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Holwerd on Sea: Coastal Design from a Different and Integrated Perspective

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Abstract: The local community network of Holwerd has launched an ambitious idea to create an opening in the sea dyke to bring the sea back to Holwerd. This measure is necessary to make Holwerd more attractive for tourists and reverse the economic decline of the northeast Friesland region. This paper shows the opportunities for redesigning Holwerd-on-Sea in a more sustainable way. The plan integrates spatial, natural and economic cycles in a climate-proof design proposal. The approach is based on building with nature and economic value creation. The plan increases the livability of Holwerd, turning the downward spiral into an upward spiral.

Holwerd adapts to trends as climate change and salt water intrusion, by changing the current freshwater cultivations into salt water cultivations. To reverse the downward ecologic cycle within the region new nature is created and the salt marshes will be excavated. To create more economic values in the region, this new nature is open for tourists and introducing a fairway for recreational ships to the Wadden Sea. The tidal basin that is created by breaching the sea dike will flush the fairway clean and store energy using a reversed hydro storage plant.

Key words: integral spatial design, water management, fish migration, circular economy, energy storage

1. Introduction

Holwerd is an village at the northern part of Friesland. The village Holwerd is impoverished. Inhabitants leave the village the city's. The economic of Holwerd is descreasing. Furthermore the area has problems with decreasing quality of ecosystems and salinization. The local community of Holwerd want to solve these problems. Therefore the local community wants to bring the see back to Holwerd. In the past Holwerd was located on sea. The modern dyke and land reclamations led to a larger distance between Holwerd and the sea.

The local community network of Holwerd has asked students of the University of Applied Sciences Delft to draw up a plan for the spatial redesign of Holwerd. This article describes the result of this research.

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1.1 Design and Vision

Spatial planning and environmental management are relying more and more on managing the economic and ecological flows that run in a certain area. There are multiple flows, which are essential for a spatial design to behave like an organism. The main streams for this spatial design are energy, food, water, nature and waste. Water is the pillar of this design, since it influences all other streams. Fig. 1 is the design of the Holwerd-On-Sea area.

2. Water

In the context of climate warming, the new standards for flood protection in the Netherlands are adopted in the Delta Decision "Watersafety". These standards are realized with the help of a risk approximation and are based on the expected situation for 2050. The new standard specifications for the Delta Decision "watersafety" are recorded in the Delta Programme 2015 [1].

Fig. 1 Integral design Holwerd-On-Sea.

Holwerd, located at dike in the range 6-4, has a standard specification of 1/3000, which means that the probability of flooding here ranges from 1/300 per year to 1/100,000 per year. In the context of water safety, for Holwerd an exploration plan has to be realized between 2016 and 2018. Between 2019 and 2020 the plans will be elaborated and between 2021 and 2027 the plans will be realized (Nationaal Waterplan, 2014).

The dike between Holwerd and the Wadden Sea will be breached with the plan "Holwerd on sea". In the context of global warming and rising sea water level means that the breach in the dike needs to be filled with a sluice gate. The main function of this gate is to protect the people on the mainland against floods. The water gate exists of two doors, which are electrically controllable. The doors are opened most of the time, but when storm threatens the mainland, the water gate will be closed.

2.1 Water System

The plan shows how Holwerd-on-Sea, instead of fighting against the water, "embraces" the water of the Wadden Sea. A connection where seawater and fresh water can merge will be realized by a domestically located water retention reservoir. The water level in the area is electrically controlled by sluices and gates, which protect the mainland from salt water intrusion and provides opportunities for offshore sailing. A water gate which is electrically controllable is placed at the point where the gap in the dike is made.

A sluice connects the water from the domestically located retention reservoir with the so called channel "Holwerder Feart".

These measures have various socio-economic, natural and environmental effects, but an inland water retention reservoir does something else: The water from the domestically located tidal reservoir is used to decrease the dredging costs. Reduce the dredging costs forms a boundary condition for this project. The magnification and realization of a permanent retention area in the shape of a flush lake can form a solution. The increase of retention area, results in a faster flow and less material is able to sediment in the sea lane [2].

Besides protection against floods, this water gate can be used to control the flow of the effluent flush water which is originating from the domestically located tidal reservoir. At this place the flow of effluent flush water is very strong. The doors of the water gate are electrically controllable and this provides the possibility to control the flow of effluent flush water and protect the bottom against erosion [3]. At high discharge these doors are used to slow down the flow of effluent water.

Besides this water gate, there are other measures that need to be taken against the force of the effluent flush water. The water bottom needs to be protected against erosion from the flush water and against erosion which is generated by passing recreational crafts [4]. Geotextile is used here to protect the water bottom against erosion,

For this measure, a framework of ropes and brushwood (two layers of ropes and brushwood at right angles to each other) is assembled on top of a piece of geotextile. This framework is filled up with cobalt stones. The framework prevents that the cobalt stones can roll and it will keep the geotextile at the desirable location. It protects the water bottom against erosion [5].

