
8	system complete and qualified
9	actual system proven in operational environment

[European Commission – Horizon 2020]

CAES: Resulting Ranks (1 – best, 5 – worst)



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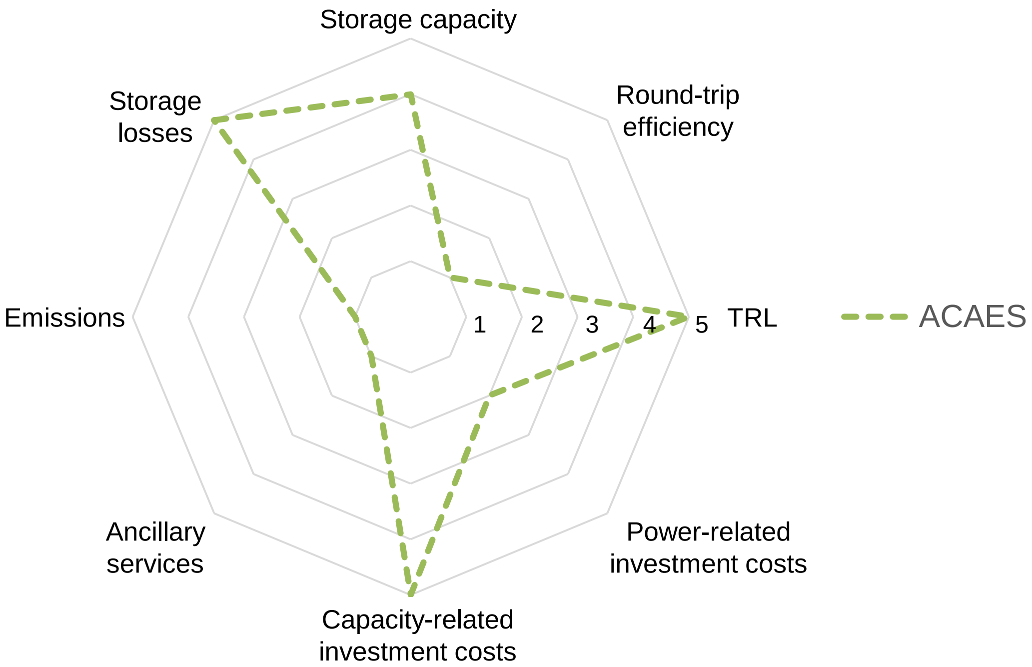
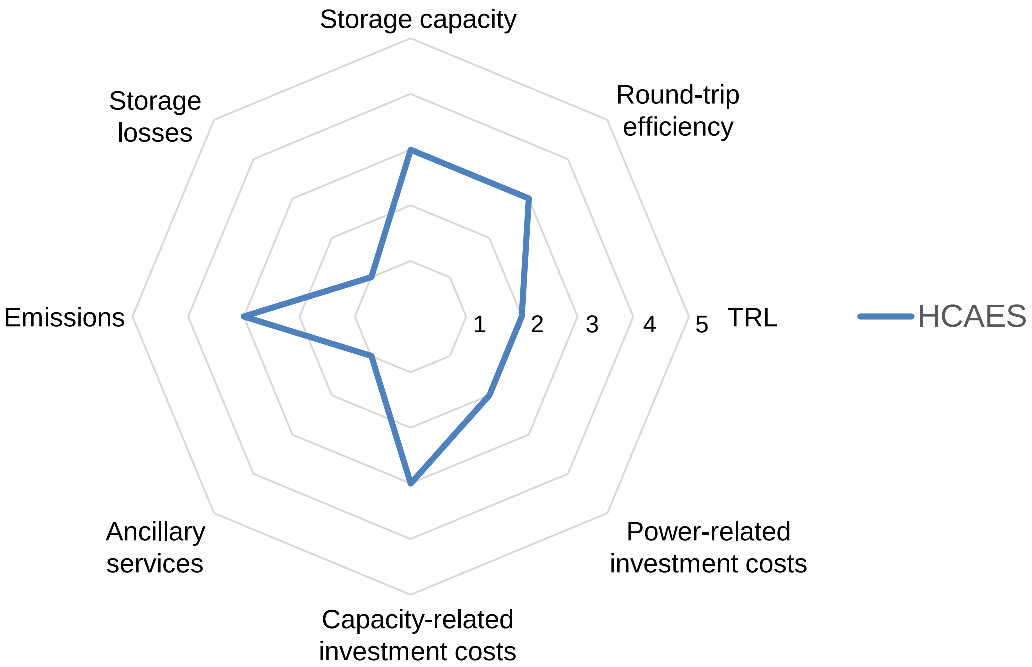
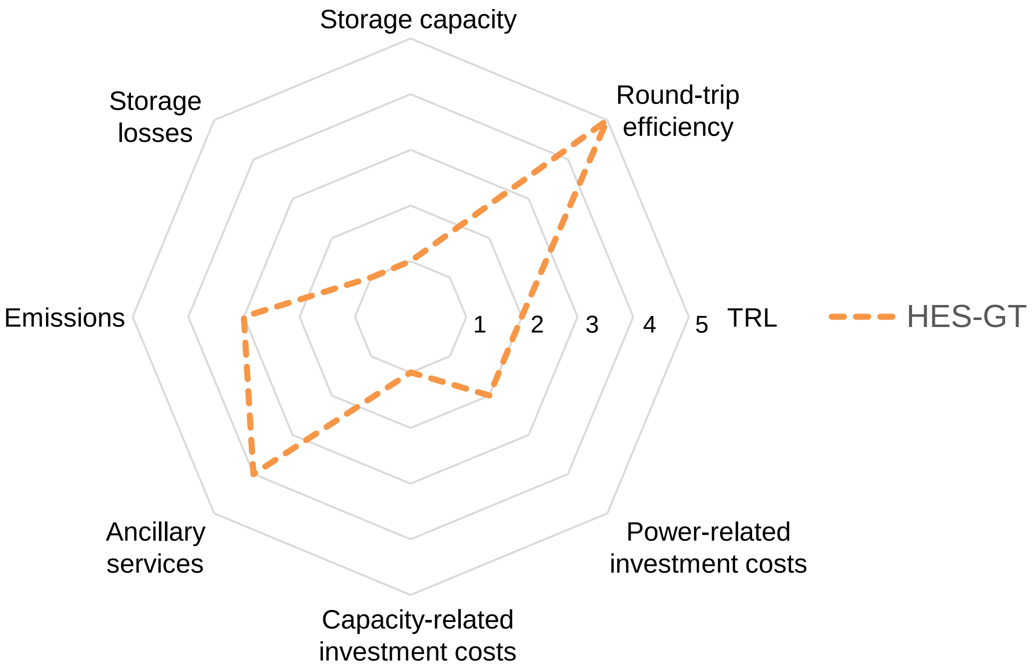
ACAES: Resulting Ranks (1 – best, 5 – worst)



