Summary

The central research question guiding this study is: *What opportunities exist for the optimal utilisation of excess heat at Mongstad Industrial Park employing industrial ecology principles, considering stakeholder engagement, technological options, and political barriers?*

The study employs several different methodologies to help create the most holistic system and landscape understanding.

Circular thinking, system theory, and industrial ecology are the guiding theories by which this study is approached. The research is carried out by a literature review aiming to understand the larger context of industrial symbiosis, technological pathways and local political context. It is expanded further by mapping out stakeholders to understand their power and interest in the system. Lastly, calculations are done to gauge the pre-feasibility of implementing excess heat pathways. These analyses are followed by a discussion aiming at addressing the gaps in the report both in terms of the lacking data, the

Technologies focusing on excess heat utilisation, such as waste heat recovery boilers, present efficient opportunities for Mongstad. However, existing policies have concentrated predominantly on carbon mitigation rather than optimising energy efficiency at an industrial level. A noticeable absence of specific mandates for utilising industrial excess heat is found.

The primary stakeholders identified are Equinor, Asset Buyout Partners, Vestland region and Alver municipality. These stakeholders are critical in implementing excess heat endeavours in the industrial park. The influence of governmental agencies is primarily regulatory, while Equinor's resource potential shapes the opportunities and challenges for implementation. Engaging stakeholders such as Technology Centre Mongstad (TCM) could prove beneficial, given their expertise in emission mitigation and potential synergies with energy efficiency projects.

The analysis suggests that converting high-temperature excess heat into electrical power via waste heat recovery boilers is currently the most viable technological option based on its limited connection to larger grid systems. Mongstad's rural context diminishes the feasibility of district heating, whereas converting the heat into electricity would provide a versatile and broader application, feeding into local energy needs.

Two pathways for utilising the excess heat from the oil refinery are presented. One that keeps the thermal energy in its original state for heating and one that converts it into mechanical energy for power purposes. While the estimations are based on similar cases and not on data directly from Mongstad, the energy seems to be better utilised converted, even if this means accepting a larger energy loss. Concrete data from the stakeholders would help inform the best-case scenario.

The report's discussion addresses several challenges while conducting the study, as well as reflections on future research recommending engaging stakeholders to obtain data for future calculation as well as informing the decision on the best technology to employ.

Master thesis

An assessment of pathways for industrial excess heat utilisation

Reviewing use of excess heat from Mongstad oil refinery

Laura Westenholz Handberg
October 2024
MSc Sustainable Cities

Aalborg University Copenhagen

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Abstract:

This study examines the use of excess heat at Mongstad Industrial Park through industrial ecology, focusing on stakeholder engagement, technology, and policy barriers. Mongstad's unique context offers an opportunity for industrial ecology exploration.
Global policy promotes energy efficiency, but ambiguity around industrial excess heat remains. Mongstad's rural location and uncertain local demands complicate excess heat integration. Retaining thermal energy is most efficient, but converting it to electricity via a waste heat recovery boiler is also viable. Engaging key stakeholders, such as Equinor and local authorities, is essential. Success relies on collaboration, cost-benefit analysis, and strategic planning. Applying industrial ecology at Mongstad could enhance energy efficiency and serve as a sustainability model.

the author.

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Preface

Aalborg University Copenhagen October 21, 2024

This thesis was carried out as a master thesis project by Laura Westenholz Handberg in the 4th semester of the engineering study program Sustainable Cities at Aalborg University Copenhagen.
A huge thank you should be given to my supervisor Iva Ridjan Skov for your valuable inputs and guidance, this thesis would not have been possible without you help.
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Laura Westenholz Handberg

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Abbreviations

A list of the abbreviations used in this report, sorted in alphabetical order:

CCS Carbon Capture and Storage

CE Circular economy

CHP Combined Heat and Power plant

DH District heating

EE Energy efficiency

EH Excess heat

GHG Greenhouse gases emissions

IE Industrial ecology

IS Industrial symbiosis

MIP Mongsted industrial park

ORC Organic Rankine Cycle

TMC Technology Center Mongstad

Chapter 1

Introduction

The purpose of this introductory section is to establish the project's context and define its scope. It introduces the topic within the broader international, national, and sector-specific frameworks, highlighting key historical milestones, contemporary issues, and political agreements that have shaped the energy landscape. A case description is then provided to ground the project's focus within a specific practical example, offering deeper insights into the subject matter.

The Global Sustainability Challenge

Sustainability has become one of the most pressing global challenges of the 21st century. The Brundtland Report, published in 1987, brought widespread attention to the concept of sustainable development, defining it as the ability to meet "*the needs of the present without compromising the ability of future generations to meet their own needs*" [1]. This principle has shaped the global discourse on sustainability, influencing international agreements such as the Paris Agreement, in which 195 countries in 2015 committed to reducing their greenhouse gas emissions and regularly report on their progress, intending to achieve a balance between emissions and removals in the second half of the century. [2]. These targets are crucial in mitigating the effects of climate change, which have been exacerbated by industrial growth over the past two centuries.

