INTEGRATING A PTX PLANT INTO AN INDUSTRIAL SYMBIOSIS USING HILLERØD AS A CASE STUDY

Sustainable Cities - Master thesis

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Abstract

This report researches what the requirements of a PtX plant are and how to source the materials required for the hydrolysis process. Using Hillerød, a city located in the north of Sealand, as a case study, the materials are sourced in and around the case area where they set the current boundary for the plant's capacity. An area south of Hillerød is identified as having good connections to the local renewable energy production, a water treatment plant to act as a water source and a district heating network. This is to utilize the excess heat generated by the PtX plant and reduce the transportation costs to make the plant more efficient.

Preface

This project is made as part of a master thesis in the Sustainable Cities master's program at Aalborg University Copenhagen.

Special thanks to Lars Fage Sørensen and my colleagues at Hillerød Forsyning for helping me with the project and providing a place to work on the project. Their input and sparring helped make this project a reality.

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The green transition

international and national climate targets are key drivers of the green transition. Energy planning is strongly shaped by these targets, which serve as the basis for governing and organizing energy-related activities under relevant international and national laws and agreements. Aligning goals across borders fosters a unified approach to energy planning, with international targets guiding the development of national objectives (Cajot et al., 2017).

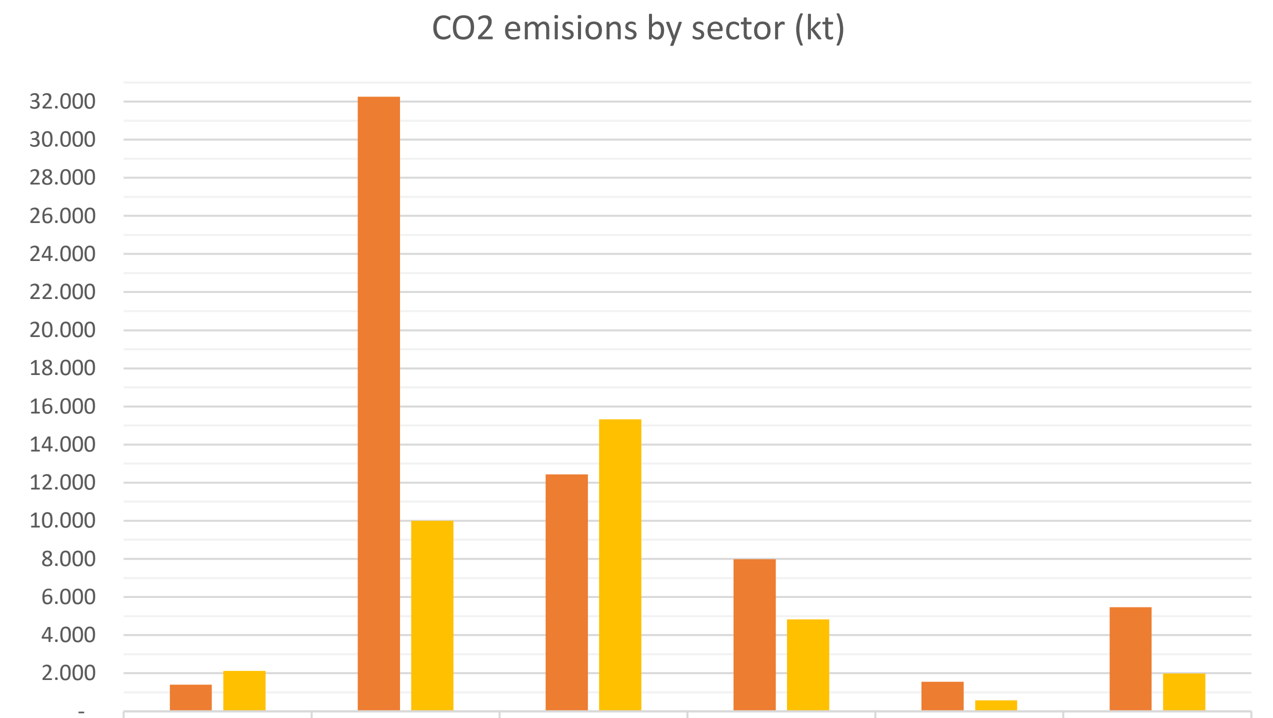
The United Nations (UN) and its subcommittees, working in collaboration with member states, regularly set shared objectives to address global environmental impacts. Key examples include the Brundtland Report, the Kyoto Protocol, and, most notably, the 2015 Paris Agreement, which plays a pivotal role in climate change mitigation efforts (World Commission on Environment and Development, 1987; United Nations, 1996, 2016).

The Paris Agreement, adopted in December 2015 by 196 Parties at the 21st Conference of Parties (COP 21) under the United Nations Framework Convention on Climate Change (UNFCCC), established a global framework to strengthen the response to climate change. It aims to limit the global temperature rise to 1.5°C above pre-industrial levels while implementing measures to reduce CO2 emissions (European Commission, 2021).

European and Danish Targets

At the regional level, the European Union (EU) has committed to cutting greenhouse gas emissions by 55% by 2030 compared to 1990 levels (European Commission, 2021). In Denmark, the 2020 Danish Climate Law set ambitious goals, aiming to reduce CO2 emissions by 70% by 2030 compared to 1990 levels, with a long-term goal of achieving carbon neutrality by 2050. These targets align with the Paris Agreement's objective of limiting global warming to 1.5°C (The Climate-, Energy- and Utility Ministry, 2021).

From 1990 to 2019, Denmark achieved a nearly 50% reduction in annual CO_2 emissions from energy consumption, as shown in Table below (Danish Energy Agency, 2021). This progress is largely due to significant emission reductions in the energy production sector. However, over the same period, emissions from the transport sector have steadily increased. In 2019, the transport sector alone accounted for 15,324 kt CO_2, which is 43% of the country's total emissions of 34,846 kt CO_2.



	Energy sector	Transformation sector	Transport	Agriculture and industry	Comercial and public services	Households
1990	1.401	32.258	12.427	7.975	1.545	5.468
2019	2.116	10.005	15.324	4.829	584	1.988

Figure 1: Overview of CO2 emissions by sectors in 1990 & 2019 (Danish Energy Agency, 2021)

EU, Denmark and many other countries are currently trying to transition from being fueled mainly by fossil fuels like oil, coal and natural gas, into renewable power like wind, solar and biogas. However, there are parts of their industries and public sectors where not using energy dense fuel is not an option, like in the transport sector. In these sectors, an energy dense and stable fuel source is needed. By converting the power produced by renewable sources into synthetic fuels like e-methane and hydrogen the industries can continue with minimal refits. This process is Power to X (PtX) where one type of power is converted into fuel for another (Worley, 2022).

While every EU member state must follow EU guidelines, they are free to set more ambitious goals. Denmark has long aimed to be a global leader with its high environmental targets, especially as an international pioneer in wind energy (Ministry of Foreign Affairs of Denmark, n.d.; Auken, 2002).

An agreement of expanding the hydrogen production capacity by 4-6 GW was signed be all Danish political parties (The Danish Government, 2022a). The agreement emphasizes the importance of using renewable energy for fuel production to ensure it qualifies as a sustainable alternative for sectors, like heavy transport, that cannot be easily electrified (Klima-, Energi- og Forsyningsministeriet, 2021; The Danish Government, 2022b).

In addition, Denmark signed a joint declaration of intent with Germany on March 24th, 2023. This agreement paves the way for establishing a hydrogen pipeline between the two countries, enabling hydrogen exports from 2028. This pipeline would primarily use plants in western Denmark. (The Federal Ministry for Economic Affairs and Climate Action of Germany and The Ministry of Climate, Energy and Utilities of Denmark, 2023).

