

Industrial Scale Offshore Energy Storage

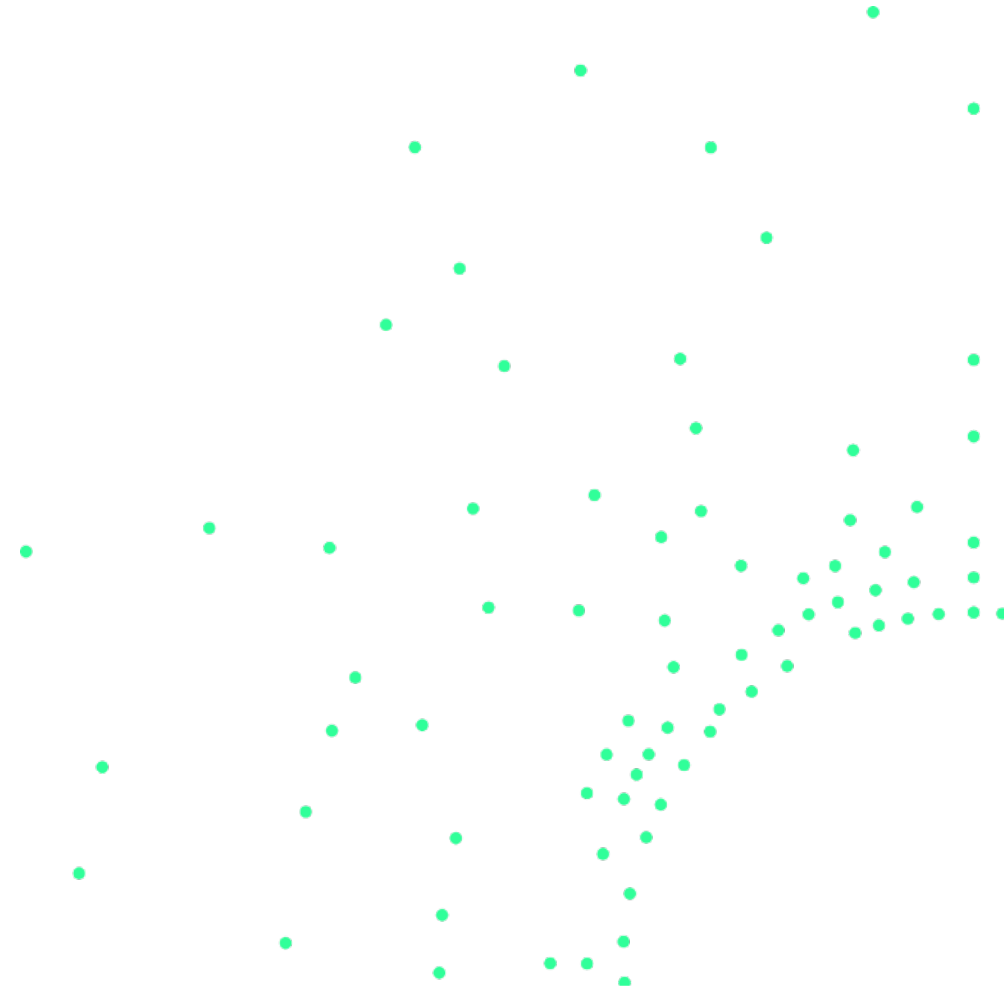
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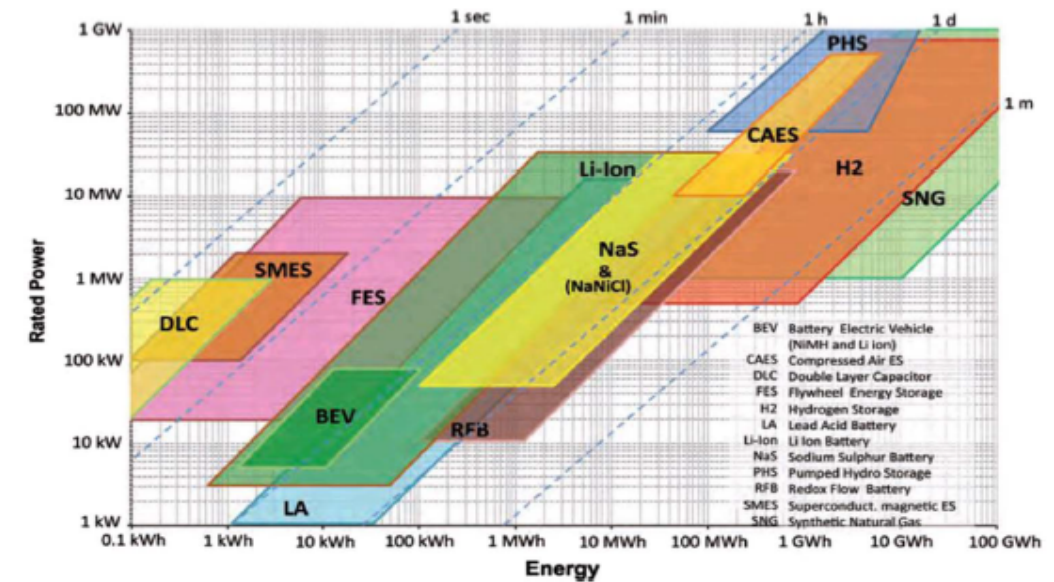
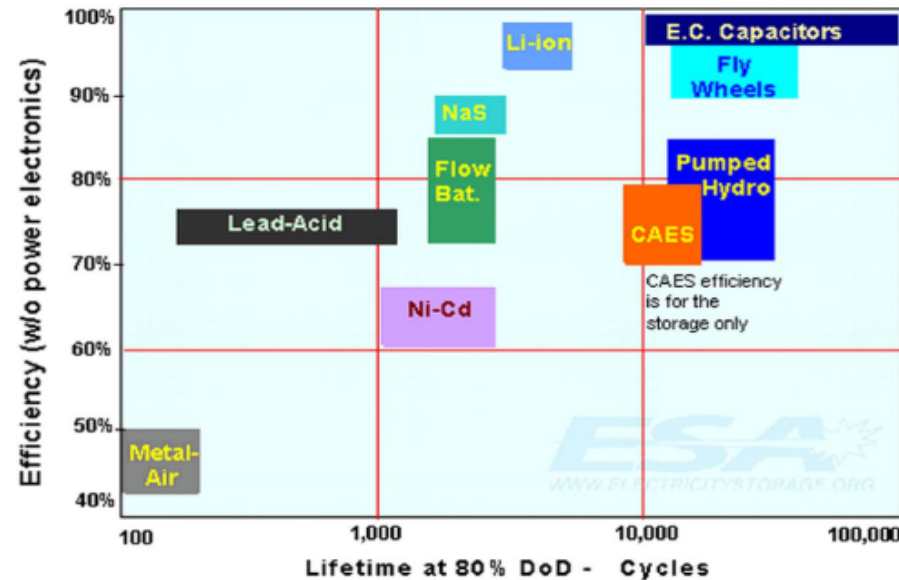
Background