The same measure should be taken at the place where the sluice is built, which connects the domestically located tidal basin with the so called channel “Holwerder Feart”.

2.2 Analyses Flush Function

For the project “Holwerd on sea”, an expert meeting was organized to find out in how far a tidal reservoir can fulfil a flush function. In this expert meeting the analysis are based on a tidal basin of 35 hectares. These dimensions are not exact the same as the dimensions for the plan “Holwerd on sea”, but this research will offers handles in order to create a good working flush function. The dimensions of the flush lake for the plan “Holwerd on sea” are 85 hectares.

The results of the expert meeting describe that the flow of the flush water has a different efficiency on the dredging fractions “fluid-mud” and “sand”. This “Fluid-mud” fraction is a silt that consists of very small fractions of dust, which will sediment on top of the sand fraction. This phenomenon can be noticed around the sea lane Holwerd-Ameland since 2007 [2].

The efficiency of the flush lake has been estimated as follows:

- fluid-mud fraction: decrease of 50-100%
- sand fraction: decrease of 10-30%

Based on the findings from this expert meeting, researchers expect a substantial decrease of 500.000-1.000.000 m^3 dredging volume a year. The total current dredging volume is about 1.600.000 m^3. Both fractions have about the same contribution of 800.000 m^3. The experts say that a permanent retention area in the shape of a tidal basin can be a technical realizable option and a decrease of a third to half of the dredging costs is realizable [2].

2.3 Building with Nature

The Wadden Sea area is in terms of security of great importance to the coast of the Netherlands. The outer deltas, the Wadden islands, tidal flats and salt marshes offer besides the high nature also an additional protection buffer for the coast of the Netherlands [6].

For the elaboration of the plan “Holwerd on sea”, use has been made by the concept “building with nature”. “Building with Nature” is an integrated approach in which water plays a major role. “Building with Nature” is a climate adaptive system and is used for creating residential, work, tourism, recreation and infrastructure. At the same time it is aimed at preserving the expansion of precious natural resources, nature values and landscapes [7].

Three natural building stones are further elaborated with the plan “Holwerd on Sea”. These are “artificial oyster banks made of gabions”, sandbanks and shell banks. The course of the flush stream will be guided by using shell banks, which is in line with the concept of building with nature. Shell banks will be grown in this part of the Wadden Sea and will give a more natural view than using cobalt or concrete. Shell banks are used to narrow the sea lane, which has to result in a more effective flush function [2]. Shell banks in combination with the saltmarsh and corresponding vegetation are giving support as natural coastal defense and research also shows that opportunities for natural improvement can specially be found for recovery of shell banks with corresponding communities [8].

At this very beginning of the sea lane, the water flow of effluent flush water is very strong. A strong guiding system which is resistant against strong water flows is needed here. For this measure, a fence of artificial oyster banks made of gabions is realized to guide the flush water. Critical places are the locations where the flush water has to make turns. Shoreline T-Gabions are used here. Shoreline T-Gabions are specially designed to deflect tidal flows. This system is used for sea lanes and gives oysters a safe place to grow [9].

Further seawards the guiding system will consists of shell banks which are developed on Shoreline Gabion Matrasses. These matrasses are specially made for the establishing of artificial reefs and oyster beds. These constructions look more naturally than shoreline gabions and shoreline T-gabions. The mattresses are filled with concrete, stones and oyster shells. Shoreline gabion matrasses conform to the contour of the sea bed and allow oysters to attach itself to the matrasses [9].

Shell banks are used to capture sand and settle the sediment at the desirable locations. These shell banks will also help to clear the water [10]. With the plan "Holwerd on sea", "fences" of shell banks are connected with the already existing sandbank, the so called "Piet Scheve Plaat". This measure will result in a larger area of shell banks, silt- and sand plates. This is desirable because sand- and shell banks are both part of the national conservation objective: Conservation of dispersion and conservation of current space and quality improvement of habitat type "Silt- en sand plates in tidal areas" (habitat type 1140, subtype A) [8].

The habitat forms a rest place for seals and it has an important function as habitat for young fish to grow up. The rich biodiversity of bottom fauna, makes these sand plates indispensable feeding grounds for migrating birds [11].

Shell banks in combination with the saltmarsh and corresponding vegetation are giving support as natural coastal defense and research also shows that opportunities for natural improvement can specially be found for recovery of shell banks with corresponding communities [8].

This habitat type is characterized by a high biodiversity, but the conservation of this habitat type for the future is assessed as unfavorable. In the long term a seawater level increase of more than fifty centimeters, may reduce the size of this habitat type. Because the ecosystem is large and complex, it is difficult to predict how certain developments will proceed and what effects will occur by gradual changes [12].

2.4 Fish Migration

The water system of the Netherlands consists of huge quantities of "water islands" rivers, canals, lakes and ditches that are separated by dams, dikes and sluices. These measures are necessary to protect areas for floods. These measures also allow Dutch inhabitants to live in the deltas. These measures have resulted in a fragmented landscape and led to changes in the composition of flora and fauna [13].

