



DELTA21

Combining flood protection,
energy storage
and nature restoration

Design by Esmée van Eeden, Delft University of Technology, the Netherlands.

Sustainability, innovation and collaboration are key to successfully facing today's global challenges of grid congestion and climate change. To combat these challenges, the Delta21 concept has been developed in the Netherlands. Located in the mouth of the Haringvliet estuary in the Dutch Delta, the project combines energy storage, flood protection and the restoration of nature. The concept could be elaborated upon and applied worldwide, inspiring governments, public bodies knowledge centres and developers to face climate change and move away from fossil fuels.

Building with nature through an integrated approach

The Delta21 project involves creating a 32-metre-deep lake in the Dutch Delta, which will be used to store approximately 34 GWh (gigawatt hours) of sustainably generated energy using the Pumped Storage Hydro (PSH) principle. Utilising pumps with a capacity of 10,000 m³ per second, the project will also improve the flood protection in the Dutch Delta. The strategic position of the site near Maasvlakte 2 (Rotterdam's new port area) in the offshore Delta also offers great opportunities to strengthen both biodiversity and the ecosystem in the mouth of the Haringvliet. It provides an outstanding example of the building with nature approach. The initiators of the concept, Huub Lavooij and Leen Berke, joined forces with several companies, educational institutions and public bodies for the development of this innovative concept.

The Delta21 concept consists of two basins. The 50 km² storage lake will

be the lower basin. Its different water levels will be interconnected with pump turbines, allowing for the generation of gravitational energy due to the differences in height. The North Sea will form the upper basin of the PSH system. The installed capacity could be increased from 2 to 12 gigawatts, allowing the surplus of generated energy to be stored. PSH is proven to be a mature principle that is responsible for 93% of energy storage worldwide.

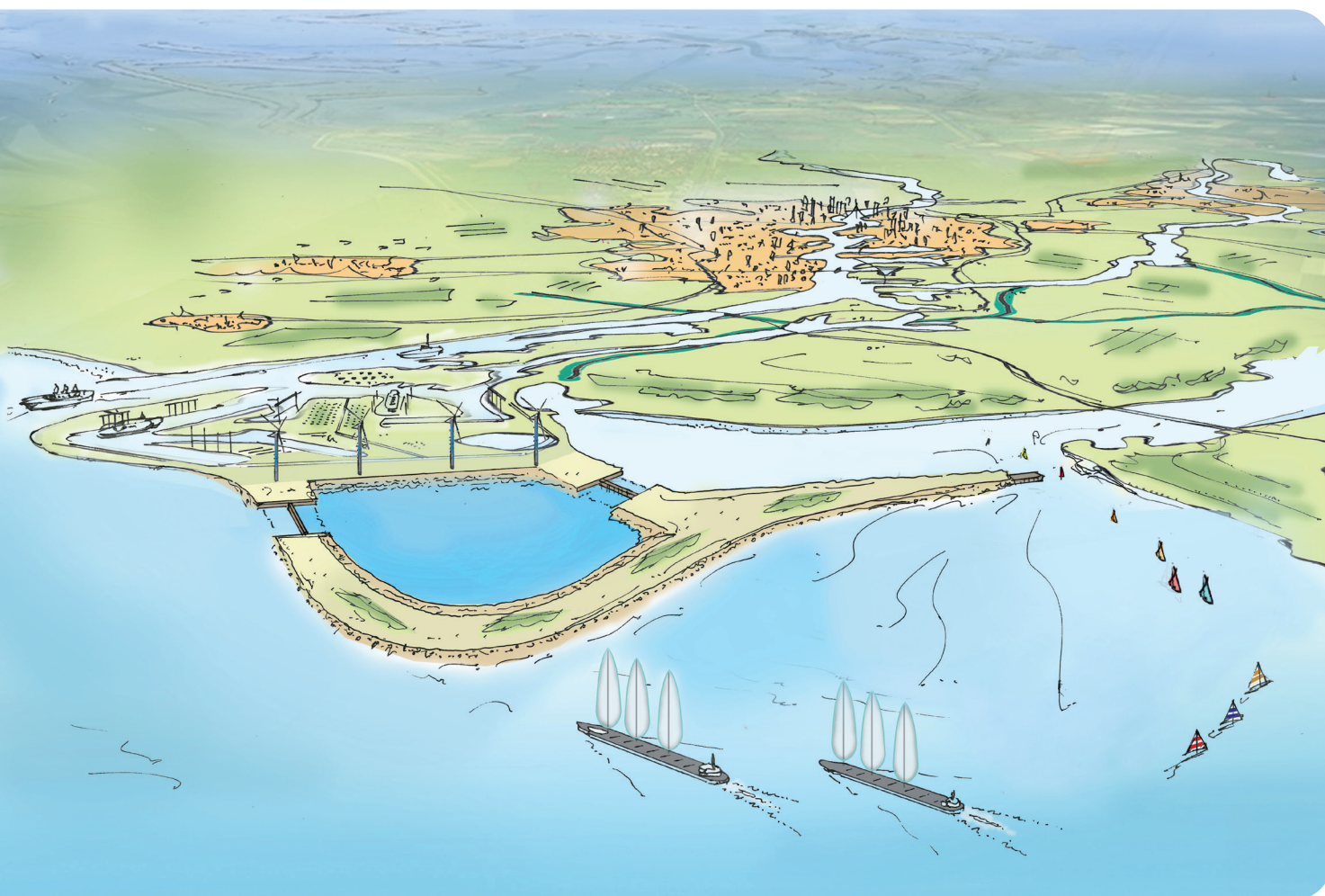
Given the minimal height differences in the Netherlands, "low-head/high-volume" pump turbines will be used. The storage lake will also provide the possibility of discharging excess water from the river by means of pump turbines, preventing flooding in the hinterland and providing an attractive alternative to constructing dykes in densely populated areas.