Integration of large share of fluctuating renewables requires large scale energy storage capacities.

Pumped hydro storage (PHS) and compressed air energy storage (CAES) most promising due to e.g.:

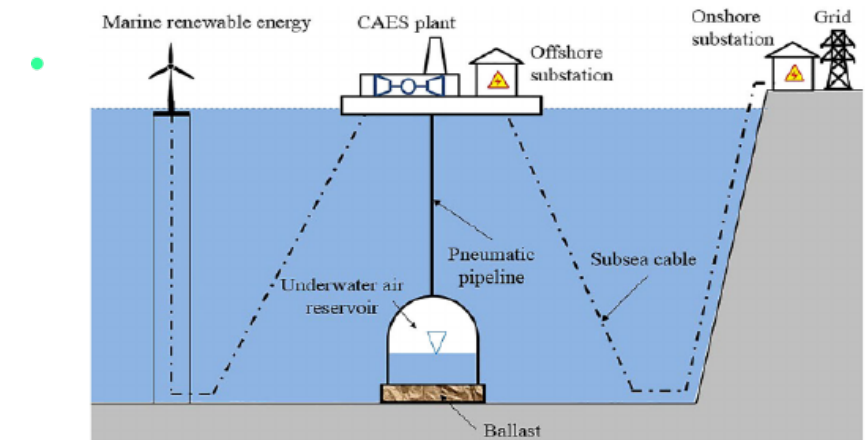
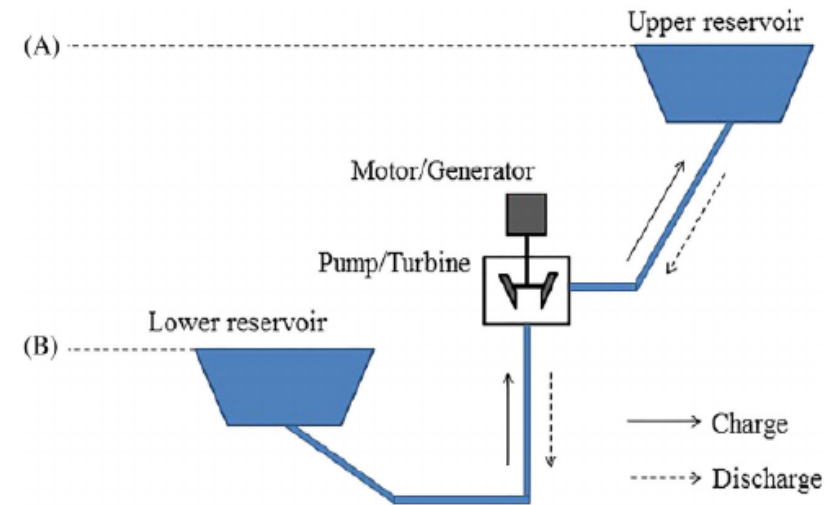
- scale,
- costs,
- cycles