The dike between the Waddensea and the mainland is closed for fish between the "Lauwersmeer" and "Ijsselmeer". Because of that, migration for fish between salt and fresh water is very limited. The plans for Holwerd at Sea give a change for migrating fish. The creation of an opening in the dike makes this possible. The new created lake is the connection between the canal called "Holwerder Feurt" and the sea. With this connection Holwerd at sea is an important link for the recovery of the ecological system in the Waddensea. For fish the area between salt and fresh water are very important. These areas are used as foraging, migration and breeding area [14]. The fish using the area can be divided in two different groups. The diadromous species who use the area as migration route and marine juvenils for who the area is used as a nursery area [14].

Species that can profit from this connection species for Holwerd-on-Sea include the twait shade (*Alosa fallax)* and European eel (*Anguilla Anguilla*). Both species are diadromic species who can migrate between salt and fresh again [15].

Besides the diadromic species there are also opportunities for marine juvenil species who can use the new lake as nursery area. The European seabass (*Dicentrarchus labrax)* is a specie that lives in the coastal waters from The Netherlands. This specie uses estuaries' as nursery area [49]. The new lake by Holwerd can be used by this specie.

For the plan "Holwerd on sea" a fish ladder is built next to the sluice. The dike and the sluice form a barrier for migrating fish, but with the plan Holwerd-on-Sea, fishes are able to migrate again between salt and fresh water. A solution is found by the realization of a "fish ladder", next to the sluice.

The fish ladder is giving fishes the possibility to travel between salt and fresh water, 24 hours a day. For the design of the fish ladder, use has been made of the "manual fish migration". Natural or semi-natural solutions seem to be impossible [13].

In order to regulate the flow rate as a result of changing seawater levels, three valves are designed that move along with the movement of the constantly changing sea water levels.

Another measure to control the flow rate are the bulkheads which are placed into the fish ladder [13]. These bulkheads form the steps of the ladder and fishes can rest behind the bulkheads and climb up step by step. Gravel and stones are used to cover the bottom of the fish ladder. The pump which controls the water level between the sluice gates is used to create a stream to attract the fish.

3. Nature

The redesign of the area offers new opportunities for nature. The gap in the dyke will restore fish migration from fresh to saltwater. To compensate the effects of the sea lane through the salt marsh measures need to be taken [16]. Therefore, it is necessary to take measures for recovery the existing salt marsh and creating a new salt marsh.

3.1 Saltmarshes

The area north of the sea dike is a salt marsh. The salt marsh is a unique ecosystem of salt tolerating vegetation. The saltmarsh by Holwerd is part of a larger area of salt marshes.

The Dutch salt marshes are at the southside of the Waddensea at the northern part of Groningen and Friesland. The saltmarshes are part of UNESCO World Heritage area the Waddensea (UNESCO). However the ecological quality of the salt marsh is decreasing [16].

There are different causes for the decreasing of the ecological quality of the salt marsh. One of the main reason for the decreasing is the drainage system that has been created for agricultural means. The drainage system causes a decrease in the influence of the salt water. This leads to the disappearing of pioneer vegetation and an increase of climax vegetation. The existing drainage ditches in the area are not in relation with a natural situation. In a natural salt marsh area the drainage system consists of creeks [17].

To improve the ecological quality of the area, the influence of the sea needs to be bigger. Closing the current surface water system will increase the influence of the sea [17, 18]. The vegetation of the salt marsh has aged and is in the climax stadium. The salt marshes were used for agricultural activities.

The farmers used the land for the cattle. The cattle increased the number of pioneer vegetation in the area [17, 19].

The intensification of the agricultural activities in the area lead to a larger cattle in the saltmarsh. These large cattle's had an effect on the vegetation. The number of flora species was decreasing [19, 20].

Recent decade the use of salt marshes for agricultural purposes has decreased. The cattle's disappeared out of the salt-marsh. This had an large impact on the ecosystem. The salt marshes recovered and the numbers of vegetation species grown [17, 19]. However the effect of the disappearing of cattle's on the long term was different. The speed of succession of the area was increased.

Pioneer vegetation disappeared and Sea couch (*Etrygia atherica*) dominated the salt marshes [17, 19, 21]. The increasing succession even leads to vegetation types with species that are not typical for the saltmarsh like Common reed (*Phragmites australis)* and Creeping thistle (*Cirsium arvense*) [20, 22].

To stop the rate of succession in the salt marshes grazing cattle's were re-introduced. In most salt-marsh areas there has been chosen for horses but also sheep and oxen were used. The results of the introduction of these grazing cattle's were a decreasing of the rate of succession and more horizontal structure in the vegetation [18-22].