Power to x

PtX is the missing link between the current power sector, where fossil fuels are the standard for most power production, and a sector powered by sustainable sources such as wind and solar. This is because by converting the electricity created sustainably into synthetic fuels like hydrogen and e-methane they can be used instead of oil and gas in industries where fuel density is important, like transport and heavy industry. It also serves to utilize the excess power produced by the renewable sources so that there is no wasted potential energy (Worley, 2022).

The created fuel will also be able to be used as storage. The current storage technology for electricity is expensive and not suitable for larger quantities. While the conversion from electricity to hydrogen isn't very efficient, it is a better alternative than slowing down the windmills when their power production is greater than the need. The process for hydrogen production can also be made more efficient by using the excess heat that is a biproduct made during the electrolysis process. This heat can be used in other processes during the fuel upgrading or as district heating in the local community (Dansk Fjernvarme et al., 2022).

Industrial symbiosis

Industrial symbiosis is an innovative and sustainable approach to industrial operations where traditionally separate industries collaborate to use each other's by-products, waste materials, energy, and resources. By utilizing by-products and waste from one process as inputs for another, industrial symbiosis maximizes resource efficiency and reduces the need for virgin materials, leading to significant reductions in waste, emissions, and environmental impact. Companies involved in industrial symbiosis can achieve cost savings through reduced waste disposal fees, lower raw material costs, and shared infrastructure and services, improving competitiveness and profitability. This approach fosters innovation by encouraging companies to explore new ways of using by-products and waste materials, while collaborative partnerships and knowledge sharing among businesses can lead to the development of new technologies and processes. By reducing waste and emissions, industrial symbiosis contributes to environmental sustainability, helping to mitigate climate change, decrease pollution, and promote the conservation of natural resources. Additionally, it can enhance regional economic development by creating new business opportunities, jobs, and value chains, supporting the growth of local industries and the circular economy at a regional level (Lombardi and Laybourn, 2012).

A well-known example of industrial symbiosis is the Kalundborg Eco-Industrial Park in Denmark, where several companies share resources such as steam, cooling water, and by-products, resulting in substantial environmental and economic benefits for all participants. In summary, industrial symbiosis represents a strategic shift towards a more sustainable and circular economy, where waste and by-products are transformed into valuable resources through collaboration and innovation among industries (Olsen, 2016).

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Problem statement

Using Hillerød as a case study, how can PtX be integrated into a industrial symbiosis and where would a PtX plant be located around Hillerød to reduce transport of input resources?

To answer the question above 2 theories will be used rational planning and spatial analysis. They will be used with the methods document analysis, interviews and GIS to create an understanding of the unique opportunities surrounding the integration of PtX with district heating in Hillerød. In a spatial analysis of the resources required for electrolysis one or multiple locations will be presented as sites to consider for a future PtX plant.

Theory

Rational planning

Rational planning serves as the foundation for this project, as it emphasizes a logical and evidence-based analysis to guide the process of decision making. By using a step-by-step approach to the empirical data, previous work findings and expert opinions it gives a framework for achieving the desired outcomes (Herbert, 1976).

For decisions affecting society it is important to remain objective and impartial as to avoid personal interests (Allmendinger, 2009). That applies to urban planning too as it can have big impacts on how people's day-to-day lives. So, in order to achieve more efficient and effective results, decisions should be based on reasoning and evidence that takes all the data into account (Leoveanu Constantin, 2013) (Herbert, 1976).

By utilizing rational planning and applying it to the data collection and analysis in this report, the results and conclusions drawn from them, should be objective and provide the basis for further work in the field of energy planning and industrial symbiosis.

Spatial analysis

Spatial planning theory provides a foundational framework for effective decision-making in organizing the spatial distribution of activities within a given territory. This theory supports an understanding of the principles, goals, and processes that underlie spatial planning practices (Stead and Nadin, 2008) (Yoshida et al., 2020).

Spatial analysis can be condensed down into two sentences:

"The process of examining the locations, attributes, patterns, and relationships of features in spatial data to address a question or gain useful knowledge,"

"A method of advanced spatial modeling that assists with terrain modeling, finding suitable locations and routes, discovering spatial patterns, and performing hydrologic and statistical analysis."

(ESRI, 2024).

At its core, spatial planning theory acknowledges the significant influence of land use and spatial organization on social, economic, and environmental outcomes. It highlights the complex interdependencies among different spatial elements and their impact on sustainable development (Yoshida et al., 2020).

Moreover, spatial planning theory underscores the importance of integration and coordination across different sectors and levels of governance. It acknowledges that land use decisions are interlinked with various policy domains such as transportation, housing, infrastructure, and environmental protection (Yoshida et al., 2020). The theory advocates for aligning sectoral policies with spatial objectives to achieve a balanced and sustainable territorial organization that considers social, economic, and environmental dimensions (Yoshida et al., 2020).

The integration of spatial planning theory into practical applications allows for a more holistic understanding of territorial dynamics. It encourages the use of spatial data and geographic information systems (GIS) to analyze patterns and trends, enhancing the precision and effectiveness of planning initiatives. This approach not only facilitates better land use and resource management but also helps mitigate potential conflicts between different land use interests (Yoshida et al., 2020).

Finally, the application of spatial planning theory can enhance cross-border cooperation and regional integration. By fostering collaborative planning efforts, regions can address transboundary issues such as migration, transportation networks, and environmental conservation more effectively. This collaborative approach is essential for achieving broader sustainable development goals at both national and international levels (Stead and Nadin, 2008) (Yoshida et al., 2020).

Incorporating this theory into planning practices enables effective analysis and informed decision-making, promoting integration across various sectors and facilitating the development of a sustainable and inclusive future (Stead and Nadin, 2008).

In summary, spatial planning theory is an invaluable tool for guiding spatial planning practices, particularly in the context of geographical analysis of the potential for PtX in Denmark. It provides a robust theoretical framework that promotes a balanced approach, taking into account social, economic, and environmental factors (Yoshida et al., 2020). Additionally, spatial planning can identify areas where PtX plants may have the greatest impact and be most effectively implemented. By considering various factors such as existing infrastructure and natural resources, spatial planning informs decision-making and supports sustainable development（Stead and Nadin, 2008）.

Methods

Document analysis

Definition

Document analysis is a research method used to systematically examine and interpret documents to gain insights and draw conclusions about a particular subject or phenomenon. It involves identifying, analyzing, and synthesizing content from various types of documents, such as reports, letters, policy papers, meeting minutes, diaries, legal texts, and media articles. This method allows researchers to study written, visual, or digital records, providing a rich source of data for understanding social, historical, political, or organizational contexts (Bowen, 2009).

The primary function of document analysis is to extract relevant information from the documents and interpret it in relation to the research questions or objectives. Researchers begin by selecting documents that are relevant to their study. These documents can be either primary sources, like original reports or legal documents, or secondary sources, such as reviews or interpretations of primary documents. Once the documents are selected, the researcher carefully examines the content for key themes, patterns, concepts, and other critical details (Bowen, 2009).

One of the strengths of document analysis is that it allows access to a wealth of information that might not be easily gathered through other methods, like interviews or surveys. Documents often provide historical data, legal frameworks, or policy decisions that offer a deep understanding of the context in which events or processes occur. For example, in social research, policy papers and government reports can help uncover how specific decisions were made or how policies have evolved over time (Bowen, 2009).