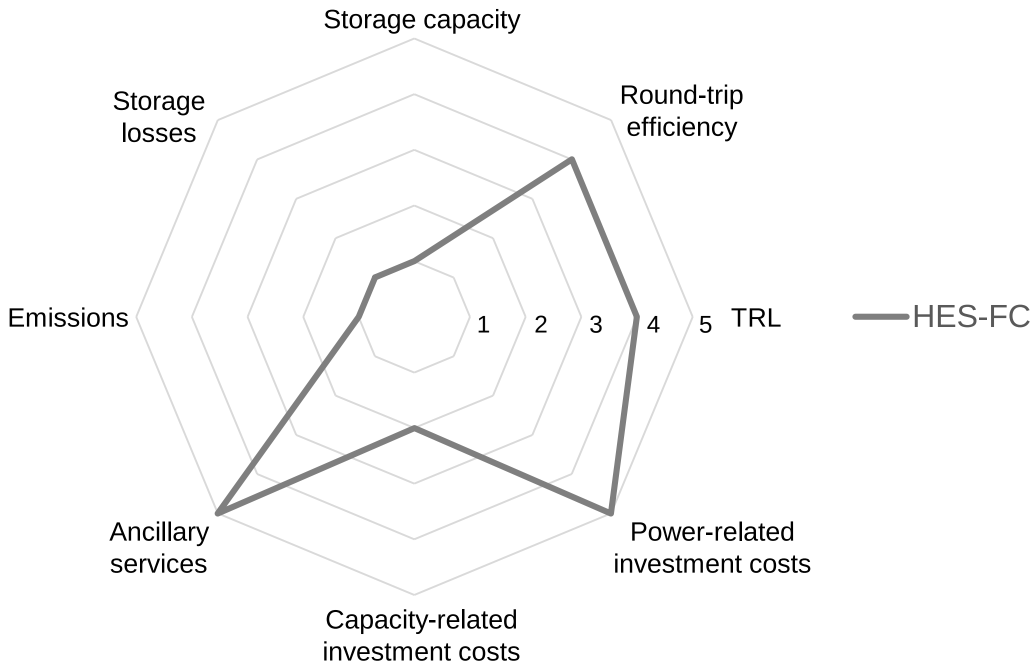
HCAES: Resulting Ranks (1 – best, 5 – worst)