To improve the quality of the ecosystem at the salt marsh by Holwerd-on-Sea the reintroduction of a grazing cattle is necessary. Grazing cattle's clearly have positive effects on the salt-marsh. However there are some risks. The cattle's mainly graze of Sea couch (*Etrygia atherica*). But cattle's also graze the pioneer vegetation. Therefore zoning of the cattle is necessary to protect the most vulnerable vegetation at the lower part of the salt-marsh [19]. Another risk of grazing is trampling of vegetation and nest by the large herbivores [17-19].

Especially horses have a large effect on the vegetation and breeding success because of trampling [18, 23]. Because oxen have a smaller negative effect on the breeding bird success than horses, grazing with oxen is preferred. Because of the wet circumstances of the salt marsh Galloway oxen are the preferred choice [24]. With the reintroduction of cattle Galloway oxen in the salt marsh the rate of succession will be decreased.

3.2 New Nature

To create a sea-lane in the existing salt marsh compensation is necessary [16]. To compensate the loose of salt marsh area there will be a new nature area behind the dyke**.** The agricultural area at the eastside of the lake will be redesigned as a salt marsh. This is possible because of the influence from the salt water off the new lake.

The ground will be levelled to increase the influence of the salt water. The new nature will develop into salt tolerating vegetation. With the introduction of salt water into an system it is possible to create a salt tolerating ecosystem [18]. There are examples In the Netherlands of agricultural areas that transform into salt-tolerating ecosystems.

The influence of the salt-water into an agricultural area will re-introduce salt tolerated vegetation species. Especially the lower parts of certain areas will transform in a salt tolerated vegetation [25]. To prevent a high succession rate this area will be grazed too [17, 18, 25]. Within in four years in the research area from Van Duin et al the area did transform into a salt marsh like vegetation [25]. Within ten years the 23 target species for a salt marsh grow within the new salt marsh area [26].

3.2 Birds

The Waddensea is a unique area for bird species. It is used as rest place for migrating birds. But it's also a hatchery for a lot of birds. Especially the sandbanks in the "Wadden sea" are important for species like eider (*Somateria mollissima*), sandwich tern (*Thalasseus sandvicensis*), artic tern (*Sterna paradisaea*) en common tern (*Sterna hirunda*). These species show all a negative development in the period off 1990-2014 [27].

These species have in comment that they breed and foraging on the sandbanks. Because of higher sea levels and more extreme floods these areas are endangered (Ecomare). To compensate the loss of these areas there will be create an alternative. In the eastside of the lake there will be bird breeding islands. The pied avocet (*Recurvirostra avosetta*). Is a breeding bird at the saltmarsh. This bird knows an increase in breeding in the period between 1970 and 1990.

But since 2000 there is a decrease in the numbers of successful breeding pairs. This decrease is mainly cost by succession in the saltmarsh [28]. The pied avocet will provide off the introducing of grazing cattle's.

4. Tourism

The development of nature area will increase the number of tourists. With floating walkways in the saltmarsh the tourist can walk through the nature in all seasons. The floating walkways make the wet salt marshes easy accessible for tourists. The floating walkways are already applied in other wetlands in the Netherlands (Natuurmonumenten). In the new nature are will be a bird observatory. The bird observatory offers tourists the opportunity to watch the breeding birds.

Besides nature recreation, Holwerd-on-Sea will be an important place for water recreation. Holwerd-on-Sea is the new connection between the lakes and channels of Friesland and the sea. In Germany are different examples of villages the profit from this kind of connections. Based on estimates made by experts from "Holwerd On Sea" with 500 new possibilities for nights there will be an increase in the income for Holwerd-On-Sea from 5,000,000 euro [29].

The increase in numbers of tourists creates opportunities for local entrepreneurs to start restaurants and shops.

5. Energy

One of the main causes of climate change is burning of fossil fuels. Unsustainable energy is a main emitter of carbon dioxide, which is the prime greenhouse gas. The mining and burning of fossil fuels also harms the environment and the health of the people [30]. In the year 1750 the atmospheric concentration of carbon dioxide was 280 ppm. The last years the concentrations continually rises with 2 ppm [31].

Wind turbines, hydropower plants and solar energy are the most dominant forms of generating sustainable energy (2016). The biggest downside of sustainable energy sources like solar panels and wind turbines is that they are not adaptable to energy demands, unlike hydropower plants. To make the region independent of fossil fuels, for generating electricity a natural battery to store excessive energy is necessary [32]. Hydro-pumped storage plants function as physical batteries, which are able to store excessive energy generated [32].

Hydro-storage plants use excessive energy generated during the night to pump water from a lake to a higher located water reservoir. During the day when the energy demand is high and the price for energy is higher this water flows back to the original source. The water flows through a generator that converts 85% of the kinetic energy the water holds into electricity [32]. In Holwerd this process is reversible within the so called "tidal basin", using a reversed hydro-storage plant. The efficiency of pumped hydro storage is about 70%, but it allows countries to have a lower nominal generating power output than peak power. Additional energy produced at night is than no longer useful, but is usable when peak power is required [32].

