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Feasibility Study for Optimisation of Land Drainage by Using Renewable Energy

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Abstract

Water management at the coasts secures the drainage of the marsh region along the North Sea as part of flood protection and to guarantee a productive agriculture. Changes in coastal morphology such as silting of the outer deep and climatic changes such as the sea level rise will lead to degradation or renunciation of natural drainage. A conventional solution, replacing sluices by coastal pumping stations represents an intervention with a high energy demand. This results in great financial burdens for the drainage associations since the cost of energy is increasing rapidly. The aim of this study is to analyse sustainable solutions in order to optimise the land drainage in coastal regions by using renewable energy.

The historical development of drainage methods shows that wind-driven pumps are highly relevant for the drainage of the land. For this reason, analyses of the energy demand of a pumping station and the supply of wind energy were carried out over a period of three years in the coastal regions of the North Sea in Dithmarschen. It was found that there is a relation between the investigated quantities and as a result it could be shown that the energy demand of a coastal pumping station could be predominantly supplied by a wind energy plant. In addition a feasibility study was carried out for an investigation area in Dithmarschen in Northern Germany. Three alternatives to use wind and/or hydro power were reviewed for feasibility and evaluated on the basis of calculations of economic efficiency. The analysis indicated that electric wind pumping systems were highly appropriate for use in sustainable drainage systems.

1 Introduction

Motivation and Objectives

Water management at the coasts secures the drainage of the marsh region along the North Sea as part of flood protection and to guarantee a productive agriculture. Therefore in the hinterland the run-offs are drained off in a system of ditches and channels that leads the water to either sluices or pumping stations in order to pass the dike. Sluices are preferred as drainage structures since no additional energy supply for drainage is required since the sluice gates close at high tide respectively open at low tide due to the water level differences. Nowadays natural drainage using sluices is becoming more problematic due to changes in coastal morphology where the slope of the outer deep is reduced. As a result there is a shortening of the sluice time at low tide and the amount of water discharge that passes the dike is reduced which leads to a higher risk of flooding since the run-offs are not sufficiently drained. Moreover, climatic changes such as the rise of the sea level will also lead to degradation or renunciation of natural drainage (Maniak et al. 2005). A conventional solution, such as pumping water beyond the dike through the use of coastal pumping stations represents an intervention with a high energy demand. This results in great financial burdens for the drainage associations since the cost of energy is increasing rapidly.

A new concept for optimisation of land drainage by using renewable energy is therefore required. For this purpose, wind energy represents one appropriate alternative as a possible energy resource for pumping stations. The historical importance of using wind energy for the drainage of the land is documented. For example wind-driven water pumps have been used in order to drain the low lying areas in The Netherlands since the 15th century. Another possible renewable energy resource represents hydro power that could be utilized within the process of a cascading drainage system where the water discharge is increased by a high lying polder. Therefore the main objective of this study is to analyse sustainable solutions in order to optimise the land drainage in coastal regions by using renewable energy.

Investigation Area

Dithmarschen is a county on the North Sea coast of the federal state Schleswig-Holstein in Northern Germany (figure1). The coast area consists of polder surrounded by dikes as flood defences. In the hinterland the run-offs are drained off in a system of ditches and channels that leads the water to either sluices or pumping stations in order to pass the dike. This water management is important to prevent floods from inland discharges and to maintain an efficient agriculture which represents the main economic sector of this region.

For the feasibility study, the pumping station Hillgroven with a pumping capacity of 160 kW and a catchment area of 1.200 ha and the sluice Steertloch with a catchment area of 6.300 ha are investigated in more detail. Due to changes of the coastal morphology the slope of the outer deep of the sluice Steertloch is reduced and therefore gravity drainage becomes insufficient. For this reason, the water management of this area has to be improved and sustainable solutions were analysed. The data of the pumping station Hillgroven were used as a first estimation of the pumping times since the boundary condition in form of water level differences of high and low tide are assumed to be almost equal for the nearby sites.

