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# Assessing Resource Availability in Floodwater Systems for Use in Power-To-X Technologies

Lucas Bjarke Jensen[1,*], Jonas Lund[1], Pernille Weiland Pedersen[2] and Hugo Daniel Macedo[1]

[1]DIGIT, Aarhus University, Department of Engineering, Finlandsgade 22, 8200 Aarhus N, Denmark
[2]Klimatorium, Havnen 8, 7620 Lemvig, Denmark

[*]Corresponding author. Email address: au649412@uni.au.dk

## Abstract

Recent research works show Power-to-X is gaining momentum as a viable solution to the renewable energy storage problem. In solutions where the storage process is water intensive, for instance power to hydrogen, models are used to predict and provide input to decision makers about the feasibility of storing energy for given scenarios and whether the process would require the usage of water supplies reserved for human consumption. This paper reports on a model developed in the context of a research project aiming to assert whether the floodwater resources, which are currently available in the Lemvig region of Denmark, are enough to supply the demand of storing clean energy as hydrogen. Our model uses data from from seven floodwater pumps in the region and simulations are used to calculate the size of reservoir needed to supply a 500MW electrolyzer. Our simulations show it is possible to address the water needs for the scenarios under analysis, and we expect our model to generalise and evolve by application in other cases.

**Keywords**: Power-to-X; Energy; Hydrogen production; Sekundavand; Floodwater; Modeling and simulation; Water; Water electrolysis

## 1. Introduction

Power-to-X (P2X) is a means to use green energy to produce green fuel. The P2X technologies are a necessary aid in maximising the effectiveness of green energy. This is done by utilizing renewable energy directly at the point of production, instead of turning to ineffective storing solutions. Simultaneously, the supply chain of hydrogen-based products for industrial use is shortened. It therefore follows that P2X technologies are an invaluable tool in the green transition (Dahiru et al., 2022).

P2X works by using the electricity from green energy sources in an electrolysis process splitting water into hydrogen and oxygen. The hydrogen can be directly used as fuel or through other processes converted into other fuels and chemicals such as methanol or methane. Large amounts of water is thus one of the main requirements for running P2X.

However, establishing P2X plants in certain regions may be difficult due to an inability to satisfy the water requirements of the plant needed for creating the maximum hydrogen yield. This is especially a problem in small regions where providing adequate amounts of water to a P2X plant will strain residential water supplies and is therefore directly competing with the population's need for potable water Kasten et al. (2019).

One solution is linking water from flood control pumps in areas that receive frequent flooding or have high water tables near residential areas to the P2X plant. These water sources, along with lakewater, reclaimed water and wastewater will be commonly referred to as non-groundwater sources or "sekundavand", and a P2X system reliant on it is called a Sekundavand Power-To-X (SP2X) system, an overview of which can be seen on figure 1.

In a SP2X system, water is collected from pumping stations, treated using reverse osmosis to obtain ultrapure

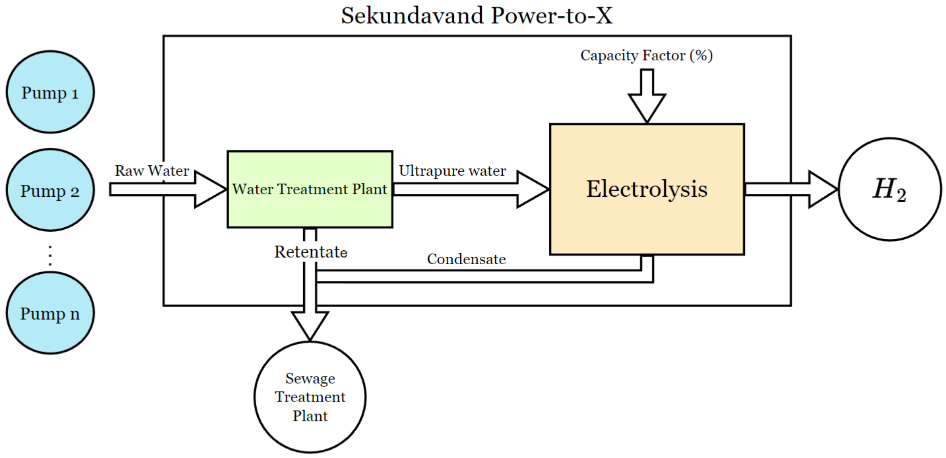


**Figure 1.** Figure depicting the full SP2X system.

water and fed to the electrolyser, which separates the hydrogen from oxygen. In the process there is residual water that is sent to treatment. This, however, posits that the water available from these pumps can reliably satisfy the required amount of water needed to sustain full production. Therefore models that can analyse and predict the output of water from sekundavand sources and how it relates to the water requirements of the P2X plant are needed. This paper presents the initial findings in creating such a model.