5.1 Reversed Hydro-Pump Storage System

The reversed hydro-pump storage system lets water from the tidal basin in during the day to generate energy. This water flows through Keplan turbines to generate energy. During this process the water level within the lake rises. During the night wind turbines provide energy for the pumps to pump this water out during the night. The water level drops so that the energy island can produce energy during the day [33].

Holwerd offers space for a reversed hydro-pump storage system with a diameter of 300 meters, with a depth of 45 metres. The slope that starts from the bottom of the reversed hydro-pump storage system until NAP will have a ratio of 2:1. This means the bottom of the Reversed hydro-pump storage system has a diameter of 272.5 meter. The total volume of the reversed hydro-pump storage system is $\pi \times 126.25^2 + \pi \times 147.5^2 : 2 \times 30 = 2{,}207{,}137.5\ m^3$.

The reversed hydro-pump storage plant empties itself within 9 hours so the flow for the outgoing water needs to be 68.12 m^3/s. The reversed hydro storage plant fills itself during the day when the energy demand is at its highest. Full capacity filling is possible between 7 AM and 10 AM, and from 3 PM until 4 PM. After that half capacity filling is used with a second turbine between 4 PM and 9 PM. The flow of the intake during 7 AM and 10 AM and 3 PM and 4 PM is 91.96 m^3/s. During the other stated times the intake flow is 45.98 m^3/s. Energy being delivered to the net, when the demand is high, is worth €11 cnt/kw/h, while energy delivered to the net when the demand is low, is only worth €6 cnt/kw/h [33].

With this data the power of the pumps and the generators is calculated, using the formula $P^*\eta$ =

ϕ*ρ*g*h. This formula translates into flow × density × gravity × mean height. Using an efficiency of 85% for both the pumps and the generators [33]. Using an 85% efficiency rate for the turbine gives the following results (91.96 × 1027 × 9.81 × 23.75) × 0.85 = 18.7 MW during full capacity filling and (45.98 × 1027 × 9.81 × 23.75) ×0.85 = 9.35 MW during half capacity filling [33].

On a daily basis, with custom made generators the Reversed hydro-pump storage system could generate 121.55 MW/H a day. Annually the Reversed hydro-pump storage system generates 44.365 Mw/H. With an energy price of €0.11 per kw/h [33], the total revenue of the reversed hydro-pump storage system is €4,880,233. The power necessary to empty the reversed hydro-pump storage system using pumps with 85% efficiency is bought for €0.06 per kw/h [33]. The total energy costs for draining the Reversed hydro-pump storage system are 168.25 × 365 × 0.06 = €3,684,353. Meaning the Reversed hydro-pump storage system will make €1.195.880- income.

5.2 Costs of the Reversed Hydro-Pump Storage System

To realize a reversed hydro-pump storage system the mainland of Holwerd needs to be excavated, the ground is build up as followed. The area where the reversed hydro-pump storage system is supposed to be realised lies at 1.22 meters above NAP [34].

Table 1 Ground layers and costs of removing [35-38] (din16)[1](bod16)[2].

Depth [1]	Soil[1]	Volume	Costs m^3 [2]	Total costs
0 till -5 m	Sandy clay	345.000 m^3	€2.25	€776.250
-5 till -5.5 m	Peat`	35.000 m^3	€3	€115.000
-5.5 till -6 m	Sandy clay	34.500 m^3	€2.25	€77.625
-6 till -6.5 m	Peat	34.000 m^3	€3	€112.000
-6.5 till -46.22 m	Sand	2190740 m^3	€2.25	€4,929,165
Total		2,2191,188		€ 6.010.040

The ground also needs to be drained of groundwater using depth drainage with an underwater pump. Per 100 square meters a drainage filter is to be applied. This means there are 710 filters necessary to realize the reversed hydro-pump storage system. The costs of a single filter is €150/m, each filter needs to be 50 meters long, this means the cost of each drainage filter is €7.500. Each filter needs to be connected to an underwater pump that costs €4,000 each, but can be sold after the project is finished for about €2.000. The montage and removal costs for the pumps are about €1,000 per pump. The total costs for drainage is (7500 × 707) + (3000×707) = 7,423,500 (bod161).

The Reversed hydro-pump storage system needs to be non-water permeable, the costs of applying non-permeable foil to the ground are €5 per square meter. The taluds and bottom of the Reversed hydro-pump storage system have a surface area of 45.000 m^2 (300 × π× 47). The total costs of making the Reversed hydro-pump storage system non-permeable are €225,000 [36-38].

The pump house will be placed inside the dam of the reversed hydro-pump storage system, this ensures the turbines and pumps are easy accessible. However, a hole and a waterproof staircase need to be made inside the dam to achieve this [33]. The costs of building the waterproof staircase and rooms for the pump and turbines are estimated on €2.500.000. The costs for the turbine and pumphouse which are placed inside the same room and the north side of the reversed hydro-pump storage system [33]. The costs for the turbines, pump, pipelines are based on the study of realizing a reversed hydro-pump storage system in the Markermeer by Inholland Alkmaar and teamwork technologies and are shown in Table 2. The main activities to realize a reversed hydro-pump storage system and the total expenses are shown in Table 3.