Document analysis also involves assessing the reliability and credibility of the documents. Researchers need to consider who authored the document, why it was created, and in what context it was produced. Understanding the background of a document helps in evaluating its objectivity or potential bias. For instance, a government report may present information in a way that supports the administration's policies, while an advocacy group’s report might emphasize different issues based on their particular focus. A critical approach to document analysis requires researchers to weigh these perspectives carefully and consider multiple sources to avoid relying on a single, possibly biased, document (Bowen, 2009; O’Leary, 2017).

The flexibility of document analysis also means that it can be used in combination with other methods, such as interviews or case studies, to provide a more comprehensive view of the subject under investigation. For example, when paired with interviews, document analysis can help corroborate or challenge the information provided by interviewees. It can also fill in gaps where data collection through other methods is not feasible, offering an independent source of information (O’Leary, 2017).

However, it’s important to note that document analysis has its limitations. The researcher is constrained by what is available in the documents. If the documents are incomplete, outdated, or not publicly accessible, the analysis may be limited. Moreover, documents are often created for purposes other than research, which can influence the way information is presented, thus requiring the researcher to carefully interpret the material considering its intended purpose (O’Leary, 2017).

In summary, document analysis is a valuable research method that allows for the in-depth study of written or recorded materials. It enables researchers to gather contextual, historical, or policy-related data, analyze the content critically, and synthesize the information to draw meaningful conclusions. By carefully selecting and interpreting documents, researchers can uncover insights that contribute significantly to understanding the topic at hand, especially when used alongside other research methods.

Utilization

Throughout the project document analysis has been used to gain knowledge and data to better understand the topic of power to X and what the benefits and challenges it could bring to Hillerød. Through document analysis, the technologies of hydrolysis and their different requirements were identified and compared. The knowledge gained from that created the foundation upon the spatial analysis was done. It also helped putting the results of that analysis into perspective with other rapports and projects done by other researchers on the same or similar topic.

Interviews

Definition

In interviews, researchers conduct systematic and purposeful conversations to gather data, often within the context of specific fields. This method allows researchers to explore complex, in-depth phenomena that cannot easily be quantified, making it especially valuable for understanding subjective experiences. In scientific settings, interviews serve as a tool for uncovering the "why" and "how" behind specific research questions, complementing other methods such as surveys or document analysis (Kvale, 2007).

According to Steinar Kvale, who extensively discusses interviews in the context of qualitative research, interviews are designed to generate knowledge through dialogue. These interviews aim to produce insights that are not merely anecdotal but systematically connected to the research framework. Interviews in scientific studies are typically framed to explore hypotheses, test theories, or generate new conceptual understandings, grounded in the goals of academic rigor and reliability (Kvale, 2007).

There are several types of scientific interviews:

1. Semi-structured interviews are most common in scientific research. The interviewer prepares a set of questions or themes in advance, ensuring that key areas are covered while also allowing flexibility for the interviewee to elaborate on responses. This structure balances the need for consistency across interviews with the opportunity to explore unexpected findings (George, 2023).
2. Structured interviews are used when consistency is crucial. Every participant is asked the same questions in the same order, making it easier to compare responses across a sample. This method is often used when large amounts of data need to be compared or when research demands strict standardization (George, 2023).
3. Unstructured interviews are rare in strictly scientific contexts but may be useful in exploratory phases of research. They provide a broad, open-ended approach, allowing the researcher to investigate the topic without predefined constraints (George, 2023).

Interviews are characterized by several important principles, that the interviewer should strive to remain as neutral as possible, avoiding leading questions or influencing the interviewee's responses. Once collected, interview data is typically transcribed and analyzed using methods such as thematic analysis or coding, where researchers identify patterns, themes, or significant insights from the conversations (Kvale, 2007).

Overall, interviews are a robust method for capturing rich, detailed data. They provide a way to explore phenomena that are difficult to measure quantitatively, offering valuable insight into human experiences, behaviors, and thought processes that are crucial for understanding and advancing scientific inquiry.

Utilization

Multiple interviews were conducted during the process of creating this rapport. All the interviews were with Lars Fage Sørensen, who at the time worked at Hillerød Forsyning. He had researched the potential of PtX in Hillerød along with the company European Energy, as well as other research projects with Aalborg university, Grøn Energi and Region Hovedstaden.

These interviews were not recorded outside of the notes taken by the interviewer, which is why they are not used directly. The information from the interviews was researched further and other sources were found. The interviews were approximately 30 minutes to an hour in length and were done in a semi-structured approach often with the prepared questions leading to new unforeseen discussions.

GIS

Definition

Geographic Information Systems (GIS) are a scientific tool used for capturing, storing, analyzing, and presenting spatial or geographic data. In scientific research, GIS is widely used to understand patterns, relationships, and trends across geographic spaces. By linking location-based data with descriptive information, GIS allows researchers to visualize, model, and analyze various phenomena in fields ranging from environmental science to urban planning, public health, and social sciences (GISGeography, 2024).

GIS integrates spatial data (information tied to a specific location, such as coordinates) and attribute data (descriptive information about the spatial features, such as land use, population density, or temperature). By combining these two types of data, researchers can create layered maps or models that help reveal spatial relationships, patterns, and trends that may not be obvious when looking at individual datasets (GISGeography, 2024).

In summary, GIS in scientific research provides a powerful platform for analyzing spatial data, uncovering geographic patterns, and visualizing complex relationships across various fields of study.

Utilization

GIS was mainly used during the spatial analysis. Using publicly available data from Plan- og Landdistriktsstyrelsen as well as their website kort.plandata.dk, which has the data with an interactive GIS map. By combining the data presented in the map and the data obtained through the document analysis and interviews with Lars Fage Sørensen, an area suitable for a PtX plant was identified and presented.

Originally a more thorough spatial analysis was intended and the use of QGIS an open software was planned to do a hotspot analysis combing the resource requirements of the PtX plant with the sources of said resources. However, due to time constraints the other method was adopted. Although not as precise as originally hoped, the result was acceptable and used as part of the project.

Analysis

Integrating PtX with district heating

Power to X is a broad concept. The different hydrolysis technologies have different operating temperatures and with that, different amounts of waste heat. If a PtX plant should be integrated with district heating it should not be a technology where the waste heat is minimal and does not provide any benefit to the district heating system. The main three methods are analyzed below.

Alkaline Electrolysis (AEC)

AEC is the most commonly used and developed electrolysis technology, with a liquid alkaline solution and uses relatively common resources such as steel, Nickel and Nickel-plated steel, which makes it more affordable. It operates at relatively high temperatures around 70-100 °C and requires high pressure to reach the desired effectiveness. That does result in the electrodes getting badly damaged when the electrolysis is paused, which means it needs a constant energy input to function efficiently. It uses around 20-25 m^2/MW and has a lifetime of 70.000 hours (Danish Energy Agency, 2024).

With the low area requirements and commonly available materials needed AEC would be suitable to use in more urban areas where a connection to the district heating network is close by.

Proton exchange membrane (PEMEC) Electrolysis

PEMEC uses a solid electrolyte and operates at much higher current densities. This makes it able to reduce the area it needs to around 10 m^2/MW. It does however use more scarce materials such as platinum, titanium and iridium, which could be problematic in the future or with large scale production. The efficiency is slightly lower than the AEC at an energy requirement of 56,3 kWhe/kgH_2 compared to 52,3 kWhe/kgH_2 (Danish Energy Agency, 2024).

By having higher area requirements, needing scarce materials and not having a high efficiency with waste heat PEMEC will not be used further in this project.

Solid Oxide Electrolysis cells (SOEC)

SOEC operates at a much higher temperature around 550-850 C° and is the most efficient with an energy requirement of 40,4 kWhe/kgH_2. They use abundant materials, ceramic oxides, so are easier and cheaper to scale up. Because of the high operating temperatures, it reaches the thermoneutral point at 1,29 V which makes it almost 100% efficient. When accounting for the energy required for the steam used in the process the energy consumption rises to 45 kWhe/kgH_2. It does have the shortest lifetime of the three technologies at 21.250 hours (Danish Energy Agency, 2024).