Since the Industrial Revolution, industrial processes have been central to economic growth but have also been responsible for a significant portion of global greenhouse gas (GHG) emissions. The increase in global energy demand, coupled with the reliance on fossil fuels, has driven emissions up and aided in climate change [3]. In recent decades, industries, particularly those in the steel, oil, and chemical sectors, have been identified as major contributors to global emissions. These industries are classified as "hard-to-abate" sectors due to the complexity of their decarbonisation challenges, which involve high energy demands and process-related emissions [4][5]. According to IEA, from 2000 to 2023, industrial emissions rose by 70% and the industrial sector worldwide consumed 37% of energy overall [6].

Technological innovation plays a crucial role in addressing the global sustainability challenge. However, while renewable energy technologies such as wind, solar, and hydropower significantly contribute to reducing emissions in the energy sector, these technologies are not always commercially viable in energy-intense industrial settings[4]. Many industrial processes still depend on fossil fuels. This gap between technological potential and commercial readiness makes it essential to focus on energy efficiency improvements within existing industrial systems as both an immediate and long-term improvement.

Given the difficulties associated with decarbonising industrial sectors, energy efficiency has emerged as a critical strategy for reducing emissions[7]. Energy efficiency refers to the optimisation of energy use within industrial processes, aiming to reduce energy waste and improve the overall performance of energy systems[8]. The potential for efficiency is particularly high in energy-intensive industries, where significant amounts of energy are often lost as waste heat during production.

Industrial excess heat is a by-product of many industrial processes and represents a substantial, yet underutilised, energy resource[9]. Recovering and repurposing this excess heat offers a promising pathway for improving energy efficiency and reducing the need for external energy inputs.

Circular Thinking and Industrial Ecology

Circular thinking and the broader concept of industrial ecology provide a useful framework for understanding how industrial systems can become more sustainable by mimicking natural ecosystems. Industrial ecology aims to transform industrial processes by reducing waste, increasing resource efficiency, and creating pathways where the by-products of one process become inputs for another [10]. This approach is inspired by the principles of natural ecosystems, where materials and energy are continually cycled and reused. Circular thinking specifically focuses on reducing the overall material and energy inputs into industrial systems by recovering waste and repurposing it for other uses[11]. In the context of energy systems, this can mean capturing industrial excess heat and using it to meet

energy demands elsewhere, either within the same facility or in neighbouring industries and communities. By reducing reliance on external energy sources, circular thinning helps to improve the resilience and sustainability of industrial systems .
In recent years, there has been growing interest in applying circular thinking principles to industrial parks, where clusters of industries are located in close proximity, often with complementary energy and material needs. Industrial symbiosis, where waste from one industry is used as a resource by another, can significantly reduce overall energy and resource consumption [12]. These concepts are particularly relevant for energy-intensive industries that produce large amounts of excess heat, as they offer opportunities to recover and repurpose this heat for other uses. However, industrial sites are not always located in proximity to urban areas and recirculation within these places becomes more prevalent.

The case of Norway: Energy, Industry, and Sustainability

Norway presents an interesting case study for analysing the intersection of energy efficiency, industrial ecology, and sustainability. The country is globally recognised for its commitment to renewable energy, with over 90% of its electricity generated from hydropower, but interestingly, its largest energy production comes from oil [13]. This high penetration of renewable energy in the electricity sector positions Norway as a major player in the transition to a low-carbon economy. However, despite its clean energy credentials, Norway's heavy industries remain significant sources of GHG emissions[14].
Industries such as oil refining, chemical production, and metal manufacturing are central to Norway's economy, yet they also account for a large proportion of the country's CO_2 emissions. Industrial processes were responsible for approximately 23% of the country's total emissions showcased in figure 1.1 [13].

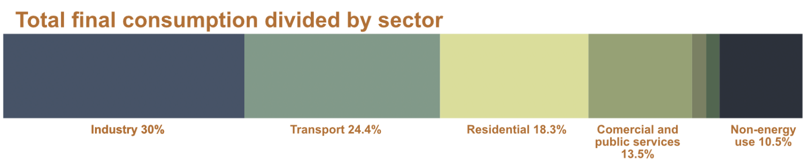

Figure 1.1: Figure from IEA showing total energy consumption of Norway, divided by sector[13].

This duality—where a country 0predominantly consumes renewable energy but struggles with industrial emissions—makes Norway an important case study for exploring how energy efficiency and industrial ecology can help reduce emissions in hard-to-abate sectors.