6. Food

A rising sea level means that river deltas and coastal areas will suffer from salt-water inclusion, which will

Table 2 Costs turbines, pump, valves and pipelines [33].

1. Expense		1. Unit	1. Price in [€]
2. High turbine	2. Turbine	2. 9 MW	1. 1.000.000
3.	3. Pineline	3. 57 m	2. 2.000
4.	4. Gearbox	4. 9 MW	3. 500.000
5. Low turbine	5. Turbine	5. 19 MW	4. 1.750.000
6.	6. Pipeline	6. 57 m	5. 2.000
7.	7. Gearbox	7. 19 MW	6. 1.000.000
8. Pump	8. Pomp	8. 20 MW	7. 1.750.000
9.	9. Pipeline	9. 70 m	8. 2.000
10. Valve	10. Valves	10.6st	9. 12.000
11.	11. Total	11.	10.6.018.000

Table 3 Total costs realizing the Reversed hydro-pump storage system.

1. Expense	1. Costs in €
2. Excavation	2. 6,000,000
3. Drainage	3. 7,750,000
4. Shielding	4. 225,000
5. Pumphouse	5. 2,500,000
6. Pipelines, turbines and pump	6. 6,000,000
7. Research and other costs	7. 2,525,000
8. Total	8. 25,000,000

make the cultivation of traditional crops harder [39]. The worldwide climate is not only heating up, it is also destabilizing, meaning that seasons are shifting and patterns of precipitation are changing. This means that dry areas on our planets will become even drier resulting in droughts that will kill crops. Areas that receive more rain like Western Europe and Southeast Asia will suffer from more intense rainfall, which will flood land with crops [39]. If areas do not adapt to these trends, the level of calorie availability in 2050 will have declined to pre-2000 levels [39].

Since 1950, the use of phosphor in agriculture has roughly quadrupled. In the next fifty years, phosphor usage will double due to the rising meat consumption and the increasing use of bio fuels. The known phosphor reserves lie in China, US, Morocco and Russia [40]. The phosphor peak production will likely occur in 2030 the year that production cannot keep up with demand. This result into increasing prices, also global reserves will be getting very scarce and increasingly more expensive with the projected increase in phosphor usage [41].

In 2015, 223 million tonnes of phosphor was mined and the U.S. Geological Survey, Mineral Commodity Summaries, expects that number to rise to 255 million tonnes in 2019. Companies use most phosphor to make fertilizers, but 43.7 million tonnes of phosphor are mined for chemical purposes, like cleaners and building materials [42].

6.1 Vision Alternative Food Supply System Holwerd

The former two indentions conclude that Holwerd as a rural coastal region should invest into a food supply system that is circular. In this paragraph, the vision of the project group on how to achieve that is shared. The supply system needs to be circular in a way that phosphor will be reused multiple times within the production cycle and will also be reused after the produced food is consumed, digested and has entered the waste stage of the life cycle assessment. Such a design is shown in the illustration below.

Holwerd is going to create a saltwater lake by breaking down a part of the dam that separates Northeast Friesland from the Waddenzee and replacing that part by a regulated intake. This saltwater lake along with the climate change will cause the farmlands in Northeast Friesland to become saltier. This means regular cultivations will grow worse and a transition towards either silt cultivations or aquatic saltwater cultivations is necessary for the region. Seaweed, algae and mussels can be cultivated in the Netherlands and could provide a sustainable food supply [43, 44].

6.2 Valorizing Waste Streams in the Region

Due to the extensive use of fertilizers today and even more so in the past, the Dutch soil, surface- and ground water in farmland contains enough phosphate to ensure exponential algae growth for decades. Usually this is seen as a huge problem for the water quality in the Netherlands [40, 45], even though it threatens nature