## 2. State of the art

In this section, we cover several of the recent works on the approaches to modeling of P2X systems. Works typically use modeling and simulations as an important tool to study cost, environmental impact, process effectiveness, and qualitative analysis of water sources. With our work, we also extend current modeling and simulation of the domain with a focus on a quantitative approach to water availability.

In (Subramanian et al., 2018) the authors recommend the combination of modeling and simulation approaches found in the low level field of Process Systems Engineering (PSE) and the high level field of Energy Economics (EE), for a hybrid method. Our model can be considered an implementation of such a hybrid approach since technical parameters like reservoir size and water loss of filtering is viewed in concert with seasonal rainfall patterns and price fluctuations of electricity.

An instance of a pure EE model can be found in (Feijoo et al., 2022) where an updated version of the H2RES long-term energy planning and operational model is presented. The objective of the model is to minimise yearly operation and capacity cost. This model takes a high-scale approach and is applicable at national level. Our model functions at the scale of a specific plant, and considers water availability compared to the requirements of the P2X plant.

In (Ince et al., 2021), a review of various P2X system configurations is conducted. The so-called P2X pathways are measured on performance, environmental impact, and cost. By reviewing multiple life cycle assessments, which measure the lifetime environmental impact of a system, it is concluded that a P2X plant using electricity from renewable sources can lessen the impact of climate change. However, some systems fare worse than conventional methods when it comes to certain factors, including water depletion. Our model attempts to quantify this water depletion.

In (Simoes et al., 2021), a qualitative assessment of water sources is conducted. Our work has a similar goal but takes a primarily quantitative approach based on data from pumping stations, similar to the approach in (Macedo et al., 2022).

## 3. Materials and Methods

Our approach to analyse and predict the output of water from sekundavand sources consists of creating a model that predicts a reservoir size needed to supply the electrolyser demand and a test case that involves the collection and analysis of data available from floodwater stations.

Our test case features data from seven floodwater pumps located in the Lemvig municipality of Denmark. Spanning three years, two of the pumps feature daily amounts of water output, and the rest have monthly entries for water output. Daily rainfall totals for Lemvig municipality were used in in the preprocessing stage to refine the data from monthly into daily entries.

The model is constructed using time series analysis and the preproccesing of data is done via multiple linear regression using the ordinary least squares technique. Both are implemented using the Python programming language.

### 3.1. Sekundavand Power-To-X model

The Sekundavand Power-To-X model predicts the reservoir size needed to get through the designated time period, based on which water sources are chosen. The model is abstract enough to include any P2X end product, as long as the conversion rate between ultrapure water and electricity is known. The model can therefore include any extraneous water use in the analysis.

The main inputs of the model are the following:

- **The water source data** being the daily water pumped from a specific water source in a period. The periods of the data for the different sources do not need to overlap perfectly. However, it is the overlap of period of all the sources which is viable for the model, meaning the more overlap the better.
- **The P2X capacity factor data** being how the capacity factor varies daily over a period. In our case, this is modelled based on the variation in wind energy produced by wind mills during previous years in the same general location as the planned location of the P2X facility. If no capacity factor model is used, a constant default of 66% is used.

This means that for the model to work, it is up to the individual municipalities to retrieve data from water sources that can be used in the model.

The analysis is done by asserting a trivially small water reservoir, which is assumed to start out completely filled. For the selected water sources, the balance of water (whether water is drawn from or deposited in the reservoir) is calculated by comparing the water need of the P2X plant to the output of the water sources. The simulation then runs, drawing or depositing from the reservoir according to the overall balance that day. If at any point the reservoir gets below a safety boundary the simulation is stopped, the size of the reservoir is increased and the simulation is repeated until a suitable reservoir size is found.

Along with the input data, the SP2X model has a number of parameters that can be changed to give different simulations. The parameters of the model are as follows:

- **Generation Capacity** determines at what power the P2X plant operates at. It influences the raw water requirement of the plant in conjunction with the capacity factor. It is measured in megawatt (MW).
- **Retention Factor** controls at what ratio the water is reduced, when going from raw water to ultrapure water, which is the form of water needed by the P2X plant.
- **Safety Boundary** sets the threshold at which the reservoir is deemed too low, thereby risking loss of production from lack of water. Measured as percent of total reservoir capacity.
- **Water Sources** determines which water source or combination of water sources should be used in the simulation.
- **Allowed Water Use** throttles how much of the pumped water is available to the P2X plant. It may be the case that in the certain periods of the year, only a fraction of a source can be provided to the P2X plant, since the water is required to be fed back into the surrounding environment to maintain the health of local area water cycles.