With the high operating temperatures and the high efficiency compared to the other technologies, SOEC is more suitable for areas where utilization of excess heat is not as available.

Spatial analysis

In this analysis sources of the resources needed for hydrogen production are located in and around Hillerød and are used to identify potential locations where it would be advantageous to place the PtX plant in order to minimize transportation costs.

Energy production

To supply the large amounts of stable energy required to fuel the PtX plants, a separate energy source could be needed. It would ideally be renewable like solar or wind, but as they can fluctuate heavily a backup energy source would also be needed. In a perfect scenario, energy production such as hydro plants or even nuclear power would be able to provide large amounts of stable energy, that is needed for both AEC and SOEC. However, Hillerød and the surrounding areas have neither large rivers or streams, and nuclear power is very far away from being approved on a national level. The existing and planned wind turbines and solar panels will therefore be analyzed and provide a part of the spatial analysis along with sources for CO2 and clean water.

Figure 2: Map of wind turbines around Hillerød. Source: plan og landdistrikts styrelsen, 2024

There are 2 sets of 3 wind turbines located south and southwest of Hillerød, shown by the green dots on the map, each in the range of 500-1000 kW capacity. Located close is a planned solar power area, in the marked area, with a capacity of 200 MW, that also could provide energy to the plant. Combined to approximately 203-206 MW capacity renewable energy located close to Hillerød Forsyning the utility company in Hillerød.

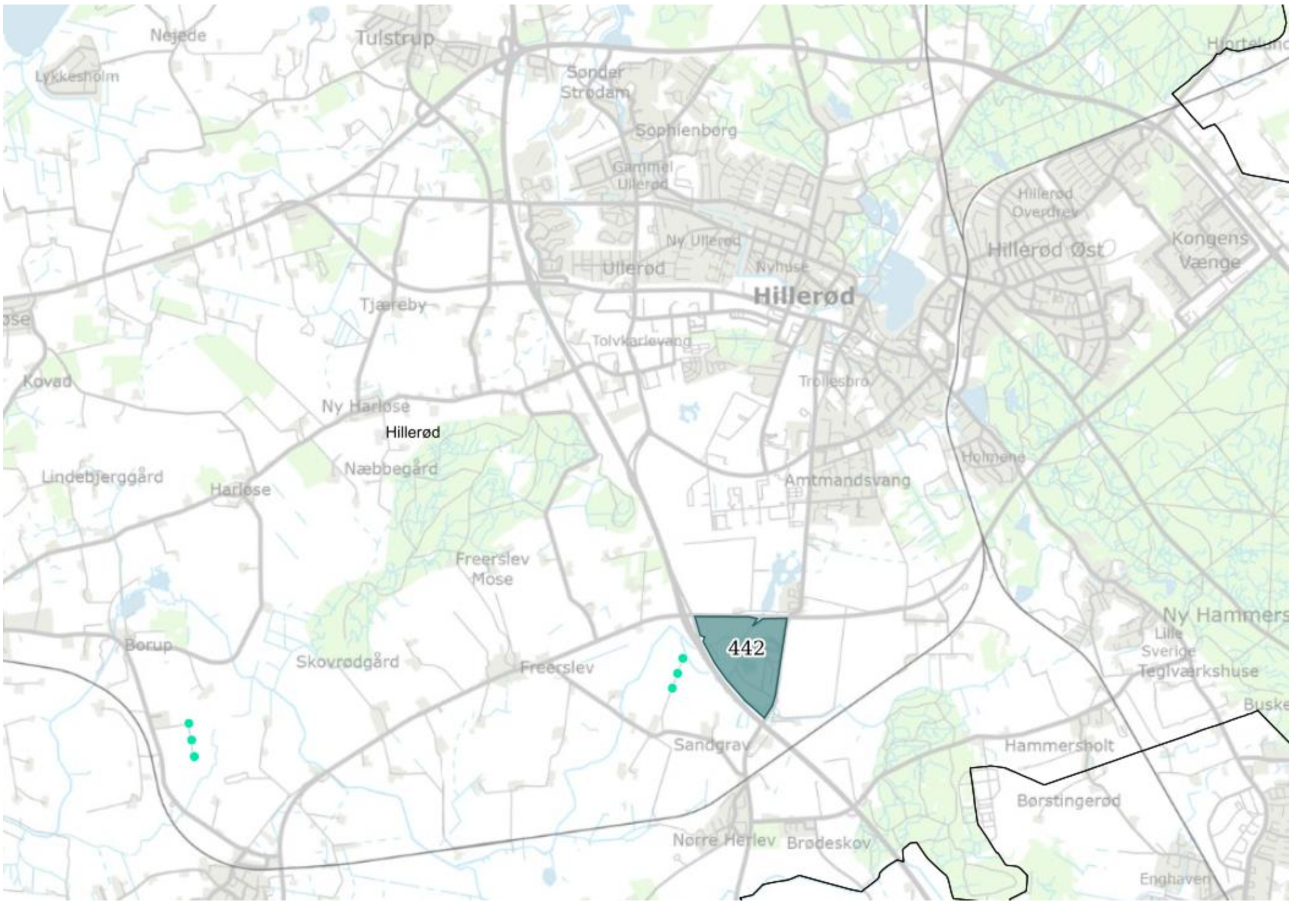

Figure 3: Map of wind turbines and PV areas around Hillerød. Source: plan og landdistrikts styrelsen, 2024.

According to the Danish Energy Agency (2023), the amount of annual full load hours for an onshore windmill is 3100 which means production capacity is reached 35% of the year. The annual full load hours for PV are 960 (Lindros et Al., 2018) which is around 10% of full capacity usage. That means that the current renewable power production is at maximum capacity 12 MW.

Water supply

For electrolysis a clean and stable water supply is important as it is the primary component in the process. If water is cut off the electrolyzer must shut down and with long start-up times this can lead to big losses in productivity (Harrison, 2023).

The water is part of the chemical process of hydrogen production as the two hydrogen molecules are separated from the oxygen molecule, written as:

$$2\ H_2O \rightarrow 2\ H^2 + O^2$$

As the molar weight of a water molecule is 18,016 g/mol and only 1,008 g/mol for hydrogen, it takes about 18 times more water to produce the same amount of hydrogen by weight.

Hydrogen has 120 MJ or 0,033 MWh pr. kg which means with a capacity of 12 MW one hour of production, 363,63 kg of hydrogen is produced, and 6.545 kg of water is needed. For a year 57.338.181 kg of water is needed or 57.338 m^3 of water.

Water purity is a key factor when sourcing the water as even contaminants or impurities can have effects on the efficiency and performance of the electrochemical systems involved. To assess the purity of the water its conductivity is measured, which is the ability to conduct electrical currents (BOS et al., 2020).

ISO, the international Organization for Standardization, has a grade scale for purity of water used in chemical and industrial settings. For hydrolysis it is needed to use grade 2 water that has a maximum conductivity of 0,1 mS/m (International Organization for Standardization (ISO), 2019).

While conductivity is a key parameter to address, additional factors for electrolysis feed water include total organic content and total silica. It's also essential to avoid contaminants like carbonate and sulfate ions, as well as silicon and aluminum oxides, to ensure water quality for electrolysis applications.

Groundwater

One source of water could be groundwater though it would have to be purified through reverse osmosis (Malaeb and Ayoub, 2011) another is using the treated water from the water treatment plant located at Hillerød Forsyning, as could be the case with other PtX plants in Denmark (State of Green, 2022).