The Delta21 concept also offers opportunities for building other eco-friendly solutions, such as floating solar

parks, wind parks, aquaculture and other opportunities to strengthen nature and increase biodiversity. The concept could be applied worldwide in flat areas, especially in densely populated low-lying coastal areas, with a demand for energy storage and flood protection where nature conservation is at stake.

The answer to energy transition challenges

The energy transition – the transition from conventional to sustainable energy – places great importance on the security of the electrical supply. The Delta21 concept allows for 34 GWh of energy storage. 2 GW of installed capacity could provide the storage or delivery of 34 GWh in 24 hours, corresponding to a maximum of 5 terawatt hours annually. According to TenneT, Transmission System Operator (TSO) for the Netherlands, this is approximately 10% of the required storage capacity for 2050. The storage capacity could easily and gradually be increased from 2 GW to 12 GW, allowing for the surplus of



Bird's eye view of the lake that will be created by the Delta21 project at the Haringvliet estuary. Image © C Concept Design.

Pumped storage hydro (PSH)

The principle of a PSH power plant is similar to a conventional hydroelectric power plant. The PSH plant foreseen for Delta21 will exchange water between the North Sea and the lower-lying storage lake. The water levels will vary between 5-28 metres, which is low compared to applications in mountainous areas. For that reason, the use of closed Archimedes pump turbines is foreseen. In times of high energy supply and low demand, the turbines will pump water from the lake into the higher North Sea. On the other hand, during times of low energy supply and high demand, water from the North Sea will be released to the lower storage lake via turbines, generating electricity. The water will remain in the lower reservoir until it is pumped back to the North Sea when energy supply is high and demand is low. As a result, the water level in the storage lake will vary between -5 and

-28 metres Mean Sea Level (MSL), whereas the bottom of the lake will lie at -33 metres MSL. During this process, 1,100 million m³ of fresh nutrient-rich salt/brackish sea water will be exchanged with the North Sea.

On the sheltered Haringvliet side, a series of Archimedes pump turbines will be located on a sand dune. The required number of 20-megawatt pump turbines will depend on the chosen installed capacity. The range of each pump turbine will be approximately 25 metres. The circular water screw will be made of a composite and have a diameter of 10 metres. The length of the screw will be approximately 80 metres. The Archimedes pump turbines will be very efficient (0.85-0.95% one way), sustainable, fish friendly, inexpensive and easy to maintain, with a life span of at least 60 years.