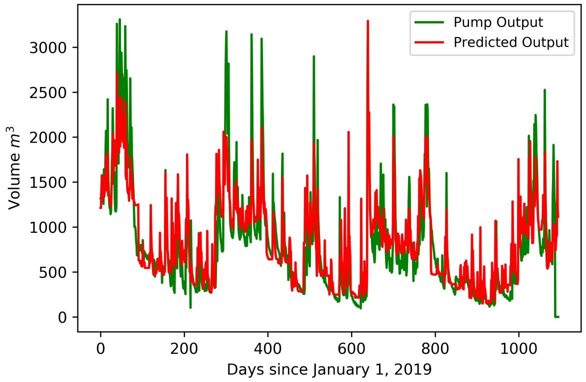


**Figure 2.** A line plot of days since 1-1-2019 and pump output featuring the predicted output based on the regression and the real world observed values.

## 3.2. The SP2X Preprocessing Algorithm

The resolution chosen for the model is a time slice per day. Unfortunately, many of the floodwater control stations feature legacy technology where detailed data collecting has not been a priority. This issue is present in the test case as well, where only two of the seven pumps had daily entries on water output. It is therefore necessary to preprocess the data and increase the level of detail. This is done by the SP2X Preprocessing Algorithm, which is based on the relation between the output of the data rich flood pumps and the local rainfall in that area. This relation is then used to turn the monthly water pump data into daily predictions of water output, which then can be used by the SP2X model.

This relation, expressed as a multiple linear ordinary least squares regression, has three predictors: Amount of rainfall, a running average of rainfall, and the total observed amount of water pumped by the pump that month. The rainfall and its running average are predictors since we know that there is a causal link between how much it rains in the region and how much the floodwater pumps have to operate. However, it may take rainwater multiple days to accumulate in certain flood-prone areas and cause the pump to operate more hours in a day, hence why a running average is considered.

A potential drawback of using the amount of rainfall as a predictor is that the data is an aggregate of the entire region, not just the local area where the pump is situated. It therefore follows that the prediction suffers decreased accuracy when rain falls far away from the pump and ends up in some other catchment area unrelated to the specific pump. This shortcoming in the regression is compensated for by using the real world observed values of the total amount of water pumped that month as a predictor. This is done because a month where a lot of rain has "missed" the

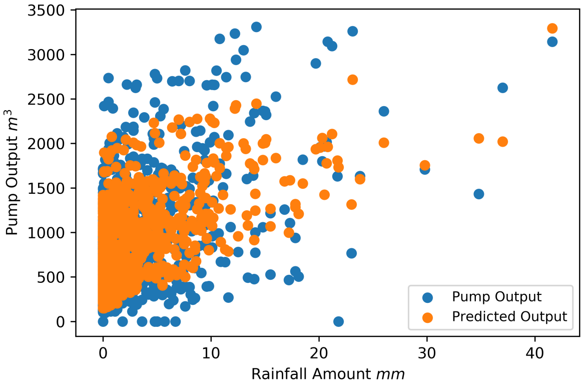


**Figure 3.** A scatter plot of rainfall and pump output featuring the predicted output based on the regression and the real world observed values. Each data point corresponds to a day.

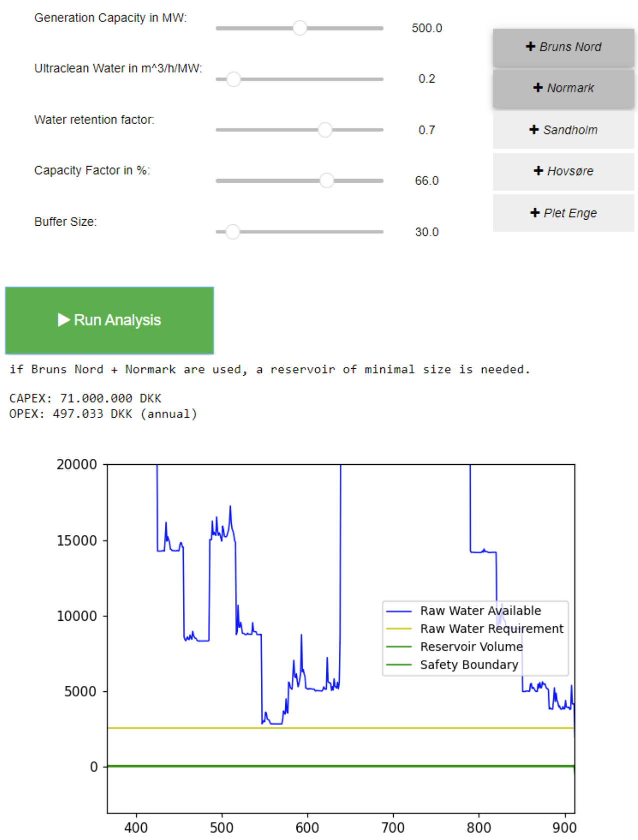
pump will have a correspondingly low monthly amount entry, and the prediction therefore ignores large cloudbursts that would otherwise have skewed the prediction. This also has the added benefit of automatically scaling the prediction, such that summing all entries in a given month leads to the observed monthly amount pumped.