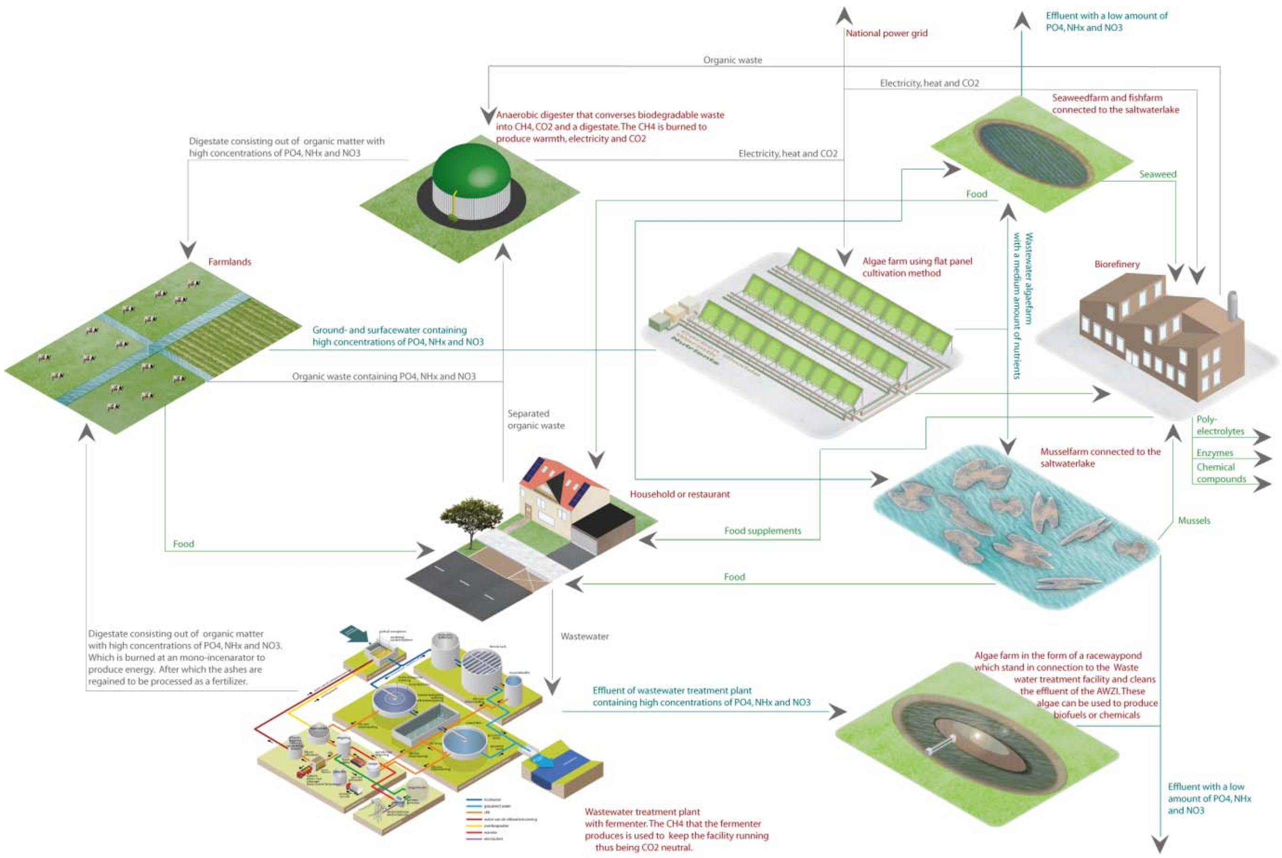

Fig. 2 A flowchart of the redesign of the Holwerd food supply.

reserves, it could very well form an element for seaweed, and mussel cultivation. The latter eats algae that consume phosphates out of the water.

6.3 Reusing the Digestate of Digesters as Soil Improver

Farmers and others use digesters in the Netherlands to harvest CH_4 out of organic waste using anaerobic bacteria. When a plant is digested by bacteria, the carbon hydrogen structures are broken down to H_2O and CH_4. The CH_4 escapes as gas into the air when farmers and others compost biodegradable waste. In digesters, that gas is won and burned to produce heat, energy and power or cleaned. The digestate contains many nutrients and is usable as a soil improver after a treatment [46].

Making use of a dry fermentation process a waste processor can break down biodegradable waste from households and biodegradable waste from the agricultural sector [47]. These products are drier than the faeces and urine from livestock that is why the traditional wet fermentation process cannot be used. Until recently, this meant that to ferment biodegradable waste a processor had either to co-ferment this waste along with a livestock's faeces and urine or add water to the process so that anaerobic bacteria keep themselves from overheating and killing themselves [47]. In Gent however stands a biodegradable waste fermentation plant that does not use water [47]. A similar installation can be realized in Holwerd.

The wet part of the digestate can be processed towards liquid compost, which is valuable for the agricultural business [46]. Meanwhile the dry part of the digestate can be sold as potting soil, which serves as nutrient rich soil improver. The reuse of the digestate prevents peat from being excavated and the additional mining of phosphor ore [46].

6.4 Algae

There are different manners to cultivate algae; you can use either a bioreactor or a raceway pond. Open-air cultivation is cheaper in purchase costs than using bioreactors, but bioreactors are more efficient. The most important bioreactors are the flat panel system, the stacked tubes system and the horizontal tubes system [48]. A recent study of the Wageningen University shows that the use of the vertical panel bioreactor is the most profitable in the Netherlands. Raceway ponds have the highest running costs per kilogram algae. In other parts of the world where the sun intensity and the temperature is higher the costs of running a raceway pond is considerably less [48].