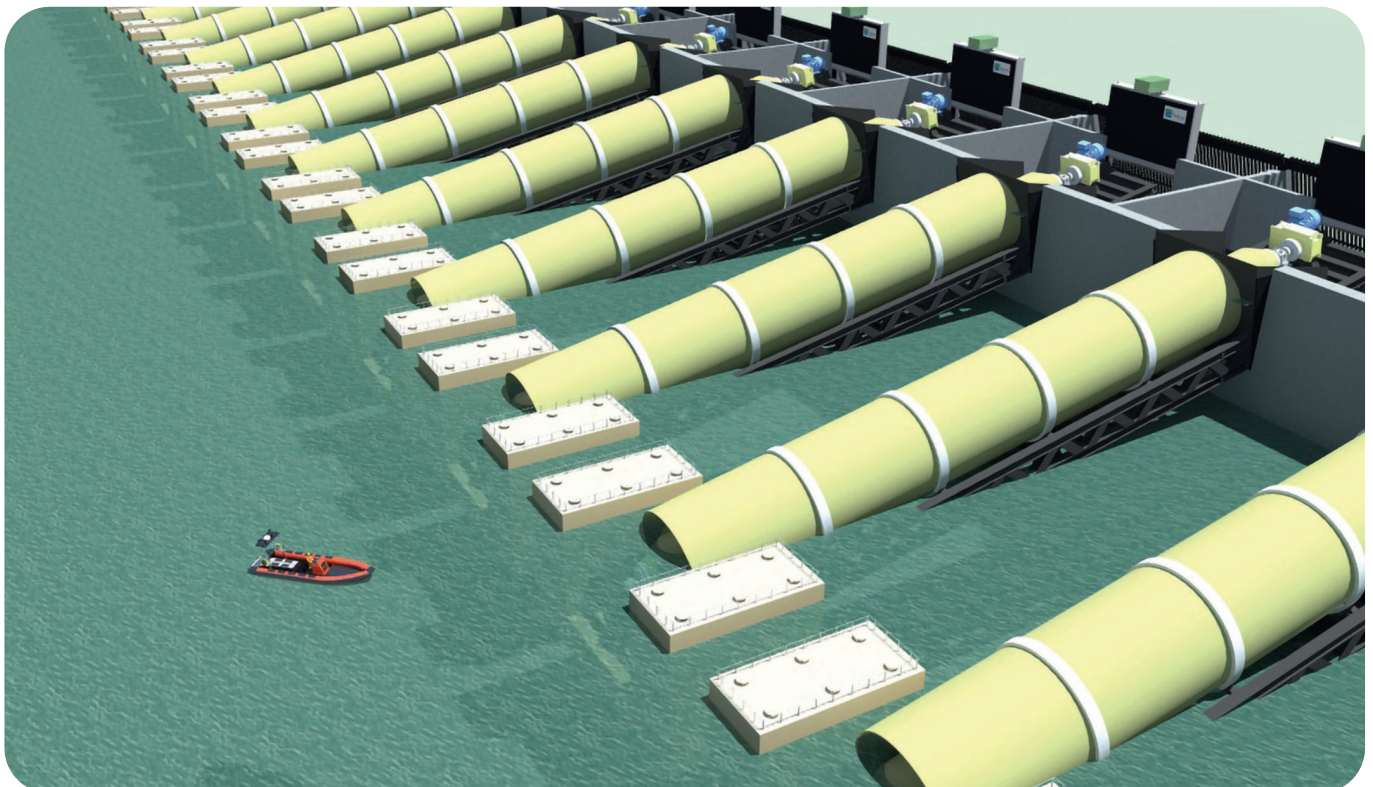
Large-scale energy storage is therefore essential **for maintaining a sustainable energy supply.**

generated energy to be stored as long as needed. At 12 GW of installed capacity and 4 hours of filling time, the storage lake could produce up to 30 terawatt hours per year. With 40 km² available for installing solar parks, wind farms and even aqua batteries at the bottom of the lake, an additional amount of energy could also be stored.

On a windless day, there is no energy generated from wind. However, if there is more wind and solar energy available than is used, we often throw that energy away. Large-scale energy storage is therefore essential for maintaining a sustainable energy supply. The energy storage lake in the Delta21 concept can make an important contribution to this.

Meeting increasing flood protection demands

The energy storage lake in the Delta21 concept offers a wonderful opportunity for temporary water storage and a huge pumping capacity during extreme weather events such as storms. The economically valuable downstream areas of the Rhine and Meuse in particular, are threatened by the combination of storm surges, high river discharges and rising sea levels. During heavy North Sea storms, the water level along the Dutch coast can rise 4-5 metres within a few hours. In those cases, the storm surge barriers along the Dutch Delta estuaries are closed to prevent flooding. However, the protective barriers also prevent the outflow of river water



Closed Archimedes pump turbines, developed by FishFlow Innovations, allow the safe passage of fish through the pump system.

into the sea. Due to climate change, sea levels are expected to rise in the coming decades. Additionally, the risk of rivers overflowing also increases as we experience more heavy rain throughout the European river basin, requiring drastic measures. Delta21 offers an attractive solution for this.

