Optimising water system operations, blue storage and the green energy transition

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Among the barriers for renewable energy penetration (SDG 7 and 13) are lack of large scale storage and irregularity and unpredictability of supply. **Ties van der Heijden** and **Edo Abraham** have a vision on how water infrastructure in the Dutch delta can contribute to the energy transition with model-based optimisation and 'demand response services'.

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Introduction

The energy-mix in the Netherlands is changing rapidly, with climate change mitigation, SDG 13 Climate Action, as a driving force. Renewable sources make up for an increasing share of this mix. However, the wind doesn't blow on command, and hardly ever at constant speeds. This complicates the reliability of our electricity supply. When energy doesn't come on demand, demand should be flexible.

In IJmuiden, the largest pumping station of Europe is stationed. The station consists of 6 large pumps, having a combined maximum discharge of 260 m3/s, or 6.25 Olympic size pools per minute. The pumps have a combined maximum power consumption of about 6 MW, which if turned on for an hour would be equivalent to the yearly energy use of two (Dutch) households. The pumps at IJmuiden are off course large energy users with a considerable impact on grid stability. However, also appliances with smaller energy use, like electric vehicle, your fridge or washing machine, can contribute at the moment the right technology and control algorithms are available.

Demand response

Demand response (DR), also known as demand-side management or demand-side control, is the principle of adjusting the demand to the supply, instead of the other way around. Traditionally, power plants generate more energy when a peak in consumption occurs. With an uncertain energy supply due to renewable sources, DR reverses the process by (mainly) using energy when it is abundant.
Balancing supply and demand is necessary to have a stable frequency on the grid of 50Hz. Grid frequency is used by clocks to measure time, which is why a disrupted power plant can lead to clocks running slower. Large deviations can also result in damages in machinery or even to the grid infrastructure. In the Netherlands, TenneT is in charge of maintaining the balance on the grid, and maintaining the infrastructure.

What can a pump do?

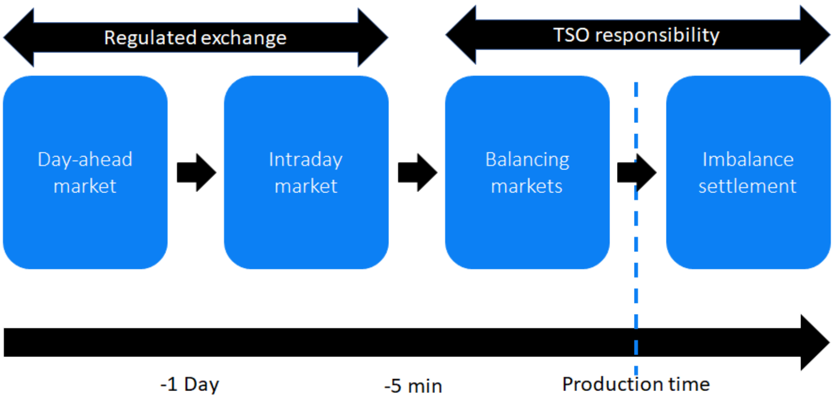
Since the pumping station in IJmuiden is a large energy consumer, its consumption has a measurable effect on the frequency of the grid. Timing pumps to be mostly active on times when renewable energy is abundant helps with the balancing of the unexpected peaks. An unexpected peak in energy production can normally cause a positive imbalance, resulting in a higher grid frequency. Being flexible with the pump scheduling would allow for the peak to be consumed by the pumping station, decreasing the frequency back to the desired 50Hz. This is called downward regulation.
Optimal use of the flexibility in pump schedule would not only lead to grid balance, but also to lower CO2 emissions caused by the energy consumption, and lower energy costs for Rijkswaterstaat, the national water management organisation in charge of pumpings station IJmuiden. Besides that, it creates room for renewables on the grid, since shifting could prevent a gas- or coal-powered plant from being turned on at a later moment. Not only leading to lower CO2 emissions for the consumer, but for the whole of the Netherlands/Europe.

What do we need to accomplish this?