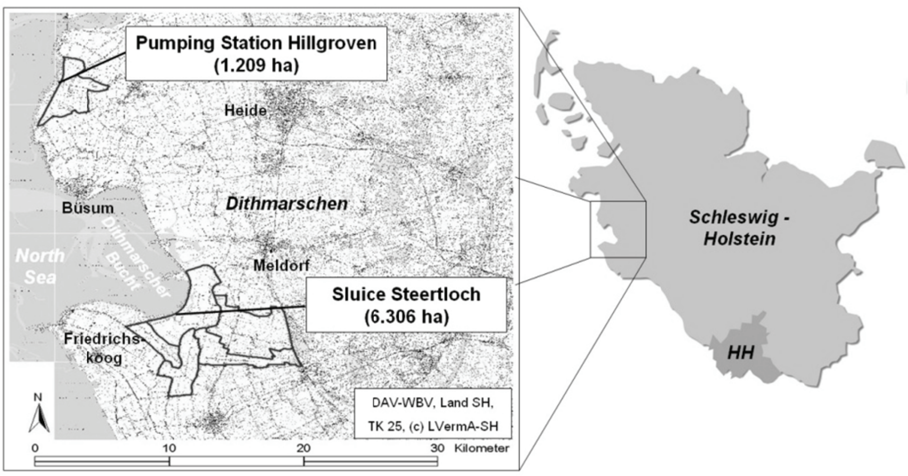

Figure 1: Investigation Area in Dithmarschen, Northern Germany

2 Analysis of energy demand of a pumping station and supply of wind energy

As wind energy was identified as being highly relevant for drainage methods (IPAT 1989), analyses of the energy demand of a pumping station and the energy supply of a wind energy plant (WEP) were carried out in more detail over a period of three years in the coastal regions of the North Sea in the county Dithmarschen.

Energy Balance with Monthly Data

In order to compare the distribution in time of the energy demand of a pumping station and the energy production of WEP an energy balance with monthly data was carried out. Therefore the electric power consumption of a coastal pumping station with monthly values over a period from 2005 till 2007 was analysed. The data were provided for the pumping station Hillgroven by the drainage association *Deich- und Hauptsielverband Dithmarschen*. Furthermore, the wind data were taken from an analysis of the Chamber of Agriculture Schleswig-Holstein *Landwirtschaftskammer Schleswig - Holstein* (LKSH 2008) where the production of wind energy was investigated for the coastline of the North Sea in Schleswig-Holstein.

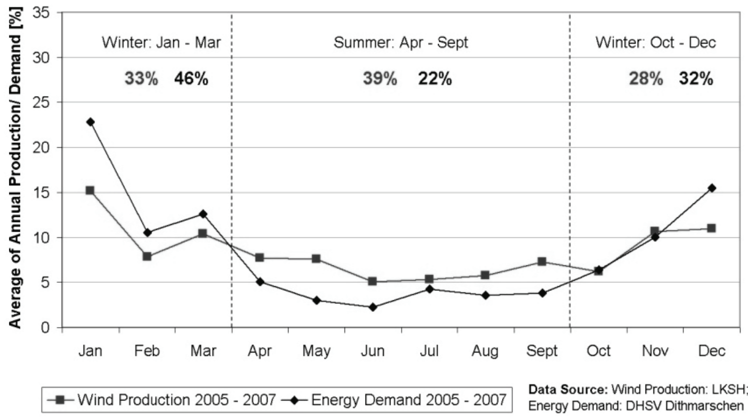

Figure 2: Comparison of energy demand of a pumping station and wind energy production along the west coast of Schleswig-Holstein (Average monthly values of the annual demand/ production for the years 2005 till 2007)

The results show seasonal fluctuations of the annual distribution of the energy demand of a pumping station as well as of the production of wind energy (figure2). During summer time from April till September a very low energy demand with monthly values of 3 % to 5 % and in total a percentage of 22 % of the mean annual need is required. Likewise during summer the production of wind energy is lower and amounts 39 % of the mean annual output. During winter time higher values are reached. Especially during the months January till March almost half (46 %) of the mean annual energy demand is recorded. In the same time period the production of wind energy is also slightly larger (33 %). During the months October till December the energy demand amounts 32 % and the wind energy production 28 % of the annual demand respectively production.

Energy Balance with Hourly Data

The results of the first energy balance on the basis of monthly data show the annual distribution of energy demand of a pumping station and wind energy production. From these results of monthly averages it is not possible to conclude whether the wind energy supply would be sufficient for a pumping station since there is a great variation in wind speed with significant changes in shorter time periods such as hours. For this reason, the temporal resolution of the calculation is increased and hourly data of the energy demand of a pumping station and the energy production of a WEP were analysed over a period of three years from 2005 until 2007. The main goal of this analysis is to investigate the percentage of energy supply of a pumping station that can be directly covered by a WEP and how high the percentage of the remaining energy is that has to be taken from the local power supply system.