Facing environmental challenges

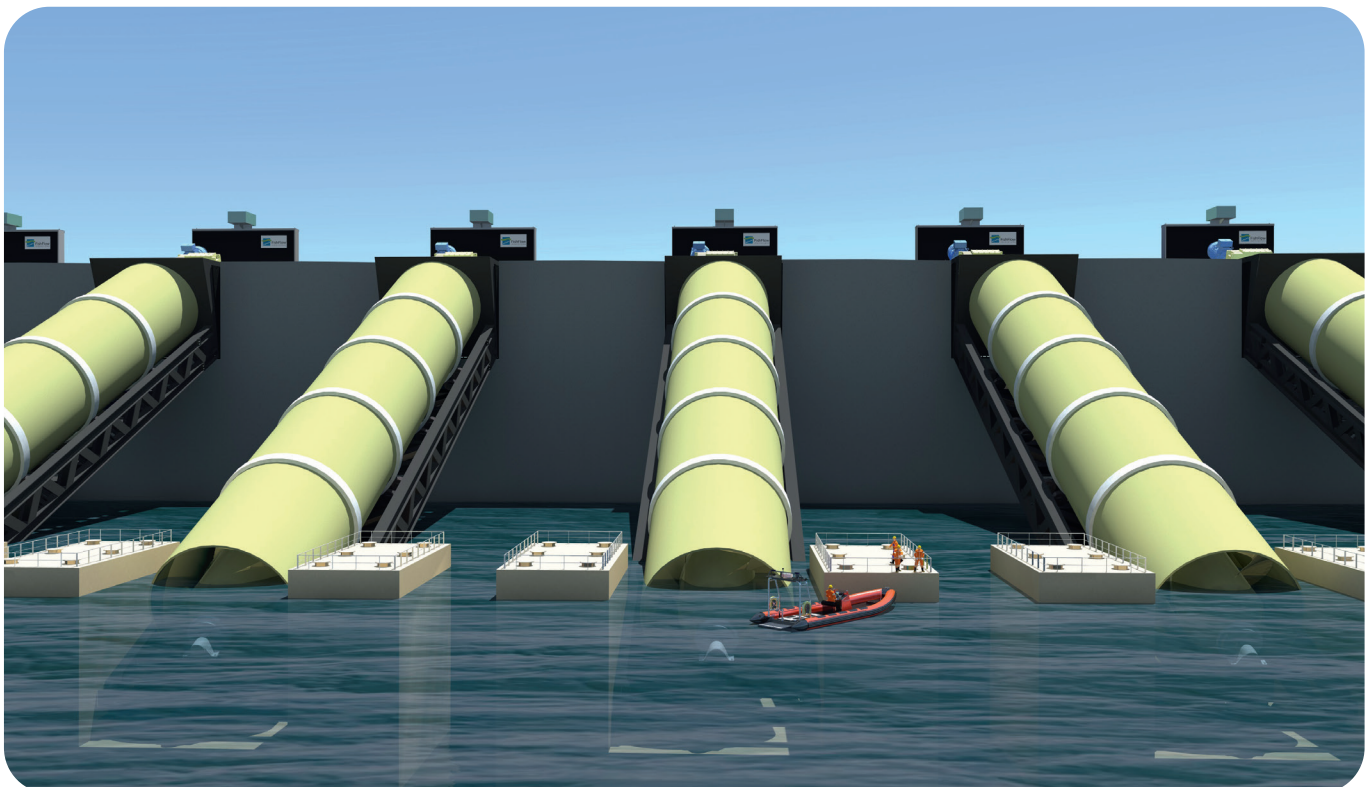
The mouth of the Haringvliet is under environmental pressure. Biodiversity in each of the four adjacent protected areas, Kwade Hoek, Duinen van Voorne, Voordelta and Haringvliet is slowly decreasing. Haringvliet used to be the main tidal estuary connecting the North Sea with the Rhine and Meuse, and was unique for its rich brackish water biotope. As part of the Delta Works, Haringvliet was cut off by a dam whose locks normally remained closed. Consequently, the Haringvliet estuary became a freshwater lake. Fish migration was strongly reduced and tidal currents weakened or even disappeared. This resulted in the sedimentation of the Haringvliet's mouth and had consequences on the brackish ecosystem and recreation.