The groundwater in Denmark is clean and widely used as drinking water, however it does contain many minerals and other impurities which are not suitable for electrolysis. Reverse osmosis would therefore be required to bring purity up. This process would require additional energy around 1-2% of the total power needed for the electrolysis. In addition, the water would need to be pumped up from underground.

Water treatment plant

The water from the water treatment plant in Hillerød is not pure enough to be grade 2, but they are currently implementing a fourth step in their treatment process. This fourth step could make it possible or close possible to use the water in a PtX setting for hydrolysis. The amount of water treated is around 7 million m^3 in a year with more coming in 2024 from big chemical industries, Novo Nordisk and Fujifilm, which is expected to bring the amount up to around 9 million m^3 (Appendix 1).

CO2 source

CO2 is needed for the process of upgrading the hydrogen produced by the PtX plant into methane and further into more energy dense compounds such as jet fuel. The sourcing of CO2 can either be done through direct carbon capture where CO2 is harvested from the air or point capture where the CO2 is taken from an industrial source where CO2 is a biproduct. For the process to be sustainable the point capture should happen at a site that uses biogenic fuel such as biomass to not perpetuate unsustainable practices where fossil fuel is used.

When Hillerød Forsyning supplies district heating in Hillerød it produces around 60% of their energy from biomass and has an emission of 21,1 kg CO2 pr. KJ energy produced (Hillerød Varme, 2023). With an energy production of around 25.000 MWh from biomass in February 2024 (Appendix 2) that is almost 2.000 tons of CO2 produced. That CO2 could be captured and used in the PtX plant.

Spatial requirements

As mentioned in the analysis before the different hydrolysis technologies have different characteristics. Among them is the footprint, the spatial requirement, of the system. AEC has a footprint of 25 m^2/MW while SOEC uses 30 m^2/MW these are expected to become shorter as the technologies gets more advanced and more common. With a capacity of 12 MW that is approximately 300 m^2 for AEC and 360 for SOEC.

To find a suitable location for a PtX plant, an accommodating amount of land must be available. As seen on the map below Hillerød (red) is surrounded by protected areas such as animal habitats, forests, creeks and lakes (Green, yellow and blue).

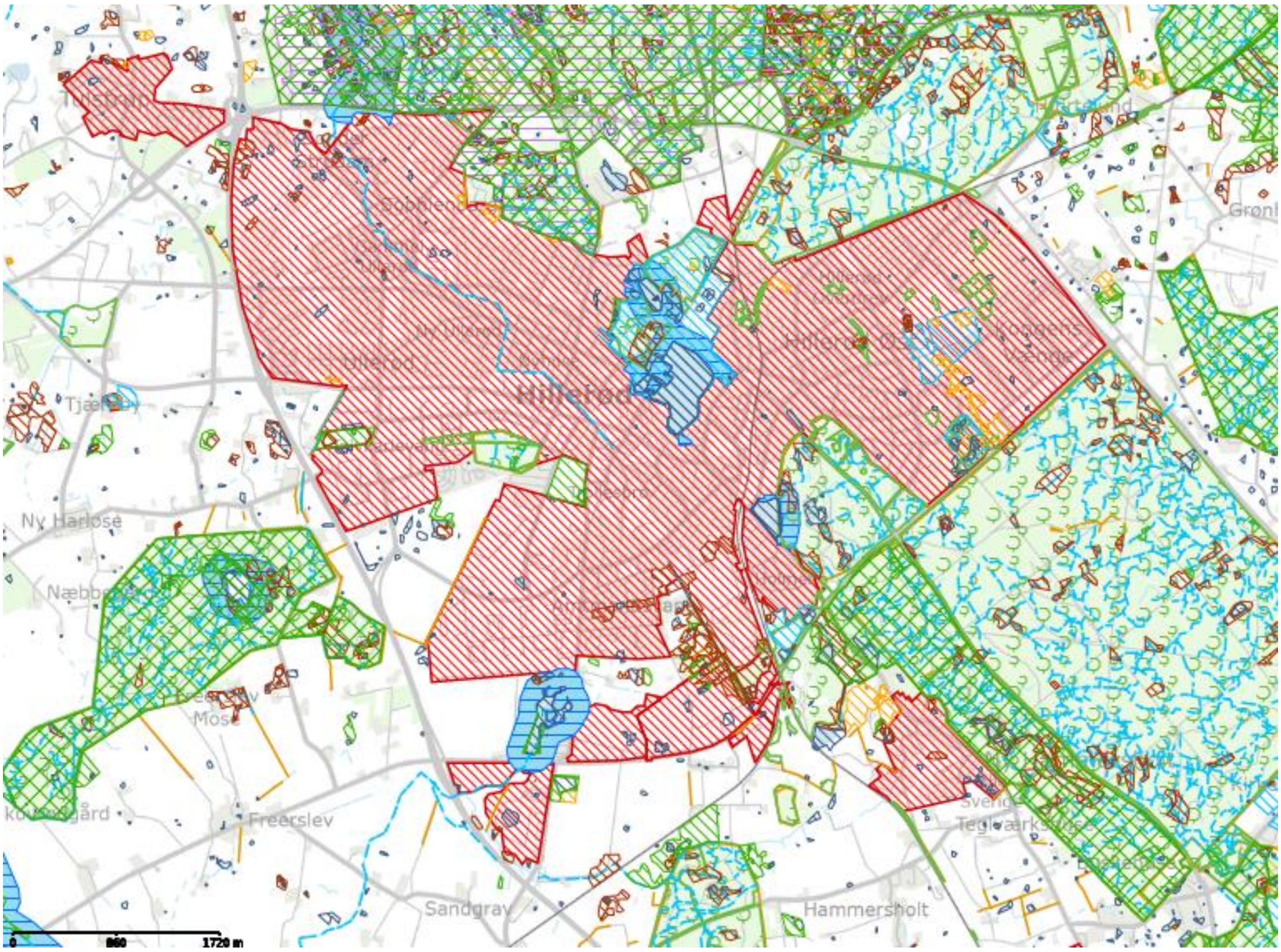

Figure 4: Map of Hillerød with city zones and protected areas marked. Source Plan- og Landistriktsstyrelsen

The area south of Hillerød also includes Hillerød Forsyning, where the water treatment plant is located. 500 meters away to the west of that are one of the sets of three wind turbines. As seen on the map below the area around Hillerød Forsyning is only protected in the northeast and on the lot the utility company is located.

