Sustainable Urban Wastewater Treatment Visualizations

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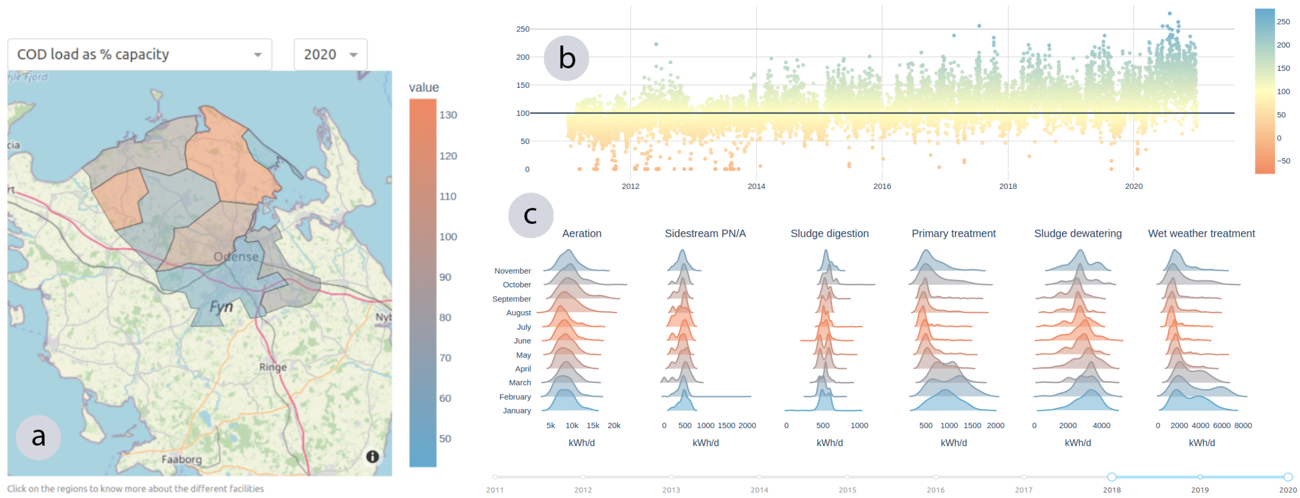

Figure 1: *Overview of our system: (a) map of Fyn shows areas connected to Vandcenter Syd's treatment facilities, (b) scatter plot shows ratio of energy produced versus consumed at the Ejby Mølle WRRF, and (c) ridge line plot shows distributions of energy consumption by type at the Ejby Mølle WRRF, by month.*

Abstract

The handling and treatment of urban wastewater are essential to protecting human health and the environment. However, its existence and importance are mostly invisible to the general public. In this work, we present a set of visualization system designed to communicate and visually explore the wastewater treatment system of Vandcenter Syd (VCS), one of the largest water utilities in Denmark on the island Fyn. It operates eight wastewater treatments, and our solution enables geographically exploring and comparing data collected in different facilities with an interactive map. We further provide a set of interactive visual interfaces to support exploring the energy consumption and production trends over the past 10 years. A case study on Ejby Mølle, VCS's largest facility, illustrates its transition from an energy consuming into an energy producing facility.

1. Introduction

Urban wastewater treatment plays a fundamental role in our society to protect human health and the environment. It is often undervalued and hidden from the public agenda and wastewater treatment is still rare in many countries: 70 % of the wastewater is treated in high income countries versus only 8% in low income countries [SQY*13]. However, the water sector is currently undergoing a revolution, which involves establishing water conservation strategies and transitioning toward closing water loops [Sed14]. An example is the ongoing transition from the concept of wastewater treatment plants into resource recovery facilities [GBCC*20].

Wastewater is now seen as a matrix containing many resources useful for society: clean water, chemicals, energy or heat. The digitalization of the water sector and the advances in the use of data

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produced by water utilities is thus necessary and expected to play a bigger role in the coming years, with an estimate of 80% of utilities in developed countries and 50% in developing countries, undergoing a digital transition, to some extent, by 2025 [WRB*18]. Vandcenter Syd is one of Denmark's largest water utility companies and it is owned by both Odense and Nordfyn's municipalities. It has been internationally recognized by its efforts on sustainability and innovation [Spa18]. Its largest wastewater plant, Ejby Mølle, achieved energy neutrality in 2013 and today is a net producer of energy, producing more than 150% of the energy that it consumes. In 2019, the whole utility became energy neutral, when the energy production surpassed the energy consumption.

We designed a set of visual interfaces to bring light to the role of sustainable urban water treatment in resource recovery facilities, where wastewater is not only treated to remove pollution, but the use of the existing resources are maximized. Whereas our final target includes conveying the importance and utility of wastewater treatment to a general public audience, our system was in the first place designed for VCS to visually explore the data from internal VCS databases.