Background

For offshore installation is pumped hydro:

- Less complex (no extra hearing required, simpler plant arrangement ...)
- Impacts the environment less than onshore PHS
- Allows, amongst others, for a combination with offshore power generation

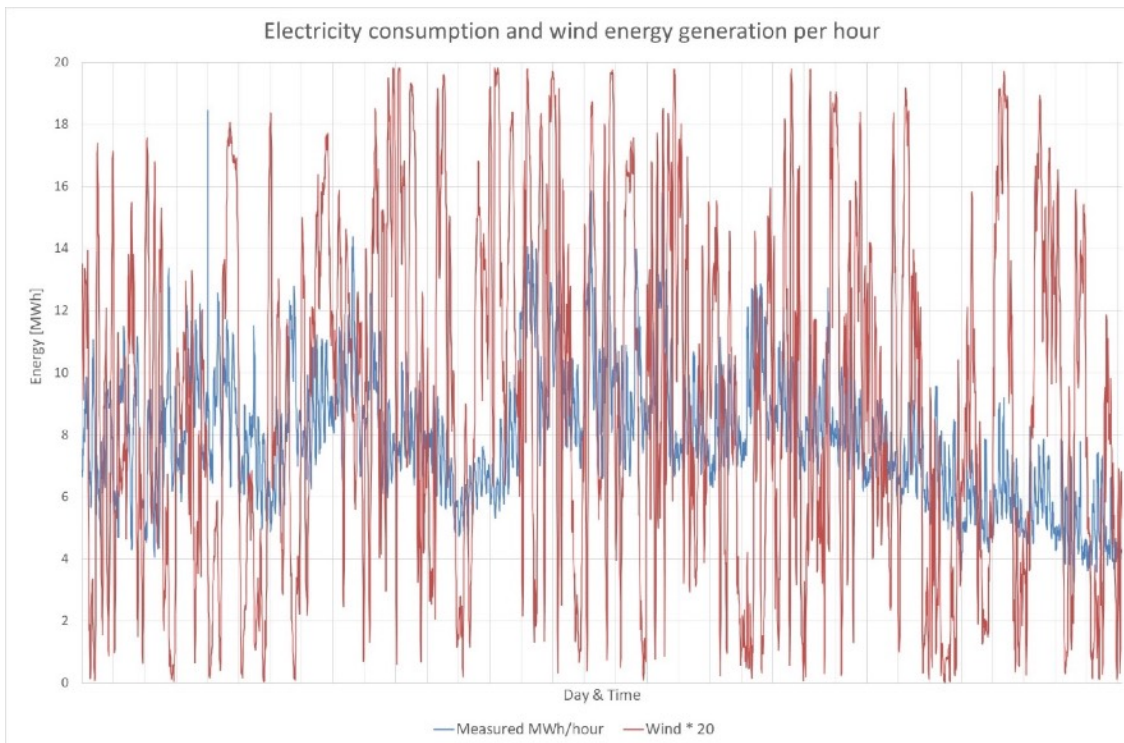
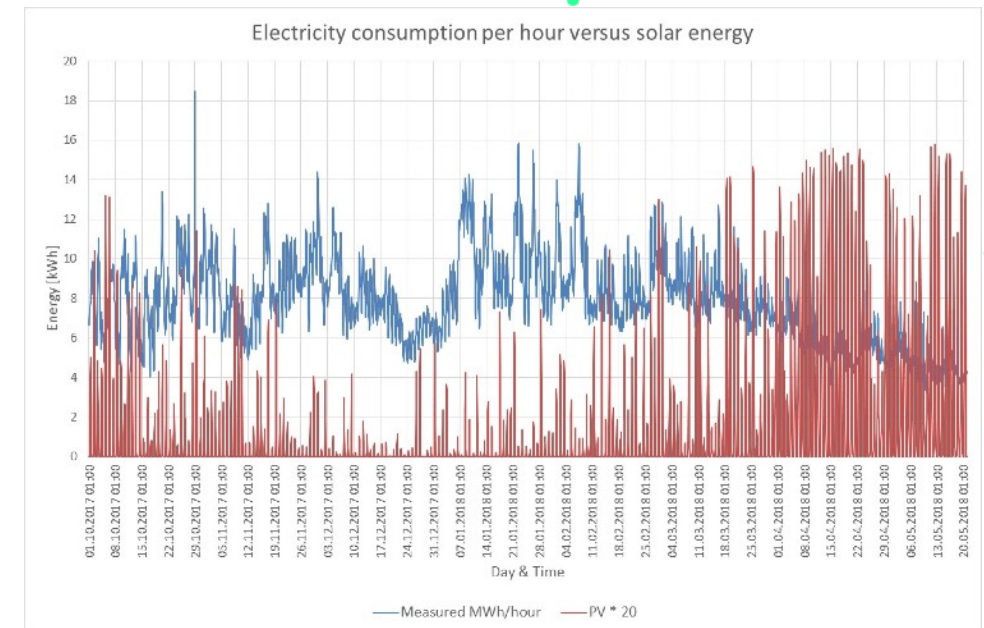
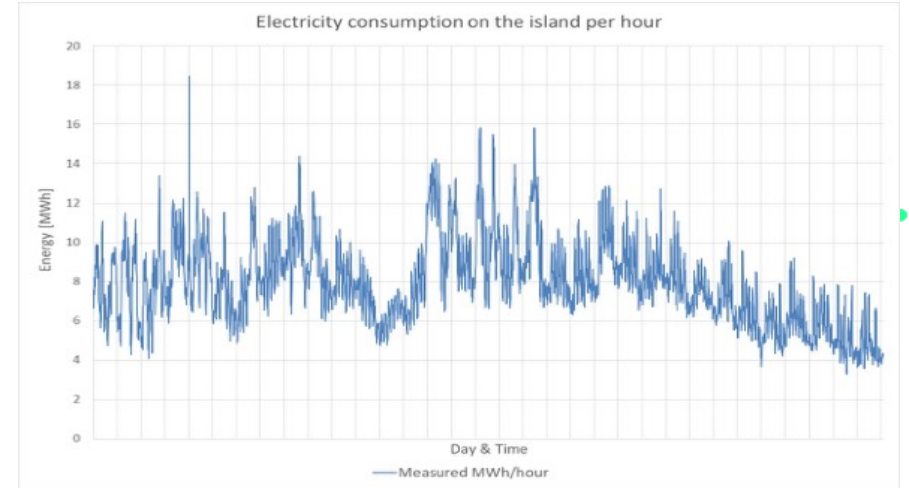