Norway's government has already recognised the issue of large emissions by setting ambitious climate targets, aiming to reduce GHG emissions by 50-55% by 2030 compared to 1990 levels [15]. Achieving these targets will require significant reductions in industrial emissions, which could be aided by employing energy efficiency and adopting more sustainable industrial practices. This is particularly true in regions like Vestland County, where industrial activity is concentrated and emissions are high.

Vestland County and Mongstad Industrial Park

Vestland County is one of Norway's most industrially intensive regions, hosting a range of energy-intensive industries that are critical to the country's economy[16]. The county has several large industrial parks, including Mongstad Industrial Park. Mongstad houses a variety of industries, including Norway's largest oil refinery, that produces petrol, diesel and aviation fuel [17].

Mongstad Industrial Park is located in a rural area near the west coast and represents challenges and opportunities associated with energy efficiency in industrial systems as it is the location of Norway's largest oil refinery. Oil refining is an energy-intensive process that generates large amounts of waste heat, much of which is currently dissipated into the atmosphere [18]. It becomes imperative to look at cases with large fossil plants present to understand how we can reduce the emissions related to these practices.

Given the scale of industrial activity at Mongstad, there is considerable potential for improving energy efficiency by recovering and repurposing excess heat. By applying the principles of circular thinking and industrial ecology, it may be possible to capture waste heat from the refinery and use it to meet other energy or heat demands. This would reduce the park's overall energy consumption and contribute to Norway's broader climate goals by lowering emissions from one of the country's largest industrial sites.

Chapter 2

Problem statement

2.1 Problem context

Globally, industries are under increasing pressure to reduce energy demand and carbon emissions in response to climate change and sustainability targets [19]. Energy-intensive industries, in particular, are significant contributors to greenhouse gas emissions [20], prompting a strong international push for improved energy efficiency and the adoption of circular economy principles [21]. A critical issue facing industries worldwide is the considerable energy loss in the form of excess heat, which often goes unutilised [22]. Reclaiming and reusing this heat could be a key strategy in reducing overall energy demand.

Norway's industrial sector, while essential to its economy, is not immune to these challenges. Despite progress in integrating renewable energy and improving energy efficiency, large-scale industrial processes still generate vast amounts of excess heat [23].

The optimal use of excess heat should be investigated to discover the best utilisation. The area and location of the park is a significant factor, as many more rural places might lack infrastructure and demand for certain energy types. Therefore, local utilisation within the industrial parks themselves is a particularly promising approach [12]. As a result, this study will focus primarily on opportunities for heat reuse within the confines of industrial parks.

Mongstad Industrial Park presents an interesting case where the optimisation of excess heat recovery could significantly contribute to energy efficiency improvements [24]. However, challenges remain in aligning stakeholder interests, implementing the necessary technologies, and navigating policy frameworks.

2.2 Research questions

What opportunities exist for the optimal utilisation of excess heat at Mongstad Industrial Park employing industrial ecology principles, considering stakeholder engagement, technological options, and political barriers

2.2.1 Guiding questions

1. What is the current landscape of technologies, policies, and challenges related to energy efficiency and excess heat utilisation, and how could it impact potential implementation at Mongstad Industrial Park?
2. Who are the key stakeholders at Mongstad Industrial Park, and how do their interests and influence shape the opportunities and barriers for excess heat utilisation?
3. What are the most viable technologies to best utilise the excess heat from Mongstad Industrial Park's refinery?
4. What are the key drivers and barriers to implementing energy efficiency through excess heat utilisation at Mongstad Industrial Park, and how can these be addressed to promote industrial symbiosis and circular economy principles?

Research Design

The research will be based on a mixed-methods approach, combining a literature review, stakeholder analysis, and supporting technical assessment. The literature review will explore the current technological landscape and policy frameworks related to excess heat utilisation in industrial settings. A stakeholder analysis will be conducted using a power-interest matrix to map out the roles and influence of various actors at Mongstad Industrial Park. Finally, energy savings estimations are carried out to see the potential use cases. Together, these methods will provide a holistic view of the opportunities and challenges for implementing energy efficiency measures at the park.