Data: VCS's different facilities data has been extracted at a frequency of one measurement per hour, for five years. This data comes from accredited external laboratory analyses. Ejby Mølle's energy data has been extracted at a frequency of three measurements per day, for 10 years. The data comes from programmable logic controllers (PLC) that log data every 10 seconds. These values are stored as deltas with respect to the previous timestamp.

Tailoring visualizations for multifaceted analysis of wastewater treatment data is, to the best of our knowledge, unique and has not been conducted at this scale.

Related Work: Prior solutions focus typically on supporting visual analyses of sensory data on chemical and biomass wastewater components [WP21]. For example, time-based visualizations have been proposed to support analyzing fouling [WGK*21, TRK22] and photoelectrocatalytic processes [PMMV21]. Some work also focus on analyzing geospatial structures of wastewater treatment plants [SLZT19, VT21].

2. Visualization Design

Our system supports visual information seeking [Shn03], starting, next to some general information on Vandcenter Syd's wastewater treatment strategies, with an overview of the eight facilities operated by Vandcenter Syd in the form of a choropleth map showing the areas connected to each treatment plant (see Figure 1a). By default, the different areas in the map are coloured according to the daily flow into each plant. The map shows the average value for the year chosen, and it is coupled with a line chart that shows the development of daily flow for each facility across the 10-year time period. The user can choose which information to display in both map and line chart: daily flow to the plant, maximum daily flow, minimum daily flow or daily load of pollutants (total chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP)). There are also calculated variables available, which provide information about the relationship between load and capacity: the amount of person equivalents the plant was receiving as COD (COD PE), what percentage of the facilities overall capacity does that load correspond to (COD percentage capacity) and what percentage of the load is estimated to correspond to inflow and infiltration. When clicking a polygon of the map, a pop-up will will show the detailed descriptive information of the corresponding facility, including a a schematic flow-scheme.

In addition, we designed a series of visual interfaces to support exploring numerous data sets compiled for a chosen facility. We showcase their design while analyzing VCS's largest facility Ejby Mølle. This facility is the only one with a dedicated rain water treatment train and energy production facilities. We firstly allow exploring more than 30 "raw data sets" (e.g., energy produced, energy consumed, and energy consuming processes) in scatter plots. Using a slider, the user will be able to explore the different periods in the data sets. The scatter plot analysis reveals first patterns to be analyzed further. For more focused analyses, we designed the following visual interfaces:

- **Self-sufficiency chart:** The first visualization shows the level of electricity self-sufficiency, the ratio between energy produced and consumed over the past ten years. A scatter plot where points have been coloured according their value (a gradient with blue for positive self sufficiency and red for negative self-sufficiency). The graph for Ejby Mølle (see Figure 1b) highlights how the facility has transitioned towards an electricity net positive position, the treatment plant produces way more energy than it consumes.
- **Electricity consumption chart:** The second visualization is a stacked area chart that shows which processes are responsible for the electricity consumption within the treatment plant and what is their share over the total consumption over the 10 year period. For Ejby Mølle, one can see how aeration, a process necessary for the microorganisms carrying out the biological conversions to grow and for the chemical compounds present in the water to be oxidized, is clearly the largest energy consumer. Sludge treatment and wet weather (rain) flows are also large consumers. A new process called "Demon" first appears in 2015, when the process unit was first commissioned.
- **Electricity consumption processes chart:** We designed ridge line plots to illustrate the distributions of the overall energy consumption per month, for the whole time period of 10 years. The distribution are colored according to the month they represent (blue for colder months and red for warmer). The ridge line plot shows monthly distributions of energy consumption for different processes within the treatment plant. Figure 1c shows seasonality effects in the data for Ejby Mølle. Expectedly, the colder months have in general larger energy consumption than the warmer months. One can further see that aeration remains constant over the year, but other processes which are very much dependent on the amount of incoming flow to the treatment plant (which is much larger in colder months due to rainfall and snow melting), such as primary sedimentation or rain treatment, exhibit a large variability over the year.

3. Conclusion

We have shown how interactive visualization tools can help bring visibility and provide valuable insights into urban wastewater treatment. Adapted different visualization techniques to analyze 10 years of operational data, we have shown how the largest treatment plant, operated by VCS Denmark, has, over time, achieved and surpassed its goal of becoming energy self-sufficient, which processes within a treatment plant are the largest consumers and the effects of seasonality on energy consumption. Although designed to support visual analyses on the wastewater treatment system of Vandcenter Syd, our solution is adaptable to other facilities that regularly collect similar data. A comparative analysis of different systems could help discovering best practices in wastewater treatment, which could be transferred from one to other areas.

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