The cost to cultivate and dry a kilogram alga is €2.50 after harvesting the dry algae mass needs to be refined. Refinery costs for alga are usually €1-€1.50 per kilogram dry algae mass (TijdelijkeAanduiding4). After that step, the right compounds that are useful for the food and feed industry need to be separated from the organic tissue. After that step, the food and feed industry can use these compounds in their products (TijdelijkeAanduiding4). To press the costs and promote symbiosis in Holwerd, the algae farm will be connected to the digester plant using pipelines, which provide CO2, Heat and electricity. To provide the algae factory from nutrients it will take in the fresh surface waters that surround Friesland and chemically clean them if necessary.

6.5 Seaweed

Seaweed is a crop that unlike traditional cultivations does not cost agricultural land or fresh water. Seaweed can be used for multiple bio refining steps, for example, a refinery can win the sugars in the cell wands as well as more recalcitrant structures like alginate (Tijdelijke Aanduiding 5). Within a natural ecosystem, seaweeds have a yield of 11 metric tons per hectare. When fertilizers are carefully used to grow seaweed, this yield can rise to 45 metric tons per hectare [44]

There are three classes of seaweed, divided by their pigment. There are brown seaweeds containing 1500 to 2000 different species, red seaweeds containing 4000-10.000 different species and green seaweeds, which count around 7.000 species. Wageningen UR studied the chances for seaweed cultivation in The Netherlands. They found out three species of seaweed would do well in the Dutch North Sea, which the Wadden Sea stands in direct connection with. The species that would do well in the North Sea are *Laminaria digitata* (Finger kelp; brown seaweed), *Palmaria palmata* (Dulse; red seaweed) and *Ulva lactuca* (Sea lettuce; green seaweed) [44].

The most promising source of income for seaweed cultivation is to isolate and win soy proteins out of seaweed. Soy is a main ingredient for feeding livestock and is found in the seaweed specie Palmaria paltama [49]. A metric tonne Palmaria paltama contains enough soy proteins for a market value of €3.000 per metric tonne seaweed. In 2010, The Netherlands imported 2.765.000 tonnes of soy to feed their livestock [50].

To provide nutrients to the seaweed farm it will stand in a regulated connection with the surface water system surrounding Holwerd. It will also receive by the wastewaters of the algae factory and stands in connection with the tidal basin trough a diver.

6.6 Mussels

Mussels could be the most sustainable "meat" product available, especially when those mussels clean the hypertrophic waters of the Dutch farmlands, before they enter another water system. Mussels are very resistant against deceases; the shells of mussels contain mostly out of calcium carbonate, which means they absorb carbon dioxide (more than any other animal with a shell in fact). Insects contain many of the same quality as saltwater mussels. Where consumers accept mussels as food, insects are seen as filthy and scary. In that, respect mussels provide a much safer economic bet to provide as sustainable meat product [51].

Mussels much like microalgae and seaweeds contain multiple compounds that are useful for industrial ends. Mussels contain polyelectrolyte and enzymes that can be used mainly in the chemical sector. For instance, enzymes are a necessary compound for detergents and pharmaceuticals. Polyelectrolytes are used for dewatering, which is necessary for the pre-treatment in the bio refinery. Dewatering is also one of the steps to make a useful digestate at a fermentation plant. The worldwide market for polyelectrolyte contains €2×10^9 revenue; the worldwide revenue for enzymes is €5×10^9 [52].

To provide nutrients and algae to the artificial mussel beds they will stand in a regulated connection with the surface water system surrounding Holwerd. It will also receive the wastewaters of the seaweed farm and stands in connection with the tidal basin trough a diver.

6.7 Wastewater Treatment Plant

Eventually food related products in Holwerd would be discarded via either the sewage or trough the collecting of separated organic waste. With the latter, the products will be fermented. If these products reach the wastewater treatment plant, trough the sewage the products will be processed there. Inside the wastewater treatment plant, the nutrients either will be stored in sewage or be broken down by bacteria. A mono incinerator will burn the sewage sludge from the wastewater treatment plant to produce energy. The ashes that come free during this process are reclaimable and can be converted into a fertilizer, which can be used in Holwerd and the region northeast Friesland to close the phosphor cycle [45].

7. Conclusion

A new integral design offers opportunities for Holwerd-On-Sea. Water safety is maintained using natural building stones in combination with the existing dyke and the new sluice. The existing dredging costs are lowered and fish migration between the Wadden Sea and the fresh waters of will be possible again, due to a fish ladder. Likewise recreational ships can travel between the Wadden Sea and the fresh surface water system of Friesland again.

The saltmarsh will be recovered and the losses of area salt marsh and the endangered bird breeding areas in the Waddensea will compensate at Holwerd-On-Sea. The new design offers new opportunities for nature and water recreation, what will improve the local economy.

The area's cultivations and food supply system need to adapt to salt-water intrusion and climate change. Holwerd can do that by focussing on a circular food economy in which seemingly waste streams are valorised, towards a product or a nutrient or material.

Holwerd will store sustainable energy generated at night using a reversed hydro pumped storage. This system will ensure net stability. Ad a higher peak nominal output when required.

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