Evaluation

- Defining a use case via:

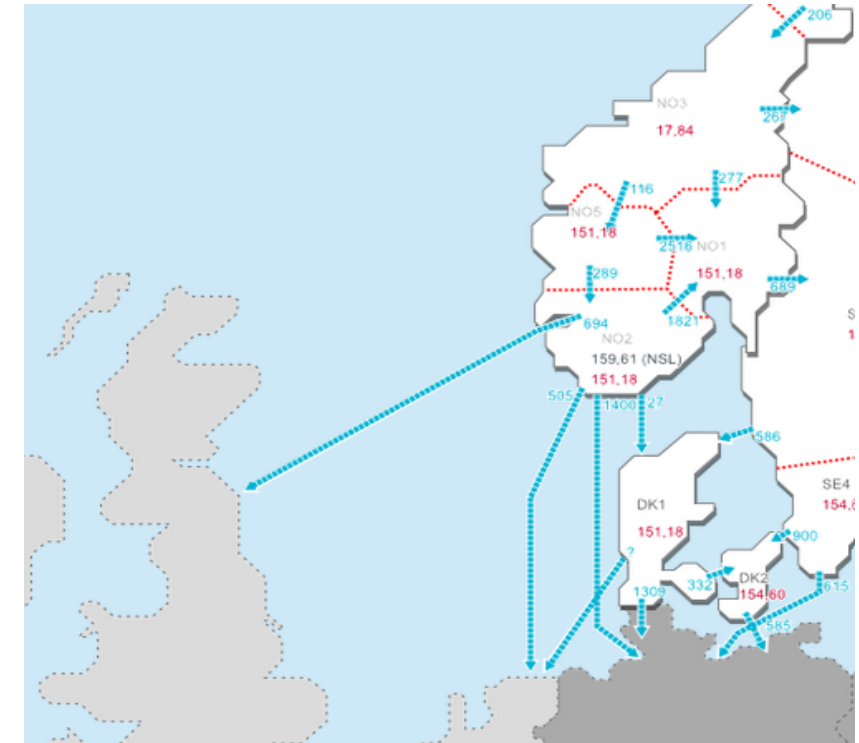
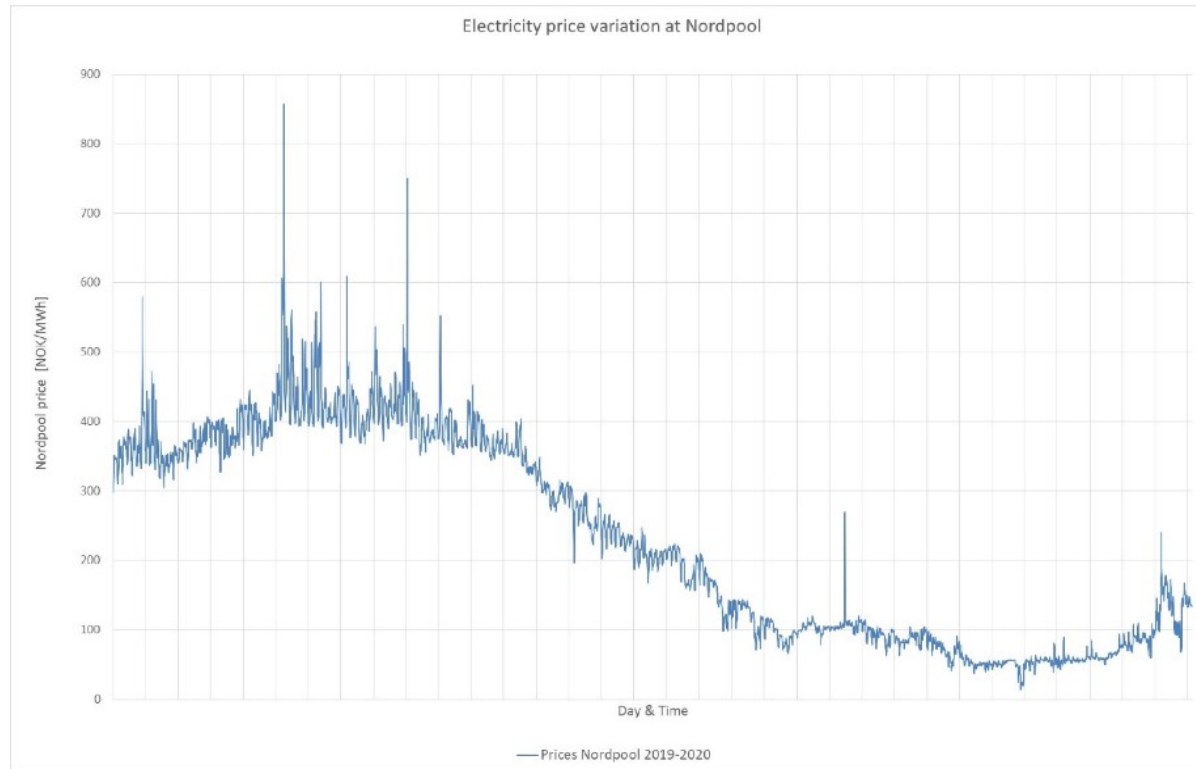
- Energy consumption profile of an island
- Considering typical wind and solar performance

Offshore wind seems to be the preferred source



Evaluation

- Commercial BC are electricity cost variations

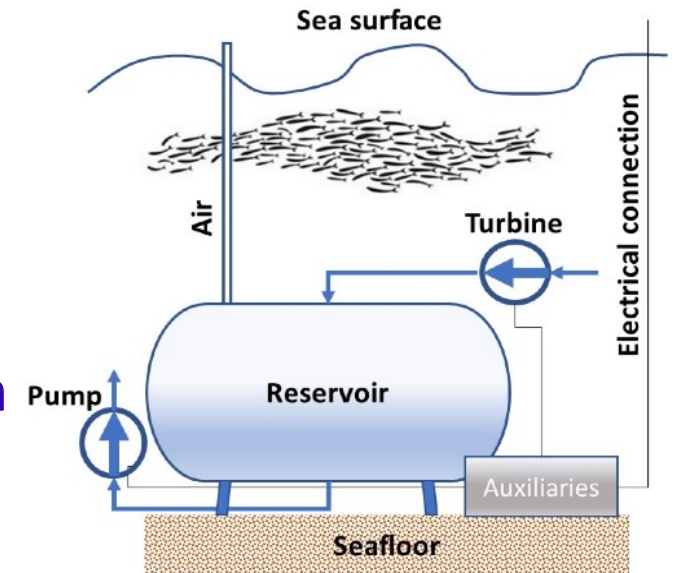


Nordpool at Kristiansand seems to be impacted by export cable connections

Boundary conditions for technical evaluation



- Seafloor at a depth of 400m & 1000m
- Water temperature 4°C
- Ambient pressure 1,013 bar (ISO), gravity 9,81 m/s²
- Inlet tube length to the turbine 1,2m
- Cylindrical volume with a half sphere as end-walls on both sides of the cylinder
- Inner diameter 18,5 m
- Cylinder length 70 m
- maximum power-output P_{Tout} of the turbine 10MW
- Pelton turbine with about 90% efficiency (η_T)