In order to make optimal use of the flexibility in the pump schedule, we need multiple things. To start, we need a prediction of the state of the water system, in this case the Noordzeekanaal--Amsterdam-Rijnkanaal, in order to know when we really need to pump in the (near) future. This is the hydrological forcing. To achieve this, we need predictions of incoming discharge from water boards and the Amsterdam-Rijnkanaal.
Besides the predictions on hydrological forcings, an indication of the sustainability of the energy produced is needed as well. This could be done by predicting energy production by source. But wind speed, for example, is hard to predict, and highly influential on the wind-energy production. A prediction of the energy price could be used as well. Markets behave more predictable, and, because renewable energy is generally cheaper than fossil energy, minimizing energy cost, automatically optimizes for sustainable energy use. This approach come however with some caveats. When sustainable energy is not yet abundant, a coal-power-plant operator could bid its energy for a cheap (or negative) price at a loss, in order to prevent shutdown of their plant during periods with abundant energy. This could drive gas-/coal-fired power plants out of business on the long term, which for now are needed to supply a base load when renewable production is low. On the other side, price is an indication of scarcity of a product. Consuming more energy at low prices is helping the balancing of the grid, matching the consumption and production levels. It would also decrease peaks in total power consumption (peak shaving), resulting in lower infrastructural cost.
Another option is to predict carbon intensity of the energy supply for optimization purposes. Which might be more predictable than actual production by source. This would in theory result in the lowest greenhouse gas emission for the consumer. However, it could increase the price of sustainable energy through the higher demand - and scarcity. It could also increase the peaks present on the grid, since it possibly drives consumption towards short periods with high sustainable energy production. This would result in higher peaks and infrastructural cost.
In other words, finding the right strategy for the operation of the pumps at Ijmuiden in view of water management and the electricity grid is not as straightforward as it might seem. All options have their pros and cons, and multiple strategies have to be evaluated thoroughly.

The energy markets

When the optimal strategy is decided on, an energy contract that would allow Rijkswaterstaat to trade energy throughout the day while not endangering the security of energy supply in times of flood-risk is needed. This can be achieved by combining two flexible energy markets; the day ahead market and the intraday market.



In the energy supply, demand and storage optimisation models, the time-dimension of the energy market has to be taken into account.

The day ahead market, as the name implies, allows for trading up to a day ahead of consumption. This market is relatively predictable, since it closes 12-36h before production. That makes this market less suitable for unpredictable peaks in supply, but the predictable peaks will be represented in the price.
The intraday market allows for trading up to 5 minutes before consumption. This makes the market more suitable for representing unpredictable peaks in supply, since a prediction over 5 minutes has lower uncertainty than a prediction over 12 hours. The market could also be used to correct uncertainties in the system, for example stemming from hydrological forcings. Estimating energy consumption the day ahead gives security of supply, while intraday trading makes it possible to optimally adjust consumption to renewable energy supply and to cope with inflow and weather uncertainties. Unexpected peaks in supply, or an unexpected peak in discharge, can be corrected for by buying energy at a last-moments notice.
The energy-market system is now being adapted to accommodate grid stability and sustainable energy in the future. Currently, the markets described above could be used. But the integration of the European markets, the increasingly dominant sustainable and distributed energy-supply and technological advances like DR will inevitably induce the markets to change rapidly. Where the changes will end up is hard to predict but will be informed by research, such as ours, that quantitatively describe the market scenarios that will induce sufficient DR participation by energy users (large and smaller ones through aggregators).

What are the next steps?

The next steps in the research are to include real-time grid-balancing mechanisms to use the water system more optimally. In addition, future changes in the energy system need to be analyzed in order to find optimal long-term strategies. This way the Dutch open canal system could become an inexhaustible battery for the grid long term.
Besides the Dutch open canal system, demand response could be applied to many assets once they are “smart enough”. The Internet-of-things (IOT) could result in a breakthrough for smart appliances, having access to energy production data. This could result in our washing machines asking when we want our laundry to be done, and figuring out the best time to start washing by themselves. The energy-storage capacity of your washing machine could be estimated by the size of your wardrobe - how long can you extend washing.
Climate control systems in large buildings or refrigerators could make optimal use of the available energy, by cooling down to the minimum temperature when energy is abundant. And letting the temperature rise gradually while (sustainable) energy is scarce. Or by heating up a building in winter when energy is abundant. Climate systems could also use new cold-heat storage systems, like aquifer thermal energy storage (ATES). An ATES-system could be used to store the cold from the winter, to be used for cooling in the summer, and the other way around. This could even happen on a neighbourhood scale, while thermostats communicate with each other to decide who uses cold/heat at what time. All while making use of a climate-model of the asset (building/refrigerator), the level of underground warm-cold water storage capacity, and possibly using weather forecasts to estimate the future energy demand.
Electric vehicles (EV’s) can learn when its user is going to work, while keeping a minimum load for emergency or spontaneous trips. EV’s could even feed power back to the grid giving a valid replacement for fossil energy plants once enough are connected to the grid. A battery can supply a guaranteed base-load, which for now only fossil power plants can guarantee with economic efficiency. This could make EV’s invaluable for the future sustainable energy system. Hydrogen could be a good addition as well, a car running on hydrogen first converts this to electricity. This way a car could be used as a hydrogen-power plant to power the grid, or off-grid communities.
Everything that has the possibility of adjusting its energy use, has a storage capacity. By measurements of the system-state and the energy supply, and means of communication, all these assets can be controlled to prioritize the use of sustainable/abundant energy and stabilize the grid. This scenario of distributed decision making by a huge number of energy users (or appliances) opens up many more control systems and communication research questions. The aim of our research is to find where water systems fit within this technologically complex part of the energy transition.