Project Boundaries

This research focuses on Mongstad Industrial Park as a focus area, exploring the potential for energy efficiency through excess heat utilisation. The analysis will primarily consider

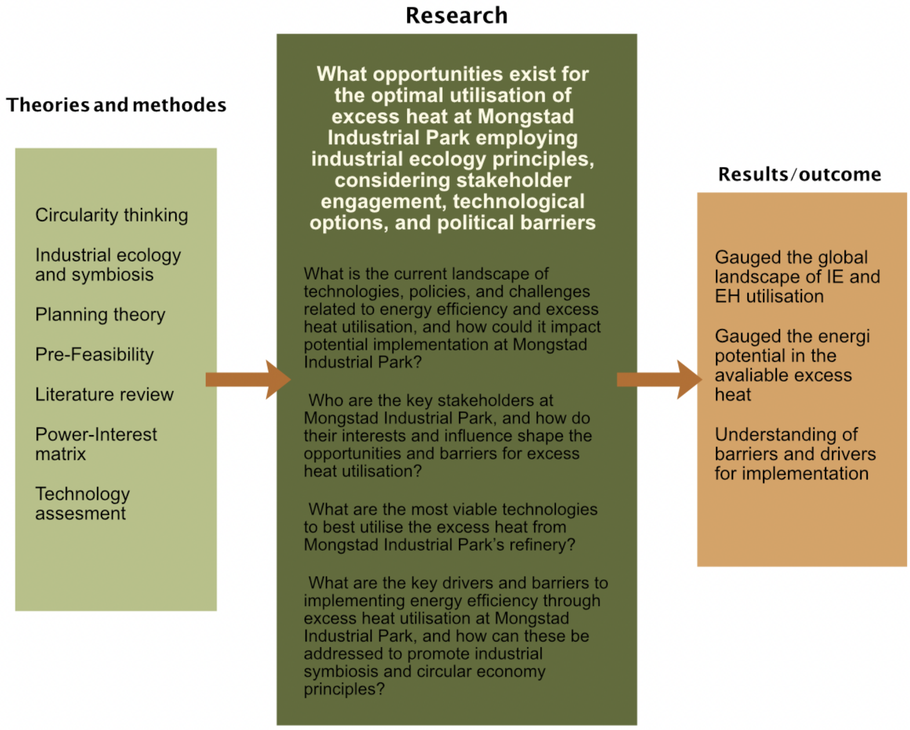

Figure 2.1: Figure showing overview of research design

possible technological solutions, stakeholder dynamics, and the political landscape of the areas. Broader global trends in energy efficiency and circular economy principles will be discussed insofar as they inform the local case.

This research presents a high-level examination that represents an initial assessment of the potential impact and viability of using excess heat at Mongstad Industrial Park. Consequently, the study is characterized by significant uncertainty across various components, including the need for energy and heating on-site, equipment expenses, and operational and maintenance costs.

Chapter 3

Theoretical and methodical framework

This chapter centres around the theories and methods used to expand the topic and problem statement.

3.1 Circularity thinking

Circular thinking is foundational to modern sustainable engineering practices, representing a paradigm shift from the traditional linear economy to one that aims to not only reduce waste but to reduce production. Circular thinking aims to eliminate waste and pollution, keep products and materials in use, and regenerate natural systems. This approach is critical in addressing resource depletion and environmental degradation, focusing on closed-loop systems where end-of-life products and materials are reintegrated into the production cycle[25].

A part of large-scale circular planning is the integration of renewable energy and resource systems. In large-scale system planning, circular thinking extends beyond individual products to encompass entire industrial systems and infrastructure. This involves rethinking how industries are structured and how they interact with each other within a broader economic and environmental context. Large-scale application of circular theory necessitates designing and implementing industrial ecosystems where waste from one process becomes the input for another, thereby creating a continuous loop of material and energy flows[26].

I) urban planning and industrial zones, circular theory encourages the development of integrated systems where energy, water, and material flows are optimised. This might involve designing industrial parks where companies are co-located to facilitate the ex-

change of by-products and waste materials. Planning can reduce transportation costs and emissions, minimise waste, and improve overall resource efficiency[10].
Energy efficiency fits into the circular thinking scheme, emphasising reducing energy consumption while maintaining or improving performance. Energy efficiency plays a pivotal role in minimising the environmental footprint of production processes. Efficient energy use reduces the demand for fossil energy resources and lowers greenhouse gas emissions, contributing to climate change mitigation[8].
Implementing circular thinking at a large scale also requires policy frameworks. Governments and regulatory bodies play a crucial role in setting standards and incentivising businesses to adopt circular models. This can include tax benefits for companies that reduce waste, increase recyclability, and regulations mandating recycling products locally[26].

3.1.1 Industrial ecology and symbiosis

Industrial ecology is embedded in the circular thinking framework. According to Graedel & Allenby (1993) industrial ecology aims to limit the input sources and thereby limit the waste outputs in industrial settings[27]. IE, therefore, examines the flow of resources to see what resources and materials can be circulated[28]. It draws inspiration from natural ecosystems, where one organism's waste becomes a resource for another, creating a symbiotic relationship. In industrial ecology, the concept of industrial symbiosis is paramount, where different industries collaborate to use each other's by-products and waste materials, creating a network of interconnected operations that mimic the efficiency of natural ecosystems[10].
Industrial ecology and symbiosis approach the industrial sustainability challenge by viewing the individual company as part of a larger system in which resources and materials can be exchanged. The driving force is looking at how using materials and resources is commonly considered waste from another company to fuel production. This way, waste is minimised, and resources are used most effectively[10].
Approaching industrial sites as a large system instead of individual practices is complex and requires understanding the individual practice. It also recognizes how changes within the system might affect one another and how to take advantage of this[25]. This endeavour naturally requires planning practises, as the industrial system should always take its surroundings into account [28].