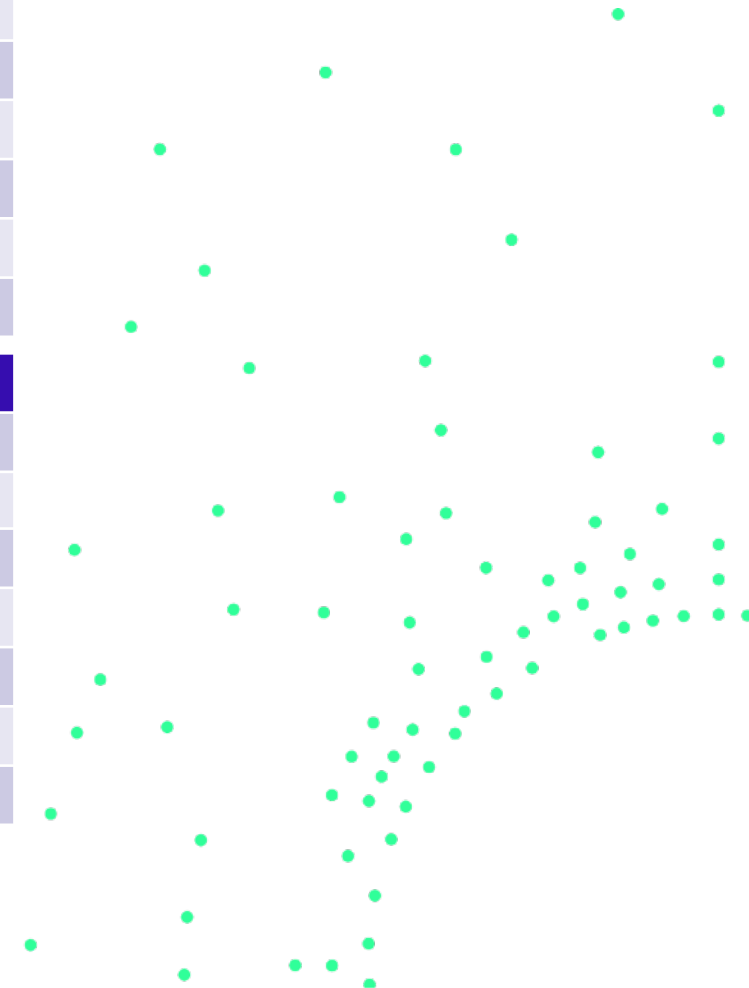
First results

- To evaluate the impact of the orientation of the reservoir:

400m	Horizontal	Vertical
Pressure at the sea floor	37,8 bar	37,8 bar
Height of turbine inlet above sea level	18,5 m	88 m
Footprint of the reservoir	1792 m ²	377 m ²
Pressure at reservoir top	36,0 bar	29,5 bar
Specific hydraulic turbine	-3,1 kJ/kg	-2,5 kJ/kg
Specific hydraulic pump power	3,3 kJ/kg	3,3 kJ/kg
Round trip efficiency (idealized!)	93,94%	75,75%

1000m	Horizontal	Vertical
Pressure at the sea floor	94,6 bar	94,6 bar
Height of turbine inlet above sea level	18,5 m	88 m
Footprint of the reservoir	1792 m ²	377 m ²
Pressure at reservoir top	92,7 bar	86,2 bar
Specific hydraulic turbine	-8,0 kJ/kg	-7,4 kJ/kg
Specific hydraulic pump power	8,4 kJ/kg	8,4 kJ/kg
Round trip efficiency (idealized!)	95,2 %	88,1 %