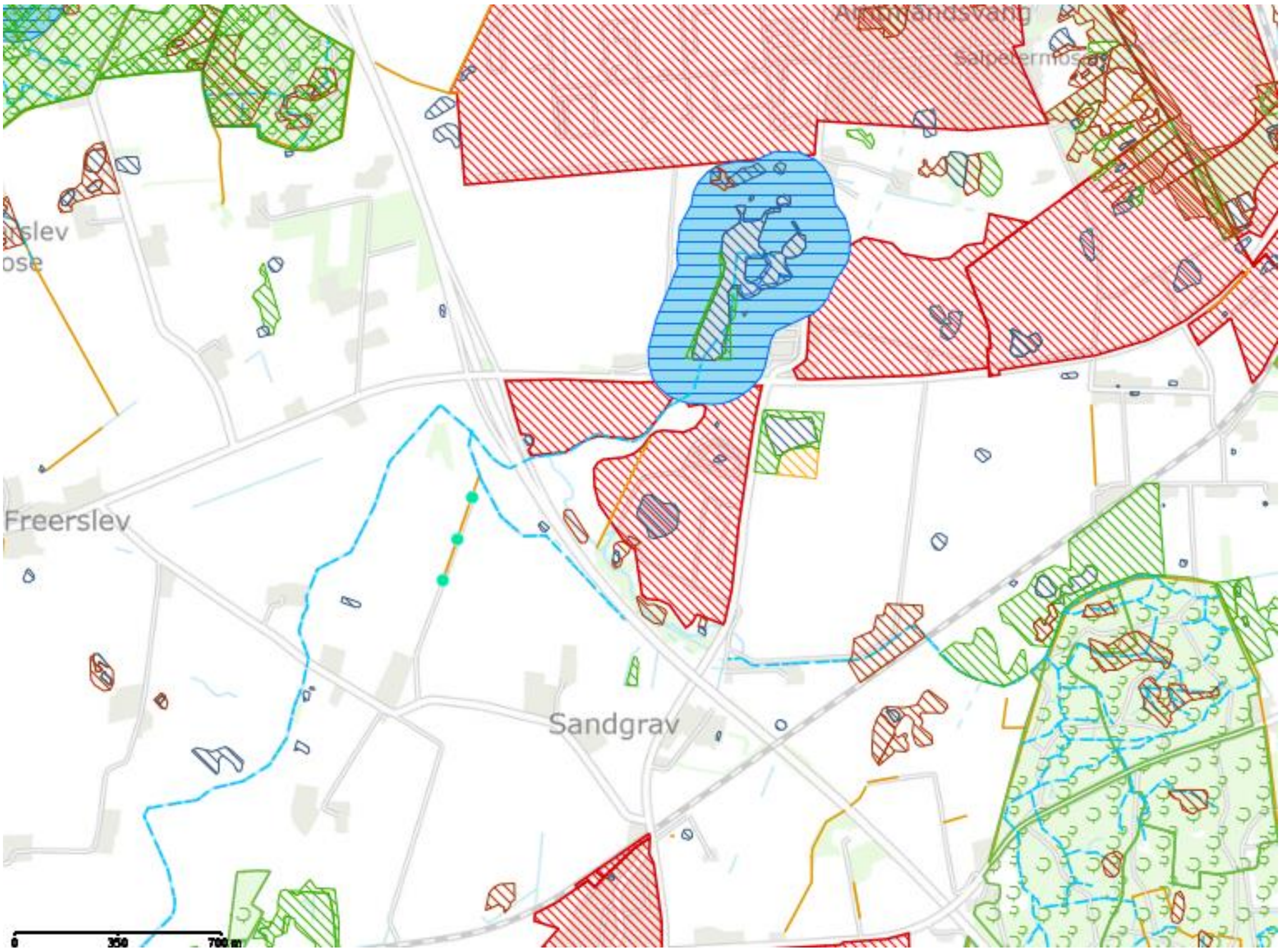

Figure 5: Map of the area around Hillerød Forsyning with city zones and protected areas marked. Source Plan- og Landistriktsstyrelsen

To reduce distance to the district heating network as well as the power and water supply, the area west of the utility company would be ideal. One possibility is the area marked on the map below.

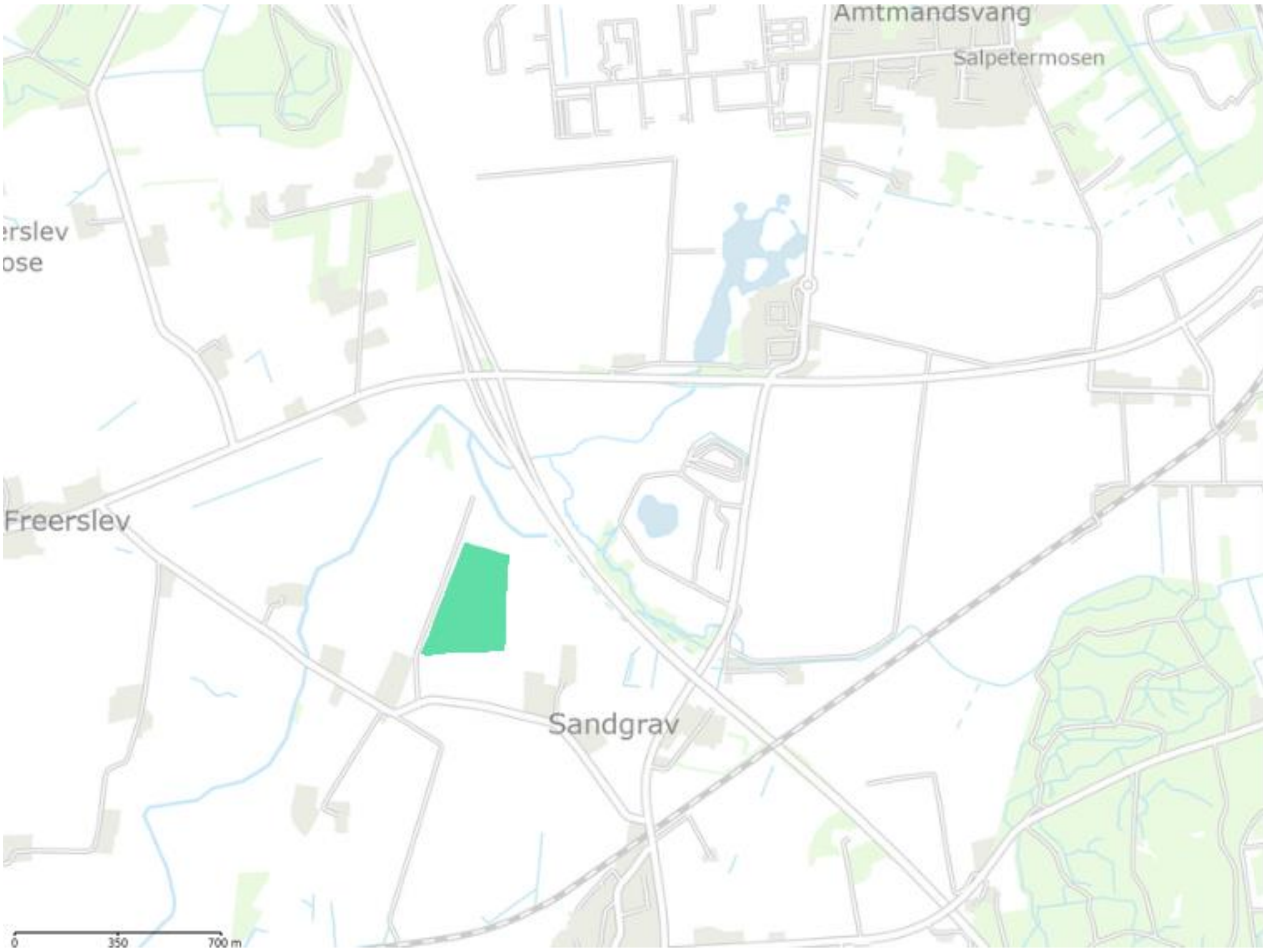

Figure 6: Area for potential PtX plant marked on the map. Source: Own production.

Summary

The current renewable power production is located to the southwest of Hillerød and can support a 12 MW capacity PtX plant. With more renewable power production either in the form of more wind turbines or PV facilities the capacity of the plant would rise. It would be far from the goal of 4-6 GW capacity (The Danish Government, 2022a), but would be on the same scale as some of the other planned facilities in Jutland, like Esbjerg, Rybjerg and Rødekro with 9-10 MW capacity each (Hydrogen Europe, 2023).

Water is available either pumped up from underground reservoirs or from the water treatment plant located south of Hillerød. The costs of pumping water from the underground reservoirs would be saved by using the treated wastewater and the cost of purification could either be saved or minimized. Therefore, using treated wastewater is the more cost-effective option. The water treatment plant can supply up to 9 million m^3 of water a year which is more than enough with the current capacity.

