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Datasheet

Energy from Water
Inverse pumped hydro storage

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Technology description

Name technology
Inverse pumped hydro storage

Description
Inverse pumped hydro storage is a variation of pumped hydro storage, the most widely used form of electricity storage worldwide. For countries with a low natural decline, such as the Netherlands, concepts have been devised where a diked reservoir is built in the North Sea or IJsselmeer, in which the water level is manipulated by means of pump turbines. This creates a drop of several tens of meters. The most recent studies assume an energy storage lake from which water is pumped out when there is a high supply (and low price) of electricity and water flows into the lake when there is a high demand for electricity through a turbine that generates electricity. (De Vilder, 2017, Witteveen+Bos, 2019).

The Lievense plan was developed in the Netherlands in the 1970s and 1980s. The most recent variant is an energy island in the North Sea with a storage capacity of 20 or 30 GWh (de Boer et al., 2007). Under certain assumptions this plan had a positive business case, however it did not progress beyond a basic design. De Vilder (2017), under the supervision of Witteveen+Bos, investigated an energy storage lake on the Dogger Bank with a storage capacity of 25-50 GWh. The only active initiative in the Netherlands is Delta21, which combines water safety and nature development with energy storage in an energy storage lake. The most recent Delta21 design has an energy lake with a pump turbine capacity of 1.8 GW, which, if necessary, can quickly drain river water at very high water levels, thereby preventing the need for reinforcement of river dikes. Furthermore, the pump turbine is used to pump water from the lake when there is a high supply of electricity and to supply energy when there is a high demand for electricity (Delta 21, 2020)."

TRL Level

2020: 3

2030: *TRL*

2050: 9

Explanation
The TRL level is estimated at TRL 3 because plans are still under development. However, it is possible to work with existing construction techniques and pump turbine concepts that have a TRL of 8 or 9 (Witteveen+Bos & CE Delft, 2019). We assume that research into ecological and other side effects and project development will take so much time that it is to be expected that Delta 21 will not be operational until the years after 2030.

Current installed capacity and annual electricity production in the Netherlands

Installed capacity
[n/a]

Annual electricity production
[Specify here]

Explanation
[Explanation]

Possible locations in the Netherlands

Locations
[Specify here]

Explanation
[Explanation]

Potential in the Netherlands

Table 1 Potential in the Netherlands (explanation is given in next paragraph).

	2030 (Main source)	2030 (Source 2)	2030 (Source 3)	2030 (Source 4)	2030 (Source 5)	2050 (Main source)	2050 (Source 2)	2050 (Source 3)	2050 (Source 4)	2050 (Source 5)
Energy potential (technical) (GWh)						20[1]	50[2]	30[3]		
Energy potential (economic)										
Mitigation potential										

Explanation
Delta 21 assumes a capacity of 1.8 GW and assumes that the lake will be filled (and thus electricity produced) for 10 to 12 hours, resulting in a storage capacity of approximately 20 GWh. The second variation is the largest variation of an energy storage lake on the dogger bank as calculated by de Vilder: 5 GW / 50 GWh (de Vilder, 2017). Source 3 is the largest variation of the energy island storage facility of Kema and Lievense (de Boer, 2007). In theory, multiple energy storage lakes are possible in the Netherlands, but too much storage capacity will flatten the price fluctuations in the energy market to such an extent that it flattens out its own business case (Witteveen+Bos & CE Delft, 2019).

Costs

Table 2 Costs (explanation is given in next paragraph).

	2020 (Main source)	2020 (Source 2)	2020 (Source 3)	2030 (Main source)	2030 (Source 2)	2030 (Source 3)	2050 (Main source)	2050 (Source 2)	2050 (Source 3)
Capex (M€)							2710[4]	1910[4]	700[4]
Fixed Opex (M€/year)							29[4]	29[4]	12[4]
Variable Opex									
Grid connection									
LCOS (€/kWh)							0,06[5]	0,05[5]	

Explanation
We assume that costs apply to after 2030, as it does not seem realistic that a large-scale project can be realized before then.

[1] *Delta 21 (2020)*
[2] *de Vilder (2017)*
[3] *de Boer (2007)*
[4] *Calculation*
[5] *Witteveen+Bos & CE Delft 2019*

Because it concerns storage of electricity, an indication of total costs is referred to as Levelised Cost of Storage (LCOS).