3.2 Literature review

To establish a comprehensive understanding of the potential for creating more energy-efficient systems in Norway's industry, a semi-systematic[29] literature review was conducted. This process is carried out by identifying relevant sources from academic databases such as ScienceDirect, Scorpus, AAU Library and Google Scholar. The selection criteria focus on ensuring the relevance and quality of the sources. The next step involved systematically extracting information from the selected literature, focusing on key themes such as existing energy efficiency measures, technological advancements, policy frameworks, and barriers to implementation. The extracted data is compiled to identify trends, gaps, and opportunities for knowledge contributions in the field.

3.3 Power-Interest matrix

When trying to implement a systemic change, it can be vital to understand the present stakeholders and their respective interests and power to either drive or hinder the challenge.
The Mendelow Power/Interest Matrix can be employed to understand and get a structured overview of which stakeholders to engage with and how to approach them. This analytical tool helps to map out stakeholders based on their level of interest and power[30]. This facilitates the identification of key players who can influence and or are affected by energy efficiency initiatives. Stakeholders were identified through the listed companies present in the park[17] and the identified political and public entities that would possibly be affected.

Stakeholders are plotted in a two-by-two matrix, categorising them into one of four groups:
High power/high interest key players who are crucial to the success of energy efficiency initiatives and need to be actively engaged)
High power/low interest powerful stakeholders who may require persuasion or incentives to support energy efficiency efforts.
Low power/high interest supportive but less influential stakeholders who could serve as advocates or partners.
Low power/low interest stakeholders with minimal impact or interest, requiring less focus in the strategy.
As clarification, the matrix does not function as a diagram in which the specific placement within each square indicates higher or lower power and or interest.

The matrix enables efficient communication, informed decision-making, and the strategic allocation of resources[30].

3.4 Pre Feasibility approach

A pre-feasibility study is an initial assessment conducted before a comprehensive feasibility study. This evaluation gathers key assumptions and relevant data to determine if a project is viable enough to move forward. It asses initial barriers and drivers for implementation[31]. In this project it is mainly utilised by looking at calculations that estimate potential energy savings of implementation of excess heat capture and to look at the overall preliminary feasibility of the project.

Chapter 4

Analysis

4.1 Literature review

This section reviews relevant literature to establish a foundation for further research by focusing on three aspects regarding the current state of knowledge and technology pertaining to energy efficiency, industrial ecology principles and the use of excess heat. The review was conducted using three guiding questions, each getting progressively more focused. the questions are as follows:

1. *what are current practises of industrial ecology?*
2. *How is industrial excess heat currently being used? A technological deep dive.*
3. *What kind of political barriers and drivers exist for Monstad Industrial Park, both on a larger scale from Norway's government and in both Vestland County and Alver Municipality?*

The questions was researched by using key phrases such as "Excess heat", "Waste heat" "Industrial symbiosis" "Heat capturing" "Industrial sustainability" "Norway climate action" and "Vestland county", "Mongstad", "oil refinery". the keywords have also at times been searched in junction with each other to further narrow the research.
All sources not written in English, topics not related closely enough to the topic and material that did not help answer the problem statement have been omitted. For the remaining literature abstract were read and the sources that provided deepest insight and were most closely related to the topic was chosen.

4.1.1 Industrial Ecology on a Global Scale

As introduced in section 3.1.1, Industrial ecology aims to reconfigure industrial processes and their resource management to minimise waste and optimise processes [28]. IE promotes establishing industrial systems where waste from one process becomes the input for another. A key aspect of IE is the development of industrial symbiosis, which enables industries to collaborate by exchanging materials, energy, and by-products. This first section of the literature review will look at the extent to which this has been realised in industrial parks to understand the success criteria and potential pitfalls of the approach. This section aims to lay a foundation of knowledge on the current landscape of industrial ecology. Focusing on how the practice is perceived and examples of implementation. This is done to better understand cases and possible pitfalls and drivers for implementation.
Over the past few decades, global attention has been paid to IE. The European Union (EU) has been an advocate for IE, promoting policies that encourage circular economy principles and the adoption of industrial symbiosis [32]. this is evident in their report *Closing the loop—An EU action plan for the circular economy* and in their Horizon 2020 programme. The latter has funded several research projects aimed at integrating industrial ecology into urban planning [33].