Figure 2 and 3 shows plots that compare the predicted and observed pump values for the pump upon which the regression was founded. The x-axis of figure 3 represents the rainfall amount whereas the x-axis of figure 2 shows the number of days elapsed since the start of the simulation. A draft of the user interface for the model is also shown in figure 4.

## 4. Results and Discussion

An initial model capable of running scenarios in which the raw water need of a P2X plant is compared to the output of floodwater pumps throughout a flexible time period, has been developed. The required size of the reservoir needed to sustain production, given the use of a specific pump or combination of specific pumps, can also be estimated. In turn, this indicates how feasible a specific implementation of a SP2X plant is. An instance of a simulation scenario can be seen on figure 5.

The SP2X Preprocessing Algorithm, working in concert with the SP2X model, allows for data of differing degrees of detail to be used in combination, which facilitates the inclusion of data from water control plants that either consists of legacy systems or plants that has simply not had data capturing as a priority. Using the model, scenarios involving different combinations of water sources was ran. In several scenarios, a water source or combination of water sources satisfied the water requirements of the P2X matching the parameters of the test case with a feasibly small water reservoir needed.


Generation Capacity in MW: 500.0
Ultraclean Water in m^3/h/MW: 0.2
Water retention factor: 0.7
Capacity Factor in %: 66.0
Buffer Size: 30.0

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if Bruns Nord + Normark are used, a reservoir of minimal size is needed.

CAPEX: 71.000.000 DKK
OPEX: 497.033 DKK (annual)
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**Figure 4.** A draft of the user interface for the model and its output.

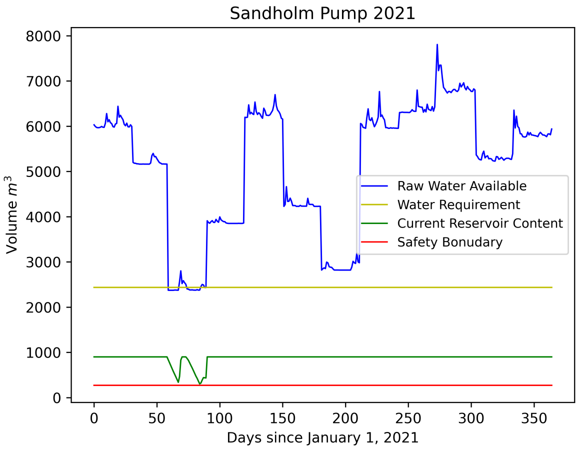

**Figure 5.** A line plot of days since 1-1-2019 and water volumes featuring a fraction of the predicted output of Sandholm Pump, the water need of the P2X plant, the contents of the reservoir and a safety boundary of 30% of the total reservoir capacity. To not exceed the safety boundary given the parameters, a reservoir size of 900 $m^3$ is needed, according to the model.

## 5. Conclusions

Our model was used to validate the conjecture that the region has enough water to satisfy the P2X requirements based on multiple scenarios that satisfy the requirements of the P2X plant. The model is therefore of use to various decision makers wanting to join the worlds of P2X technologies and floodwater management systems. At the current stage of development, the model is constrained by the resolution at which the simulation is run. By having a resolution a data entry every 24 hours, failures in respecting the safety boundary could occur within a day without it causing a failure in the simulation and prompting the model to increase total reservoir capacity. This also warrants the existence of the safety buffer, since small inaccuracies throughout the day will not lead to a loss of production since an additional amount of water is reserved.

The potential for daily inaccuracies can also be remedied by increasing such resolution. This would require a data set with more entries per time unit. An increase in data richness would also alleviate the need to use SP2X Preprocessing Algorithm described in 3.2. This would have the added benefit of not assuming similarity in how the the data rich pumps and the data deficient pumps react to changes in precipitation, since this similarity is the basis for the regression that is used to enrich the monthly data.

Besides richer data, the model would increase its utility with further development, the best application of which would be to create a framework for design space exploration. Being able to lock certain parameters, give acceptable ranges to others and optimise for certain aspects, would mean that the model would be of use in different stages of development and to a wider array of stakeholders. This may also be done in concert with a graphical user interface, to enable simple operation of the model. Another feature that would benefit the model is the inclusion of a qualitative approach to the water source analysis, detailing how dependent the output of each water source is to rainfall and how constant the output is in general. This would give an easily understood comparison between the different water sources.

Additionally the SP2X model could be used in combination with a model for predicting the variations in the capacity factor of a P2X plant to enable a greater detail of simulation.

## 6. Acknowledgements

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