- Conclusion: horizontal arrangement is preferred

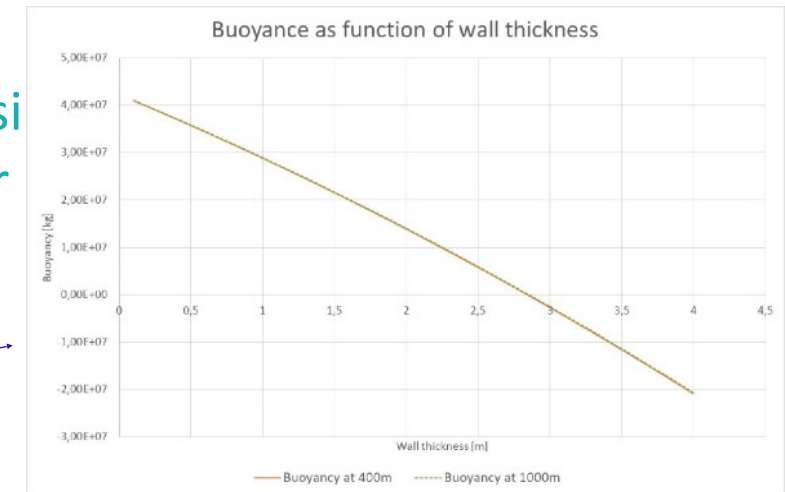


First results (to be refined in a more detailed evaluation / follow up project)



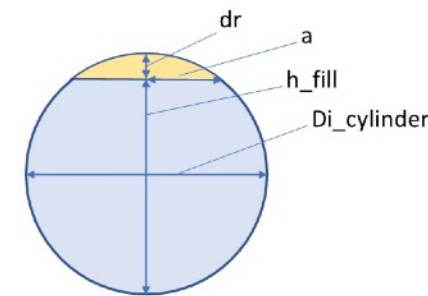
- MI-evaluation shows:

- No major MI issue to be expected when using concrete (using average strength of concrete only & tension hypothesis for brittle material)
- Additional material necessary to balance weight.



- Energy-evaluation shows:

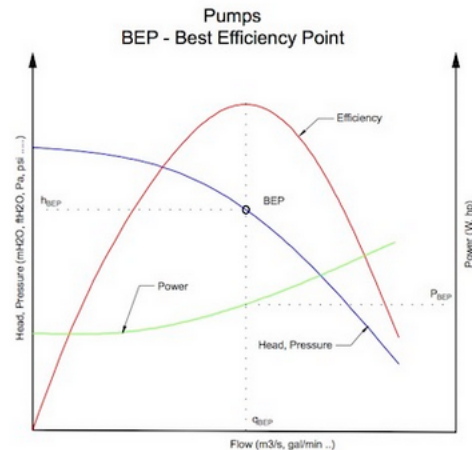
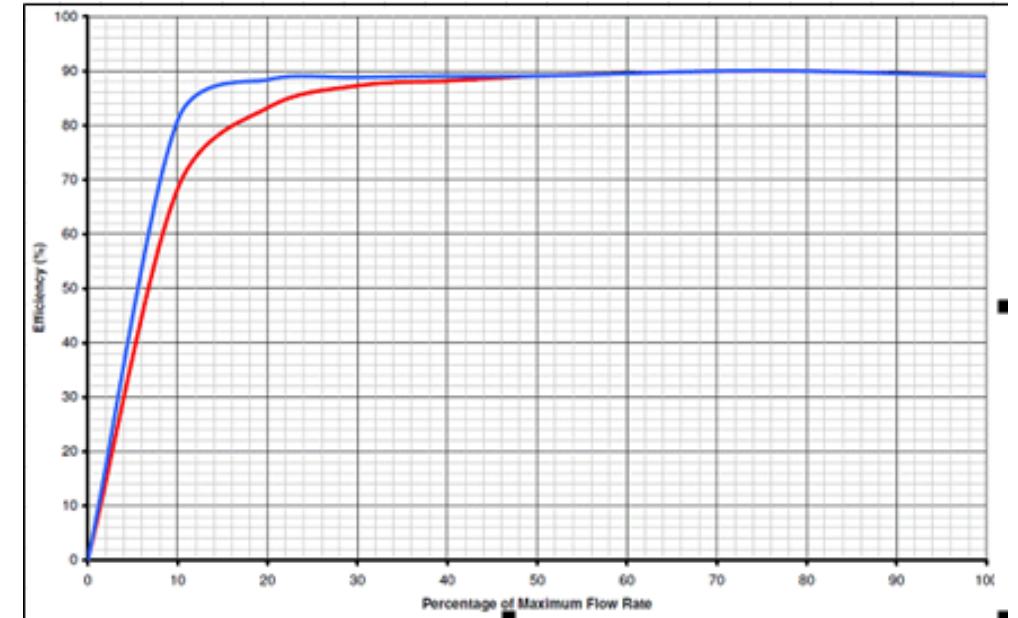
	400 m depth	1000 m depth
Total volume of the reservoir	22 131 m ³	22 131 m ³
Filling volume	21 170 m ³	21 170 m ³
Operational time to reach	1,94 hr	5,10 hr
Energy content while reaching	18,9 MWh	48,8 MWh
Operational time to reach	1,85 hr	4,86 hr
Energy content while reaching	18,1 MWh	46,7 MWh