CO_2 for upgrading the hydrogen further into methane or SAF, can be sourced from biomass incinerators owned by Hillerød Forsyning located in Hillerød.

With the capacity dictated by the power availability, the area needed for an AEC plant is approximately 300 m^2 however with further upgrading of the hydrogen a larger size is likely needed. The fields west of Hillerød Forsyning has more than enough space to accommodate the plant, while staying close power production, the water treatment plant and a connection to the district heating system.

Discussion

Industrial symbiosis

Integrating Industrial symbiosis with PtX

Integrating district heating, carbon point capture, and wastewater management with PtX technologies in an industrial symbiosis network can significantly enhance resource efficiency, reduce environmental impact, and create beneficial synergies between various sectors. By closing the loop on these processes and utilizing biproducts, the need for resource generation goes down. This approach makes the system more circular, while reducing CO_2 emissions and saving money (Neves et al., 2020).

High-temperature electrolysis, such as AEC generates substantial amounts of waste heat. By capturing this heat and using it in district heating systems to provide hot water and heating for residential, commercial, and industrial buildings the overall energy requirements goes down (Sorknæs et al., 2024). Although while improving overall energy efficiency and minimizing energy wastage, the need for biomass incineration goes down, which could mean a problem for the CO_2 sourcing.

A holistic approach to resource management is achieved by integrating district heating, biomass incineration, and wastewater management with PtX technologies within an industrial symbiosis network. Waste heat from PtX processes can be utilized for district heating. Carbon captured from biomass ovens and treated water from a wastewater treatment plant can be used in PtX technologies. This interconnected approach maximizes resource efficiency and minimizes waste, supporting the principles of a circular economy by turning waste into valuable resources. For instance, CO2 from waste incineration and wastewater treatment can be converted into synthetic fuels, while excess heat and energy are reused within the network, thereby reducing environmental impact and creating economic value from waste streams.

This integration fosters collaboration between different sectors, enhancing the overall sustainability and resilience of the industrial ecosystem. Companies can share resources, optimize energy use, and reduce costs, leading to improved economic and environmental outcomes. In summary, integrating district heating, biomass incineration, and wastewater management with PtX technologies in an industrial symbiosis network creates a synergistic and sustainable system. This integration enhances resource efficiency, reduces waste and emissions, and promotes the circular economy, contributing to a more sustainable industrial landscape.

Industrial symbiosis with other partners

Within Hillerød there already is an industrial symbiosis, wherein two pharmaceutical companies, Novo Nordisk and Fujifilm Diosynth Biotechnologies, collaborate with Hillerød Forsyning, a hospital and a knowledge center as the facilitator (C4, 2024). The companies supply some of their waste heat from their factories to the district heating grid while the utility company handles their residual waste and wastewater. They are currently trying to implement a district cooling system to supply excess cold water to the hospital (C4, 2024).

Using the already established connections, the PtX plant might be able to sell hydrogen, methane or methanol to the pharmaceutical companies directly as they could be products used in their manufacturing. That would save costs as transportation would be low since the companies are in close proximity to each other and give certainty to the PtX plant that they already have a buyer.

Sourcing more energy

Hesselø

One source of renewable energy could be the planned offshore wind turbine park Hesselø located north of Sealand in the Kattegat strait see figure below.

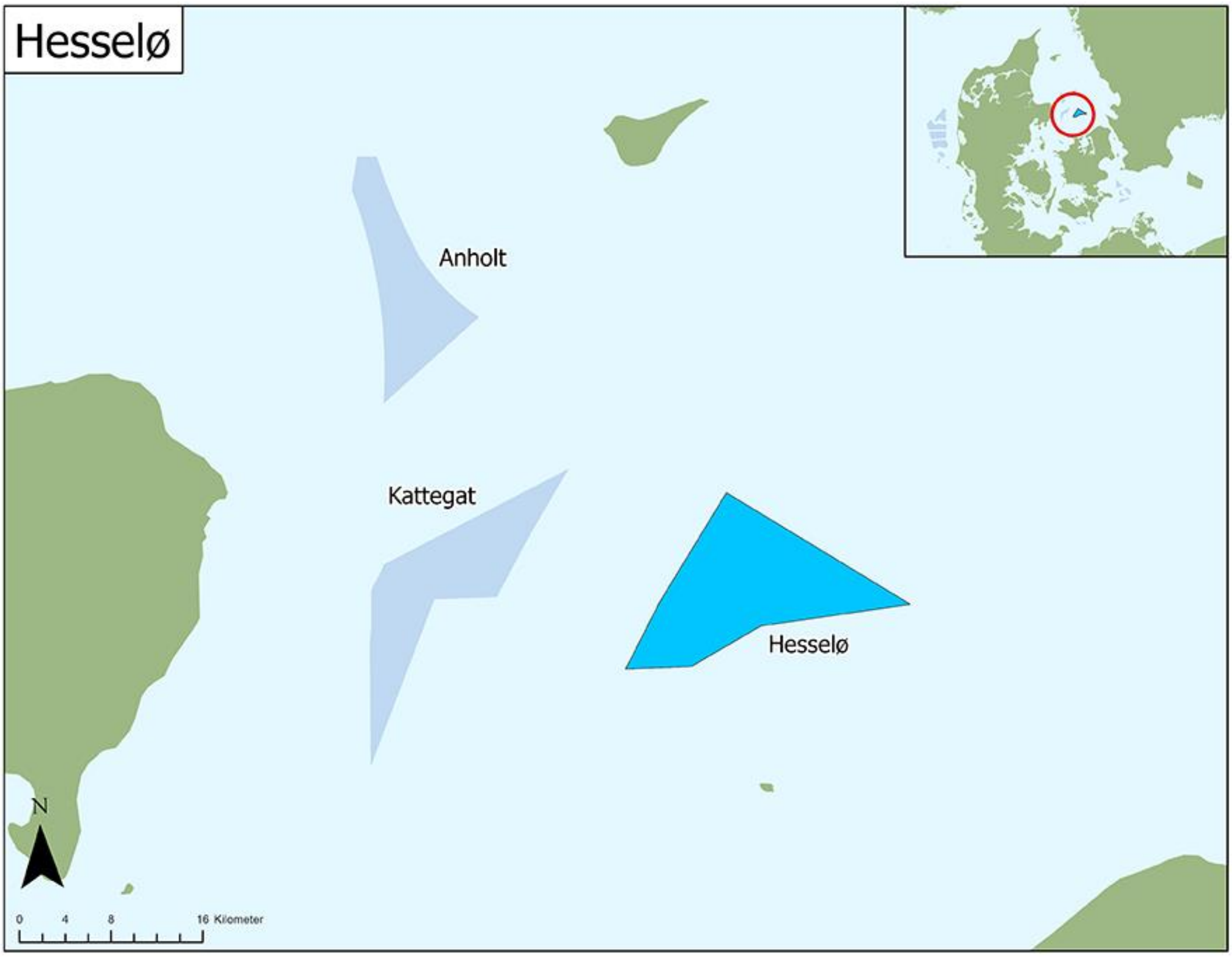

Figure 7: The location of the planned Hesselø wind park. Source (The Danish Ministry of Energy, 2024)

It will have a capacity of 800-1.200 MW and will have a transmission line running close to Hillerød. Part of the agreement is that the power generated from the turbines should be used for either PtX or storage (The Danish ministry of Energy, 2024). With 4850 average full load hours for offshore wind turbines, which is 55% capacity the maximum amount of power sourced from Hesselø would be 440- 660 MW. That would be a big increase in capacity for the PtX plant and it should not be expected that all the power would be used only in

Hillerød, however even 100 MW would be a massive increase in the capacity. The increased capacity would require additional space and input resources like water and CO_2.