For the energy demand the data of pumping times of the coastal pumping station Hillgroven were provided by the drainage association Deich- und Hauptsielverband Dithmarschen. In order to consider a variance in pumping power the total engine power of the pumps was ranged with values from 220 kW to 660 kW. It should be noted that for the following calculations the pumping power is set to a constant value, viz. 220 kW or 660 kW for each calculation. This could be an overestimation if the constant value is equalized to the rate of the required pump capacity depending on the catchment area. In reality the pump capacity is divided into several pumps which are operated as required.

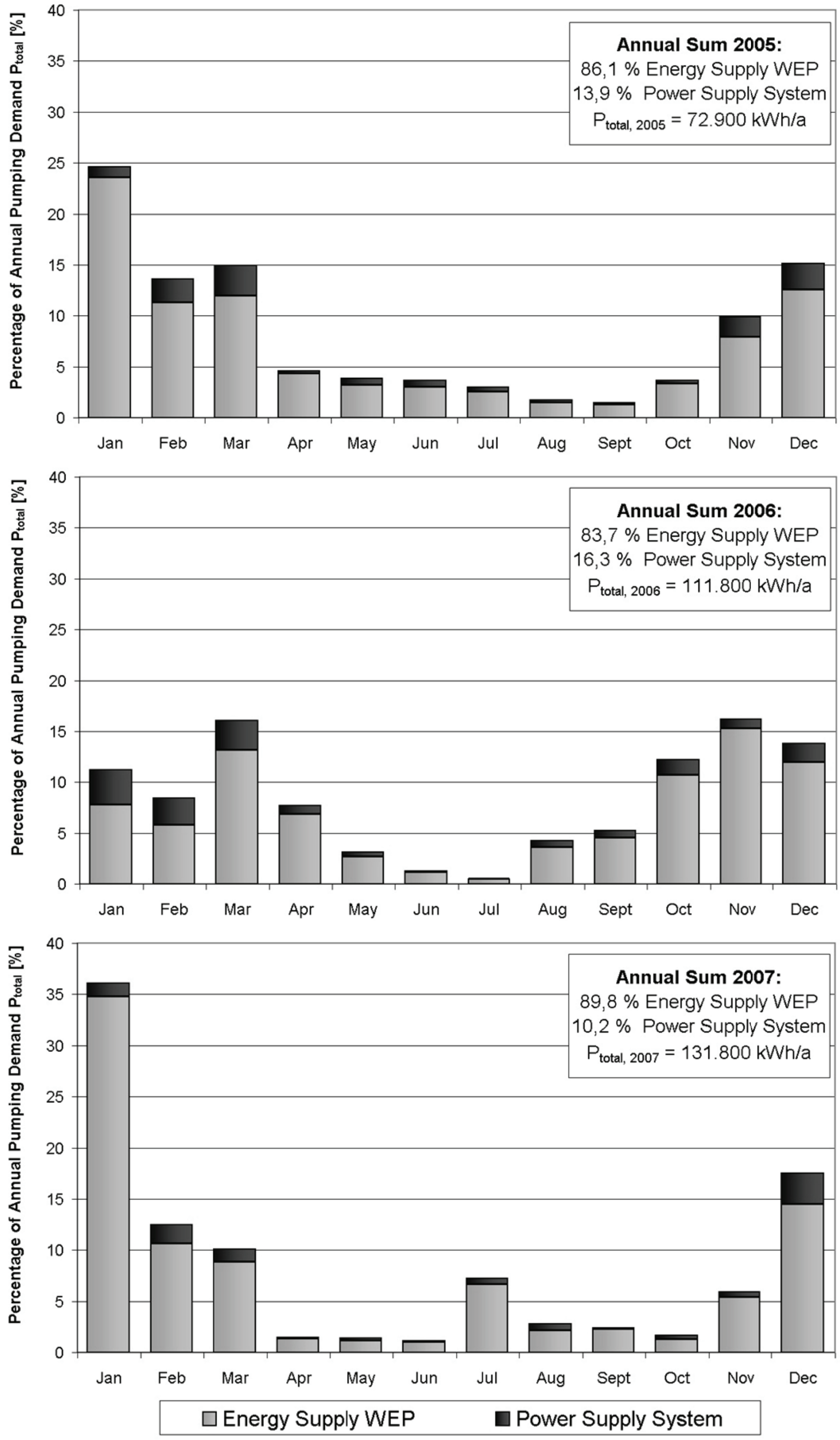

Figure 3: Electrical power supply of a pumping station with a constant pump capacity of 220 kW for the years 2005, 2006 and 2007 differentiated in energy supply by a WEP (800 kW) and by the local power system

For the production of wind energy the data were estimated using a power curve of a wind turbine. The power curve relates wind speed to the electrical power output of a WEP. As an example of a possible WEP the model Enercon E 48 with 800 kW wind turbine was applied. As input data of this calculation using the power curve of the model E 48 hourly data of the mean wind speed were used. The wind data were measured by the German Meteorological Service Deutscher Wetterdienst at the weather station Büsum in Dithmarschen.