First results (to be refined in a more detailed evaluation / follow up project)

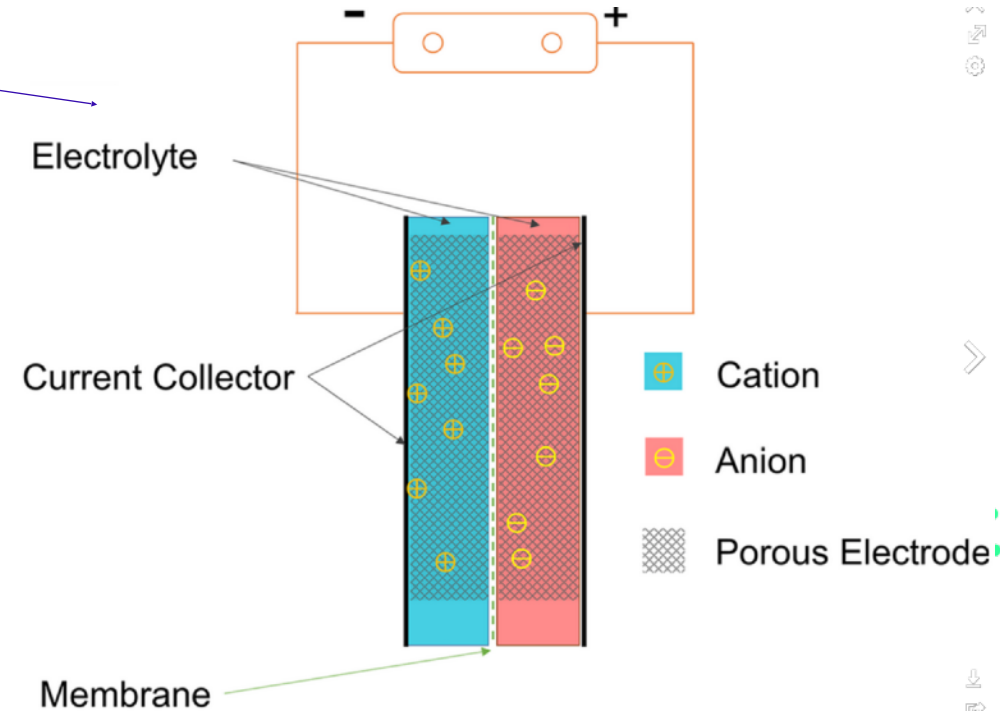
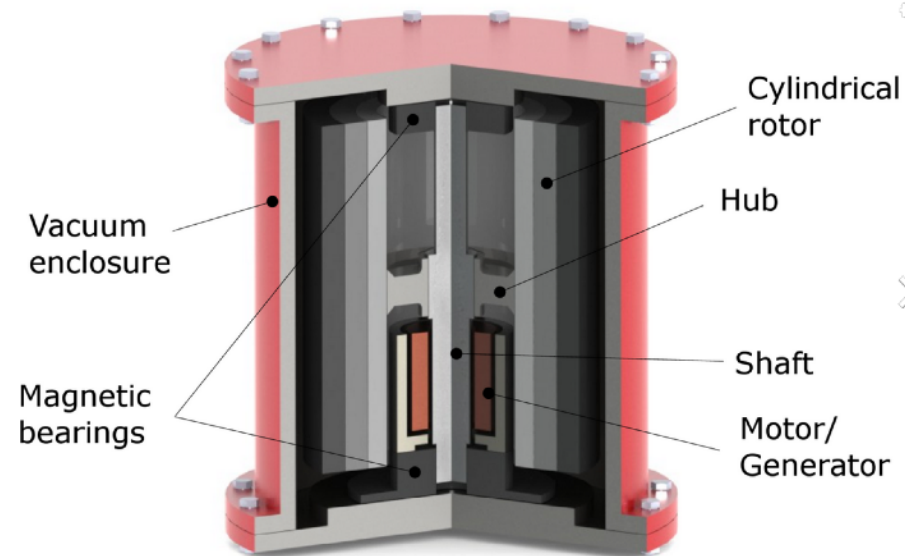


- For part load power generation might be one turbine sufficient
- For part load charging (i.e. pump) might be
 - Staged operation or
 - Additional power input balancing necessary in case of certain deviation (at least about 5%) from the opt. operation



First results (to be refined in a more detailed evaluation / follow up project)

- For power input balancing and covering the turbine start up:
 - Super capacitors
 - Fly-wheel (weight and cost)



Possible next steps



- Forming a consortium for
 - Follow up project
 - Building a demonstrator
- Maybe teaming up with renewable offshore energy systems to provide “reliable & dispatchable offshore energy to the shore.