Kalundborg Symbiosis is an Eco-Industrial Park in Denmark and one of the most notable examples of successful IE in action. Industries here share resources, including water, energy, and waste products, forming a closed-loop system that reduces emissions and waste. A central participant in this network is the oil refinery operated by Klesch, although it is not the main energy provider within the symbiosis. The refinery receives energy from the Advedøre power plant and sends its used cooling water to the energy Ørsted power plant, which utilises it for steam production [34]. Additionally, surplus sulphur from the refinery is sold to a sulphuric acid producer, reducing waste and providing raw materials for another industry. Kalundborg demonstrates how the principle of industrial symbiosis can be applied effectively on a local level[35]. It is often considered the blueprint for similar initiatives worldwide, indicative through the frequency of the name being used in related literature. Kalundborg also has a focus on EH as their surplus that does not get used internally is sent into the district heating network.

China has also adopted industrial ecology as a central pillar in its approach to sustainable development, particularly through its National Circular Economy Development Strategy.

China's focus on IE is largely driven by its need to balance industrial growth with environmental constraints. [36].
This highlights how industrial ecology is becoming an increasingly globalised practice, with countries outside the EU focusing on similar principles to meet their sustainability goals. Energy efficiency is also a core feature of China's strategy, where much of the emphasis is placed on reducing energy intensity in energy-intensive industries such as steel, cement, and chemicals [37].

Another successful case is the Rotterdam Industrial Cluster in the Netherlands, where oil refineries are integral to the industrial symbiosis network. The refineries collaborate with chemical plants, power stations, and waste processing facilities to exchange energy, feedstocks, and by-products [38]. Similarly, energy efficiency in the Rotterdam Industrial Cluster centres on reducing energy demand through material and energy exchanges, yet detailed studies of energy-specific savings through heat saving within such eco-industrial systems seem absent.

Similarly, in the Sarnia-Lambton region in Canada, efforts have been made to develop industrial symbiosis involving oil refineries. The refineries exchange by-products such as hydrogen and sulphur with chemical plants, which use them as raw materials [39]. The industrial ecology focus of this industrial park is centred on reducing energy demand through material and energy exchanges and not on excess heat-specific savings.
Lastly, in Moser & Rodin (2021) it is suggested that even though there are large amount of literature on the benefits of industrial symbiosis, there is a "information asymmetry". They highlight the issue of lack of transparency in regard to knowledge and about communicating information when establishing industrial symbiotic relationships[40].
In general there seems to be an understanding that when implementing industrial ecology and creating paths for distributing resources and materials it is naturally never the core business for the individual companies[41]. This results in some reluctance to invest in these measures if there is not immediately a potential revenue stream, though this has been inconclusive in some studies[40].

Summary of Knowledge Gaps and Areas of Focus

The global focus on industrial ecology as a key component of achieving a carbon-neutral future is evident across diverse regions and industries. Energy efficiency plays a central

role in these efforts, with significant attention placed on energy-intensive industries due to their substantial contribution to global emissions. While many of the benefits of industrial ecology and energy efficiency, such as reducing waste, improving resource efficiency, and lowering carbon emissions, are well-documented, the complexities of implementing these systems on a large scale, including coordination and regulatory challenges, remain significant hurdles to overcome.
Conducting this study has shown several global examples and cases of successful implementation of energy efficiency measures and industrial ecology at industrial parks. However, there has been a noticeable gap in the literature pertaining specifically to the utilisation of excess heat resources outside of the plant, emitting it beyond funnelling it into the district heating system. When looking at more rural locations of industrial sites, the literature seems to become scarce. The question then becomes how to best utilise it when no district heat grid is in place, and the plants themselves do not need excess heat.

4.1.2 Industrial Excess Heat: Technological Possibilities

Overview of Industrial Excess Heat Technologies

As the world gets more sustainable, it also gets increasingly more electrified. Energy efficiency has increasingly emerged as an essential element of both industrial ecology and broader sustainability frameworks. According to the International Energy Agency (IEA), energy efficiency improvements notably reduced global energy demand and GHG emissions during the last decade[42]. Energy efficiency can often be linked with industrial ecology because reducing energy use and improving energy recovery in industrial systems aligns with the principles of minimising waste and optimising resource use [43]. Common strategies include improving the energy efficiency of buildings, transportation, and manufacturing processes, all of which are critical in reducing the environmental impacts of industrial activities.
While there are certainly systemic initiatives, such as government programs and industry-wide standards, the incentives for businesses seem to often focus on immediate cost savings and improved profitability[44]. This can lead to a fragmented approach, where measures are adopted as fragments rather than as part of a cohesive strategy aimed at system-wide efficiency.