As an example the results in form of the electrical supply of a pumping station with an engine power of 220 kW for the years 2005 till 2007 are shown with monthly values in figure 3. The diagrams show that the energy demand of the pumps can be predominantly supplied by a WEP. In total the percentage of WEP supply was calculated from 83.7 % (2006) up to 89.8 % (2007) of the annual need for the pumping station. Furthermore, in this calculation the pump capacity was ranged from 220 kW up to 660 kW. As a result the mean annual power supply by the WEP was estimated between 86.5 % for 220 kW pumps and 72.1 % for 660 kW pumps.

3 Feasibility Study for Drainage Methods Using Renewable Energy

In order to analyse different drainage methods using renewable energy three alternatives to use wind and/or hydro power were reviewed for feasibility and evaluated on the basis of calculations of economic efficiency for the sluice Steertloch in Dithmarschen as follows (figure 4): (1) pumping station with WEP, (2) reservoir with wind-driven pump with a mechanical (a) or electrical (b) power transfer and (3) cascading drainage system using WEP and hydro power.

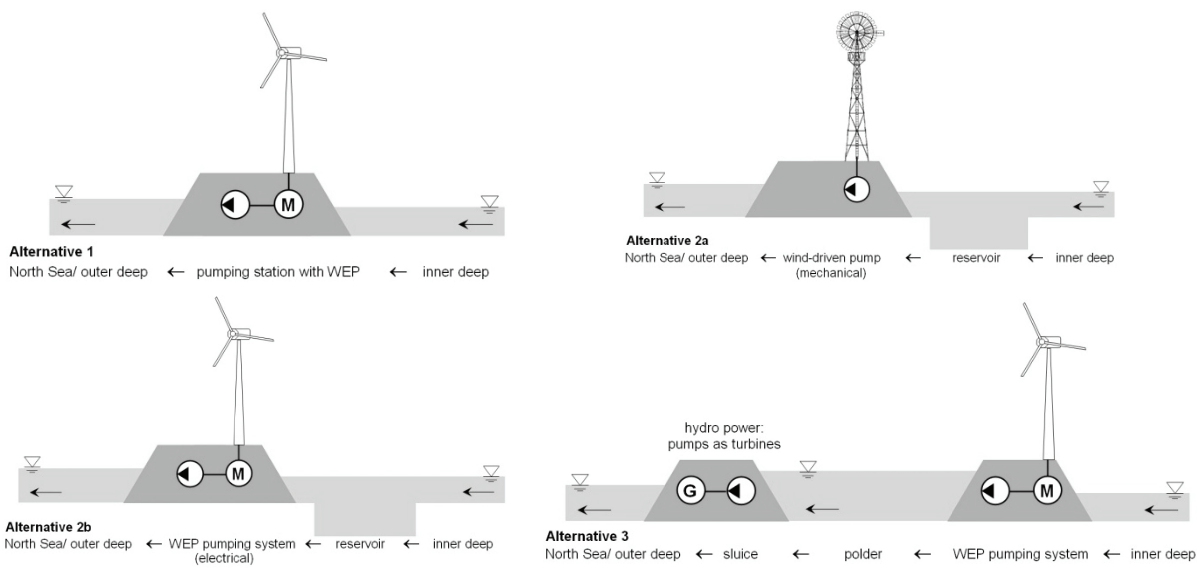

Figure 4: Sketches of the alternatives analysed in the feasibility study (with M = motor and G = generator)

Alternative 1: pumping station with WEP

The first alternative is composed of a pumping station combined with a WEP. Between the wind turbine and the pumps there is an electric power transfer. During windless periods there is the possibility to receive energy from the power supply system. This alternative is already realised by the waterboard *Bremischer Deichverband am rechten Weserufer* for the pumping station Wasserhorst and is well approved. In Bremen the energy supply of a WEP (600 kW) for the pumps with a total rated power of 560 kW averages 50 % of the annual demand (DVR-Bremen 2008). As the energy balance with hourly data showed for the site in Dithmarschen a higher wind energy supply from about 72 % to 86 % depending on the pumping capacity can be expected since the capacity of the WEP (800 kW) is higher and the surface roughness of the terrain affects the wind to a lesser extent. For the catchment area of Steertloch the total required pump capacity was estimated to about 600 kW. This equates a possible wind energy supply from approx. 75 % which represents 240 MWh. Moreover, there is a remaining energy production of 2,400 MWh by the WEP.