Currently, the sea west of the Haringvliet dam (the Voordelta) is experiencing considerable silting up. Continuous dredging in the narrow channel is needed to allow Stellendam's fishermen to continue sailing. Even though some salt water has been allowed to enter Haringvliet since 2020, the measures have been insufficient to reverse the decrease in biodiversity.

A simple and effective alternative

The question arises, where and when we will encounter the limits of building higher and wider dykes? Moreover, strengthening dykes has a major impact on the built environment. The Delta21 concept offers an alternative that is worth the calculation. The storage lake will be able to hold 1,100 million m³ of water. To put that into perspective, the Rhine discharges a maximum of 18,000 m³ per second, amounting to 65 million m³ per hour. This would mean the Rhine could flow into the storage lake for 17 hours before it is full. In addition, there would be more than a hundred Archimedes pump turbines functioning together as one mega pumping station.

In terms of water safety, the Delta21 concept is a simple and more effective alternative to continually raising and strengthening the dykes. For that reason, both the provinces and the water boards are looking into the benefits of Delta21 in the field of water safety with great interest.



Archimedes pump turbines. Images © FishFlow Innovations.

Causes and effects of biodiversity decline

The closing off of the Haringvliet estuary in 1970 by a dam as part of the Delta Works disrupted the existing nature and biodiversity in the four Natura 2000 protected areas and beyond. The decision to separate salt and fresh water by the Haringvlietdam had an impact on the biodiversity and fish migration between the North Sea and the Rhine and Meuse rivers. In addition, the consequent disappearance of tidal currents and waves caused sedimentation in the coastal morphology in the Voordelta and in the Haringvliet, negatively affecting navigation, as well as recreation and tourism. The salt spray caused by breaking waves, which

creates a number of unique salt-loving plants in the Voornse Dunes, practically disappeared.

As a result, sand is being transported along Kwade Hoek and the Hinderplaat is moving further towards Rockanje. The displacement of the Hinderplaat and the silting up create a major threat to the beach of Rockanje, as the siltation creates a sandy and mudflat biotope instead of beaches. The sedimentation also requires continuous maintenance dredging to keep the narrow, winding channel from the North Sea to Stellendam at a navigable depth.

For that reason, the Delta21 plan includes positioning a brackish tidal lake of approximately 50 km² in the shallow eastern part of Haringvliet's mouth in the Voordelta, allowing new brackish nature to emerge. Gullies, banks and creeks will transform the tidal lake into a rich natural habitat for flora and fauna. On the wind and wave sensitive North Sea side, the lake will be separated from the sea by dunes, offering opportunities for new and

extended biodiversity. The sand available from the deepening of the storage lake will be used to shape the dunes.

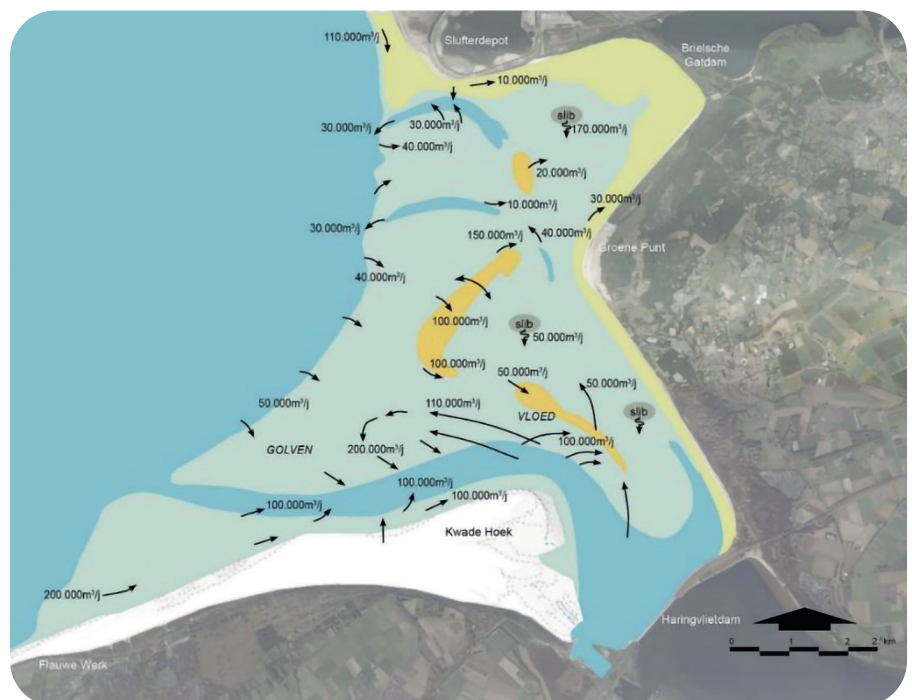
Restoring biodiversity and stopping sedimentation