Delta21 and earlier concepts such as the energy island involve a combination of functions, which leads to the question of which costs should be allocated to the storage function. A detailed cost calculation is not yet available for Delta21, but it has been calculated by TU Delft master students (de Vilder, 2017 and Paalman, 2017, supervised by Witteveen+Bos and Ballast Nedam, respectively). De Vilder (2017) has developed a formula to calculate the costs of an energy storage lake, which is used for the CAPEX calculations. CAPEX and OPEX costs are based on the Delta21 concept of 1.8 GW and 20 GWh. The differences in costs are due to differences in assumptions for the concept. The first case is based on the costs of De Vilder (2017), which amounts to € 1500 million for turbines, € 900 million for the reservoir and € 310 million for other equipment.

For the second case, lower costs were used for the turbines (900 M €) from Paalman (2017) and lower costs for the reservoir are also assumed (700 M €) (Lavooij and Berke, 2020). For the third case, the costs of the pump turbines and other equipment have been disregarded, because they can also be fully attributed to the water safety function of Delta 21. Only the extra costs that have to be incurred for energy storage are included (Lavooij en Berke, 2020). Operational costs have also been scaled back for the third case. Witteveen+Bos & CE Delft (2019) estimate the LCOS based on the Delta21 and Vilder concepts, based on 1/4 time pumping, 1/4 time generation and 1/2 time standstill, a lifespan of 50 years, OPEX of 2% of CAPEX per year and a discount rate of 3%.

There are more project plans, but because these are smaller energy storage lakes and the costs for energy storage lakes have strong economies of scale, it is expected that the costs for these projects will be higher (Witteveen+Bos & CE Delft, 2019).

Berenschot (2019) performed a cost-value analysis for underground pumped hydro storage (O-PAC). O-PAC is reasonably comparable with Delta 21 in terms of costs (CAPEX of 1800 M €) and in terms of application (relatively short-term storage, use of periods with high electricity prices). Berenschot arrives at an LCOS of 0.041 € / kWh, which results in a favorable business case, although large uncertainties (particularly around interest rates and the turnaround time) remain.

Energy profile

The delivery profile is demand-driven. Delta21 can switch up from zero to full power of 1.8 MW within a minute. Delta21 assumes a maximum period in which it can deliver full power of 12 hours. This makes it particularly suitable for bridging day-night differences in electricity supply and demand.

Explanation
[Explanation]

Export potential

Various hydraulic contractors who see potential worldwide are affiliated to the Delta21 initiative (RH-DHV, IHC, Ballast Nedam, van Oord and others). 36 places have been identified where this concept can be applied, such as the Chao Phraya (Bangkok) and the Mississippi (Lavooij and Berke, 2020; Friso Dam, 2019). Except for hydraulic engineers, there are also export opportunities for Dutch pump-turbine suppliers.

Explanation
[Explanation]

Possible non-energetic side effects

Ecological effects
"The main environmental effects will be indirect effects due to changes in hydrodynamics and morphology. The magnitude of these effects depends on the scale of the application and the location. In addition to the indirect effects, there will be direct ecological effects due to habitat loss at the

location of the energy storage lake. Because the conditions in the energy storage lake deviate from the conditions in the open sea, the habitat suitability will be different. The fish safety of the pump turbines will partly determine the ecological impact of the energy storage lake (Witteveen+Bos & CE Delft, 2019). There may also be influences on groundwater levels and groundwater flows in the region. The current location at the Haringvliet is located in a Natura 2000 area, which leads to additional requirements. The improvement of nature is explicitly considered by creating a delta and opening the Haringvliet locks.

The daily renewal of nutrients in the lake offers excellent opportunities for the development of new aquaculture in the lake (WUR). The cultivation of mussels, oysters and seaweed can particularly benefit from this."

Multiple use
"At Delta21, water safety is at least as important as energy storage. In the event of the Maeslant barrier being closed, the pumps can also be used to pump out excess water from the hinterland (Witteveen+Bos & CE Delft, 2019). This could mean that the raising of river dikes can be omitted, which could save billions (Delta21, 2020). Moreover, in the case of energy storage lakes there are generally options for combinations with other energy functions, such as wind turbines, LNG or hydrogen terminals, seaweed cultivation, aquabattery or floating solar panels. (de Boer 2007, Delta21, 2020)."

Social and landscape effects
Delta21 involves a major intervention in the coastal landscape by constructing a delta.

Material use/circularity
At Delta21, locally available sand is used to create artificial dunes. Concrete will be used for the turbine housing and a design is still being worked on, which makes it challenging to estimate quantities and impact at this point (Paalman, 2017).

Sources

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