Alternative 2: reservoir with wind-driven pump

As the second alternative the feasibility of a reservoir with wind-driven pumps was examined. It is noted that a mechanical power transfer between the wind turbine and the pumps is not feasible since mechanical pumping systems only achieve a maximum of 10 kW as rated capacity (Gasch & Twele 2005) which falls below the value of the required pump capacity of 600 kW.

With an electrical power transfer the alternative 2b corresponds to alternative 1 including an additional reservoir. By means of the reservoir there is the advantage of adopting the operation of the pumps. Since the water can be stored in the reservoir the pumping times are adjustable to periods with sufficient wind energy supply. For the existing reservoir of the sluice Steertloch the storage volume was calculated by an elevation model covering the data of the bathymetry and the terrain with the software ESRI ArcView. Between the water levels -1.5 mNN and 0.0 mNN the storage volume was estimated to 425,000 m³. With a design discharge of 12.6 m³/s the storage time amounts 9.3 hours. This alternative offers the use of control and feedback control systems where the operation of the pumps can be adjusted to the wind energy supply. Therefore the wind energy supply is estimated as a greater value than in alternative 1, viz. greater than 75 %.

Alternative 3: cascading drainage system using WEP and hydro power

The third alternative is composed of a cascading drainage system using wind energy and hydro power. Therefore at first the water is pumped by a WEP into a high lying polder. From the higher polder the water can be drained by gravity and at the same time hydro power can be gained by powering a generator with the discharge of the water. As a type of generator, pumps as turbines can be applied since the boundary conditions of a changing flow rate and a low head have to be considered. Compared to the wind energy production with a total of 2,600 MWh the production of hydro power with 240 MWh is rather low.

4 Results

Besides the review of technical feasibility the alternatives were evaluated on the basis of calculation of their economic efficiency. The costs have been estimated considering the investment and operating costs as well as the tariffs for wind energy and hydro power due to the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz/ EEG). In order to give some example of the expanses the investment costs of a WEP comparable to the model Enercon E-48 (800 kW) amount to 1.2 million euro. The investment costs of the pumping system were neglected since these values are the same for each alternative. The operating costs mainly consist of energy costs which average up to 310,000 euro/year with an electricity tariff of 15 cent/kWh for a conventional pumping station. For wind energy the tariffs following EEG 2009 are summed up to 160,000 till 170,000 euro/year for a period of 20 years. The tariffs of hydro power result in a maximum of 30,000 euro/year.

Table 1 shows the results in terms of the annuities for the different pump capacities of 220 kW and 660 kW. It can be seen that alternative 3 with the cascading drainage system using hydro power is not economic. By contrast the alternatives using energy of a WEP for a pumping system are profitable. In comparison with a conventional pumping system annual costs of up to 47,000 euro/year can be saved.

Table 1: Results of evaluation of economic efficiency in terms of annuities considering investment, operating coast as well as tariffs for wind energy and hydro power after EEG (2009) for a period of 20 years

Pump capacity	Alternative 0: Conventional pumping station	Alternative 1: Pumping station with WEP	Alternative 2: Reservoir with WEP pumping system	Alternative 3: Cascading drainage using hydro power
220 kW	-16,000 euro/year	+20,000 euro/year	> +20,000 euro/year	-337,000 euro/year
660 kW	-48,000 euro/year	-1,000 euro/year	< -1,000 euro/year	-338,000 euro/year

5 Summary

Wind energy was identified as being highly relevant for drainage methods, therefore analyses of the energy demand of a pumping station and the supply of wind energy were carried out over a period of three years in the coastal regions of the North Sea in Dithmarschen. It was found that there is a relation between the investigated quantities and as a result it could be shown that the energy demand of a coastal pumping station could be predominantly supplied by a wind energy plant. Three alternatives to use wind and/ or hydro power were reviewed for feasibility and evaluated on the basis of calculations of economic efficiency. The analysis indicates that electric wind pumping systems are highly appropriate for use in sustainable drainage systems and from the economic point of view the annual costs can be reduced by a factor of 48 compared to conventional pumping systems.

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