PtX on Sealand

Much of the PtX planned in Denmark is in the western part of the country specifically in Jutland (Hydrogen Europe, 2023), as it is well connected to the offshore wind parks in the North Sea and has high wind speeds for onshore wind turbines. They will also have the pipeline going south to Germany where the produced hydrogen will be sold (The Federal Ministry for Economic Affairs and Climate Action of Germany and The Ministry of Climate, Energy and Utilities of Denmark, 2023). As a result, there are currently not planned many PtX plants in other areas of Denmark. That could be a good opportunity for the potential plant located south of Hillerød as it could have a large consumer base serving north Sealand and Copenhagen. Although hydrogen is not high demand, methanol and sustainable aviation fuel, which is a mix of e-fuels and jet fuel (The Danish Energy Agency, 2023), could be sold to the Copenhagen airport and harbor.

Conclusion

This report and project sought out to answer the question how a PtX plant can be integrated into Hillerød as part of an industrial symbiosis, and where the plant should be located. To answer that a spatial analysis was done, and the results discussed.

By utilizing biproducts such as waste heat from the PtX plant, water from a water treatment plant and CO_2 from biomass incineration a more closed system is made. As part of this system the PtX plant not only helps reduce the CO_2 emissions created by other members of the symbiosis but reduces the need for heat production while providing fuel for hard to abate sectors. By locating the plant south of Hillerød close to Hillerød Forsyning the operational costs of the plant are reduced while enabling synergies between industries. This helps Denmark reach the goals they have set towards hydrogen production and climate neutrality.

Appendix 1

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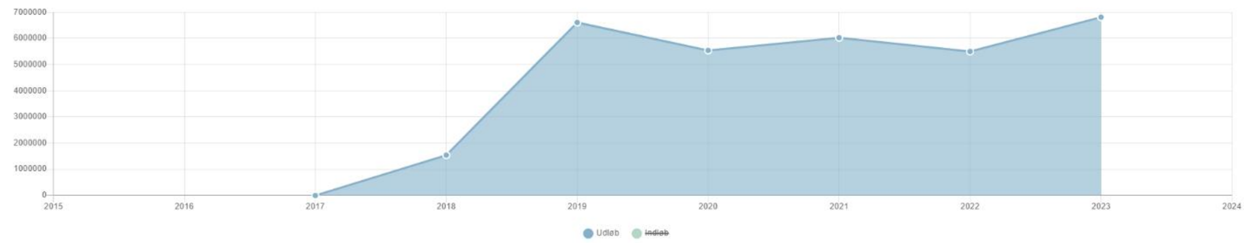
Hej Emil

Mængden er lidt varierende, så du får lige alle år for HCR Syd. Men med Fuji og Novo er den stigende, mener der er 8-9 mill. m3 i prognosen for når industrierne er færdige med deres udvidelser.

HCRSyd - Pøle Å > Renseanlæg > Spildevandsmængde

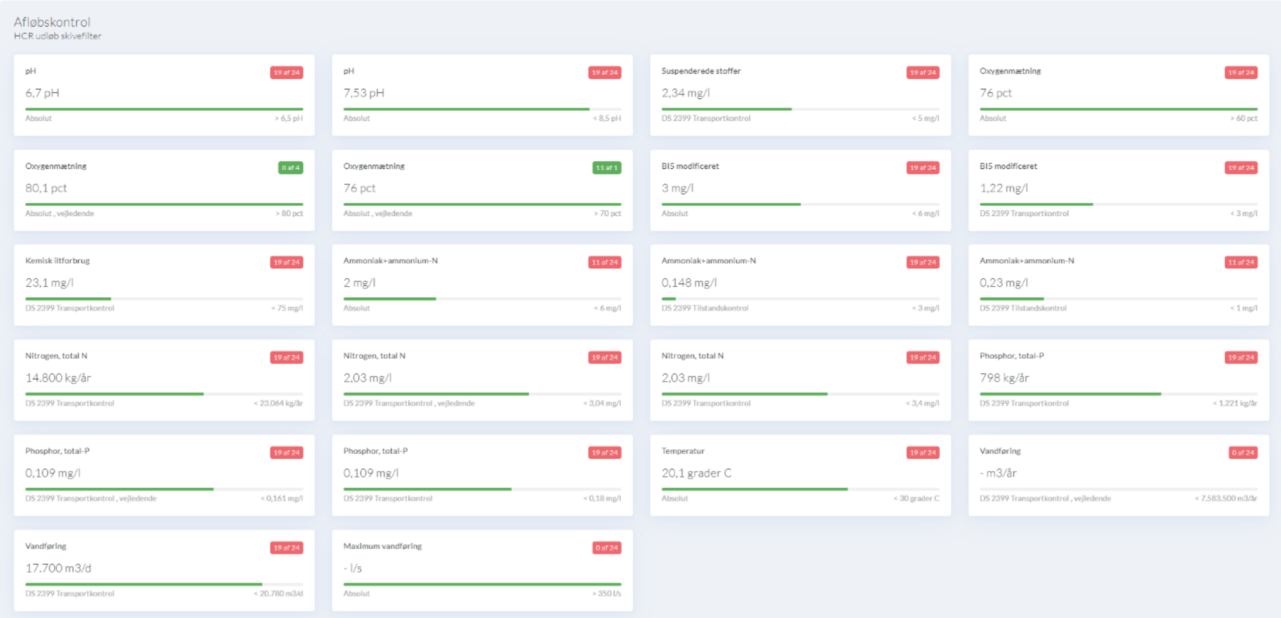
Indberetning

Senest ved fristen for indberetningen, bør den udledte spildevandsmængde indtastes her.



År	Indløb	Udløb	1. kvartal	2. kvartal	3. kvartal	4. kvartal
2024	- m³	- m³	2.102.701 m³	1.695.854 m³	1.658.726 m³	- m³
2023	6.920.351 m³	6.808.439 m³	1.933.127 m³	1.196.860 m³	1.657.945 m³	1.969.587 m³
2022	5.372.836 m³	5.500.023 m³	1.938.473 m³	1.280.065 m³	1.142.630 m³	1.138.855 m³
2021	5.913.986 m³	6.023.405 m³	1.567.388 m³	1.257.282 m³	1.508.226 m³	1.690.509 m³
2020	5.463.676 m³	5.539.737 m³	1.872.626 m³	1.226.106 m³	1.114.728 m³	1.326.277 m³
2019	6.480.573 m³	6.603.972 m³	1.780.048 m³	1.312.488 m³	1.651.386 m³	1.850.050 m³
2018	1.491.608 m³	1.539.134 m³	- m³	- m³	- m³	- m³

Jeg kan desværre ikke hjælpe med konduktiviteten, men her er det vi bliver målt og vejet på. Tallene er for 2024.



Mht. ISO 3696:1987 læser jeg det som at den specificerer 3 typer laboratorie vand (3 grades) og der er vores rensede spildevand slet ikke. Om det bliver så rent efter 4. rensetrin, vil tiden vise, men det vil nærme sig.

Jeg ved ikke, hvor rent vandet skal være for at kunne blive brugt i forbindelse med Power To X, men der er snak om, at det rensede spildevand kan bruges til Power To X, når vi har fået bygget og installeret 4. rensetrin om et par år.

Håber det kan hjælpe dig lidt.

Med venlig hilsen
Christina Spangsberg Petersen

Appendix 2

See the attached Excel file

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