It's could be assumed that many energy efficiency measures implemented over the last two decades were driven by individual companies prioritizing their own operational costs and competitiveness, such was found in the case of using energy efficiency measures to send excess heat into district heating systems by Fritz et al. (2022) [44]. In this, it was found that capital cost was often a large barrier to using EH for district heating because the up-front cost for the companies for implementation deterred them from engaging. in the same article, they also mention that this might be an issue of lack of knowledge of the potential revenue such implementation can induce.

Excess heat is thermal energy generated by industrial processes that are not fully utilised and are typically released as heat emission [41]. It has been estimated that 20-50% of input energy in industrial processes is lost as excess heat [45]. Recovering this heat offers a significant opportunity to improve energy efficiency and reduce greenhouse gas emissions, particularly in energy-intensive industries such as oil refineries and chemical plants.
Various technologies have been developed to capture and repurpose excess heat, each targeting different temperature ranges and end applications. The following sections describe these technologies in detail, focusing on the mechanisms of heat transfer and their specific applications in industrial contexts.

Exergy and Industrial Heat Recovery

To better understand the different technologies, it is relevant to understand exergy as with any system, energy is constant, but it might not be all transferred to its new objective. Exergy, a measure of the quality or usability of energy, plays a critical role in the efficiency of heat recovery systems. High-exergy heat (from high-temperature sources) can be converted into useful work more easily, whereas low-exergy heat (from low-temperature sources) has limited potential for conversion. Technologies like steam turbines and ORC systems are designed to capture high-exergy heat and convert it into electricity, achieving higher efficiency in processes where exergy losses are minimal [46]. In contrast, low-exergy technologies such as heat pumps or thermoelectric generators focus on making the most of heat that has lower thermodynamic potential, often for low-grade applications like space heating or small-scale electricity generation [47]. Understanding this will aid in technologies for heat recovery. Maximising exergy efficiency is crucial in industries like steel, cement, and chemicals, where high-temperature processes generate significant waste heat..

High-Temperature Heat Recovery Technologies

High-temperature excess heat presents higher exergy, meaning it has greater potential to be converted into useful work, such as electricity generation or direct reuse in industrial processes [47]. The technologies commonly used for recovering high-temperature heat include steam turbines, organic Rankine cycles (ORC), and waste heat recovery boilers (WHRB)[48].

Steam Turbines Steam turbines are widely used in industries where high-temperature heat is available. commonly found in CHP plants to generate energy. In this system, thermal energy is transferred to water to produce steam at high pressure. The steam is then expanded through a turbine, where the kinetic energy of the steam turns the blades, driving a generator to produce electricity [49]. This process is highly efficient for recovering heat from industrial processes such as steel and oil production, where high-temperature furnaces are common. For example, at the Tata Steel plant in the Netherlands, steam turbines are used to capture excess heat and storing it to later use in order to reduce energy use, leading to a substantial reduction in both energy consumption and CO_2 emissions [50].

Organic Rankine Cycle (ORC) The Organic Rankine Cycle (ORC) is similar to a traditional Rankine cycle but uses an organic fluid with a lower boiling point than water, making it well-suited for converting medium to high-temperature waste heat into electricity. In an ORC system, excess heat is transferred to the working fluid in a heat exchanger, where it vaporises and expands through a turbine, generating electricity [46]. ORC systems are particularly effective in capturing heat from sources between 150°C and 500°C, such as in cement kilns or chemical plants.

Waste Heat Recovery Boilers (WHRB) Waste Heat Recovery Boilers (WHRB) are employed in high-temperature environments to capture flue gases and other exhaust heat streams from industrial processes such as oil refineries. The heat is transferred to water, producing steam, which can then be used for electricity generation or in other parts of the industrial process [51]. WHRB systems are particularly common in industries with continuous high-temperature operations, such as cement and steel production. They are typically integrated into systems where both power generation and process heat are required, thereby maximising exergy efficiency by utilising all available high-temperature heat.

Heat Exchangers Heat exchangers are one of the most versatile technologies for medium-temperature heat recovery. These devices transfer heat from one fluid (gas or liquid) to another without mixing the two, making them ideal for capturing heat from flue gases or process streams and reusing it elsewhere in the system [52]. In oil refineries, heat exchangers are used to integrate heat across different units, improving process efficiency and reducing energy consumption [53].

Summary of Technological Possibilities and Applications

The table below summarises the key technologies for excess heat recovery, detailing their operation, temperature range, and potential applications. Due to the high temperature of excess heat at the refinery, only technologies that can operate efficiently on this are considered. This will guide which approach best suits the Mongstad industrial park.