Constructing the energy storage lake in the deeper part of the Haringvliet estuary would prevent Hinderplaat from moving further towards Rockanje. The silting up of the Kwade Hoek would

be stopped as well. To minimise silting, measures are being taken to direct the silt flow into a deep shipping channel that is to be constructed.

The shallow area between the energy storage lake and the Haringvliet locks also offers space for the 50 km² tidal lake in the Delta21 concept. The salt-brackish water in the tidal lake will partly restore the original brackish water

Gullies, banks and creeks will transform the tidal lake into a rich natural habitat for flora and fauna.



Current sedimentation process at the mouth of the Haringvliet. Photo © Arcadis.

biotope. Moreover, the tidal lake will be favourable for the migration of fish between the river area and the North Sea. The Delta21 concept plans to further support fish migration by constructing a fish migration river between the tidal lake and the Haringvliet.

Biodiversity will be stimulated by creating a row of dunes on the west side of the energy storage lake where breaking waves will provide the salt spray needed for unique salt-loving plants. Banks and channels will alternate in the tidal lake. Artificial reefs, terraces, floating platforms and other nature facilities in the energy storage lake will contribute to the restoration of the original biodiversity as well. The Delta21 concept offers plenty of opportunities for nature restoration, preventing the shore from slowly but surely turning into one large silt and sand plain.

Local demand for energy storage

The Delta21 concept is strategically positioned south of Maasvlakte 2, where TenneT already has an approximately 8-gigawatt transformation station available connected to the 380 kilovolt (kV) high-voltage network. However, large-scale storage is lacking. With a storage capacity of 34 GWh, the energy storage lake in the Delta21 concept will relieve the burden on both the TenneT transformation station and the 380 kV high-voltage network.

Maasvlakte is part of the port of Rotterdam, a 40% conventional energy port with an industry running mainly on conventional energy. The port sector attaches great importance to the design

of a sustainable energy hub with large-scale storage in the immediate vicinity. The Delta21 energy storage lake in the Haringvliet estuary could well serve as the sustainable energy hub for Rotterdam.

Business case

The construction costs for the energy storage lake amount to EUR 8 billion, based on 2023 price levels. Although the technical lifespan is longer, these construction costs can be amortised over a hundred years. In the existing access channel to Stellendam, there is room for a new 200-metre-wide/ 8-metre-deep navigation channel. This has not yet been included in this amount. The operating costs are comparable to the operating costs of a power plant, however, the operation of a power plant is much more complex. For the energy storage lake, only an operator is needed to switch on or convert the pumps and turbines.

The consultancy firm Horvat & Partners BV has validated the Delta21 design, our implementation method and the costs. CE Delft has investigated the quantitative merits of the energy storing of Delta21. The study shows that Delta21's levelised cost of storage (LCOS) is cost-competitive with favourable financing and sufficient full-load hours, all based on a depreciation period of 30 years.

Way forward

Since it has been determined to be technically and financially feasible based on proven methods, the "final step" is to convince politicians and the government. Various initiatives are underway to

achieve this. Several informal discussions are being held with the Dutch Ministry of Economic Affairs and Climate and the Ministry of Infrastructure and Water Management. They find the integration of solar and wind farms within the concept promising and advocate connecting the energy storage lake to the new nuclear power stations that may be built in Borssele, as well as the hydrogen factories to be built on the Maasvlakte. Huub Lavooij commented, "If we get the green light, one of the biggest challenges will be to immediately implement this project in its full extent. You cannot first 'practice' this on a small scale and then scale it up. But we will undoubtedly find solutions for this too."



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Making strict choices

Co Verdaas, the Delta Commissioner in charge of all water safety measures, when presenting his Delta Programme in 2024, urged that we speed up and set limits on the use of space and water. He added, "That also means making stricter choices about where we do and do not build, where we create space to store water for dry periods, and where we reserve space for future dyke improvements." At this point in time, the emphasis of the water safety measures lies entirely on the dyke reinforcement programme.