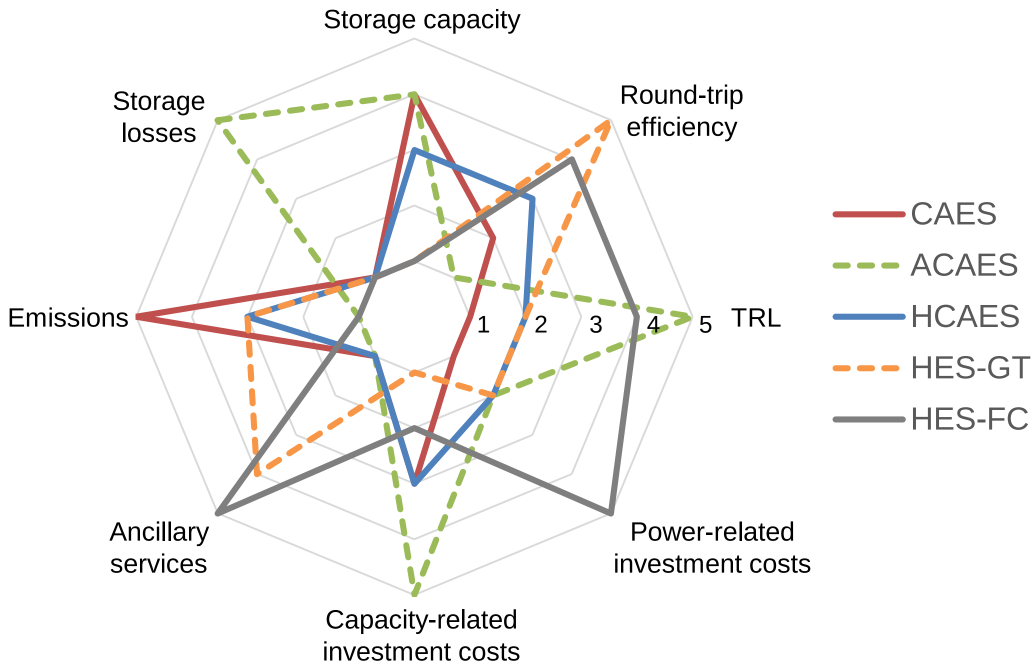
HES-GT: Resulting Ranks (1 – best, 5 – worst)



HES-FC: Resulting Ranks (1 – best, 5 – worst)



Comparison of Concepts



Unweighted average rank

CAES	2.3
ACAES	3.0
HCAES	2.3
HES-GT	2.4
HES-FC	2.9

Conclusion

- Cavern-based large-scale energy storage:
  - high storage capacity, very low capacity-related costs
  - moderate to low efficiencies, high power-related costs
- HCAES best suited for large-scale energy storage
- All other storage concepts have (severe) disadvantages
  - CAES: carbon emissions
  - ACAES: low TRL, high capacity-related investment costs, storage losses
  - HES-GT: low efficiency
  - HES-FC: low TRL, high power-related investment costs
- Existing CAES can be transformed into HCAES with additional electrolysis and hydrogen salt cavern

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Thank you for listening

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Literature

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