Technology	Temperature Range	Heat Transfer Mechanism	Potential Application
Steam Turbine [49]	High	Heat to steam, steam expands in turbine	Power generation for high-temperature industrial processes or grid electricity
Organic Rankine Cycle (ORC) [46]	Medium/High	Heat to organic fluid, expansion drives turbine	Power generation from medium to high-temperature waste heat, including chemical plants
Waste Heat Recovery Boilers (WHRB) [51]	High	Heat to steam for process heat or electricity	Process heat for chemical manufacturing, power generation
Heat Exchanger [51]	Medium	Heat exchange between fluids	Process heat for nearby industries, such as recycling or waste treatment

Table 4.1: Technologies for Excess Heat Recovery, Heat Transfer Mechanisms, and Potential Applications

These examples demonstrate the range of technological possibilities for excess heat recovery. The Mongstad Industrial Park in Norway, with its refinery and gas processing facilities, represents an interesting candidate for the utilisation of excess heat as it is a source of high-temperature processes that yield high excess heat.

4.1.3 Political Barriers and Drivers for Mongstad Industrial Park

National and Regional Drivers

Norway has a strong national commitment to reducing greenhouse gas emissions and promoting sustainable energy practices. The Climate Change Act of 2017 sets an ambitious goal for the country to achieve carbon neutrality by 2050 [54]. In line with this, the government has shown support for innovative projects such as carbon capture and storage (CCS) at Mongstad, highlighting a willingness to invest in solutions that reduce industrial emissions [55].

Moreover, the government's *Climate Action Plan for 2021–2030* recognises energy efficiency measures as holding the second-highest potential for emission reductions within the petroleum industry [56]. The plan allocates at least 25 million NOK to support energy efficiency and emission reduction initiatives in the oil and gas sector. Although waste heat recovery is briefly mentioned, it does not receive significant emphasis, and no specific mandates require industries to implement energy efficiency or excess heat utilisation strategies.

At the regional level, Vestland County, where Mongstad is situated, actively promotes sustainable development. The county's energy strategy focuses on using excess heat from industrial processes and integrating renewable energy into local energy systems [16]. Similarly, Alver Municipality's climate and energy plan advocates for improved energy efficiency and encourages collaboration among industries to explore synergies, such as recovering excess heat [57].

When looking at the drivers, the increasing emphasis on reducing carbon emissions and improving energy efficiency aligns well with Norway's broader climate objectives, providing political momentum for adopting heat recovery technologies. The planned development of a low-carbon industrial cluster in Vestland County, similar to the initiative at Kollsnes, could further support the implementation of such technologies at Mongstad.

Political Barriers

Despite these positive drivers, several political barriers could hinder the full implementation of excess heat recovery technologies at Mongstad. One significant challenge is the absence of a comprehensive national policy framework specifically addressing excess heat

recovery. While Norway has made strides in renewable energy, there is a lack of dedicated legislation that mandates the recovery and utilisation of excess heat [56].
Furthermore, industries seems to often prioritise short-term objectives over long-term solutions, which can obstruct the transition to a low-emission society [58]. The Enova Annual Report 2022 indicates that the industrial sector is responsible for a substantial portion of emissions. Implementing circular practices and waste heat recovery becomes crucial without commercially proven methods to reduce these emissions.
Economic factors also play a critical role. The potential of high initial costs associated with installing heat recovery systems can discourage industries from investing in these technologies. [40].
Equinor's Mongstad refinery, being the largest single-point emitter in the region with approximately 1,750,000 tonnes of CO_2 equivalents released [16], highlights the need for effective emission reduction strategies. However, regional initiatives like the *Green Region Vestland's Portfolio* tend to focus on energy and material exchanges in industrial symbiosis, without placing significant emphasis on excess heat recovery.

4.1.4 findings

There remain gaps in knowledge regarding the full potential of excess heat recovery at Mongstad and other industrial sites in more rural areas. Additional research is necessary to accurately quantify the possible energy savings and emission reductions that could result from implementing excess heat recovery technologies at Mongstads [58].

Excess heat utilisation represents another promising avenue for increasing energy efficiency. By capturing and reusing waste heat, industrial parks like Mongstad Industrial Park can achieve substantial energy savings while contributing to local sustainability initiatives. However, the specific challenges posed by Mongstad Industrial Park's rural setting necessitate innovative approaches, such as on-site electricity generation or using heat for local grid heating systems. Success in these areas will depend on overcoming technical and regulatory barriers and fostering effective stakeholder collaboration.
To further the understanding of the case, continued exploration of these topics will be essential. Focused research on technological solutions, stakeholder dynamics, and policy support will provide valuable insights for advancing sustainability in industrial settings like Mo Industrial Park.

4.2 Stakeholder analysis

This analysis will explore the industrial site, introduce relevant stakeholders and place them in a power interest matrix to better understand the full scope of MIP and endeavours for excess heat utilisation.

4.2.1 Site survey

Mongstad Industrial Park is located on the west coast of Norway, as shown in figure 4.1, approximately 60 kilometres north of Bergen, near the shores of the North Sea, covering over 1,400 hectares.

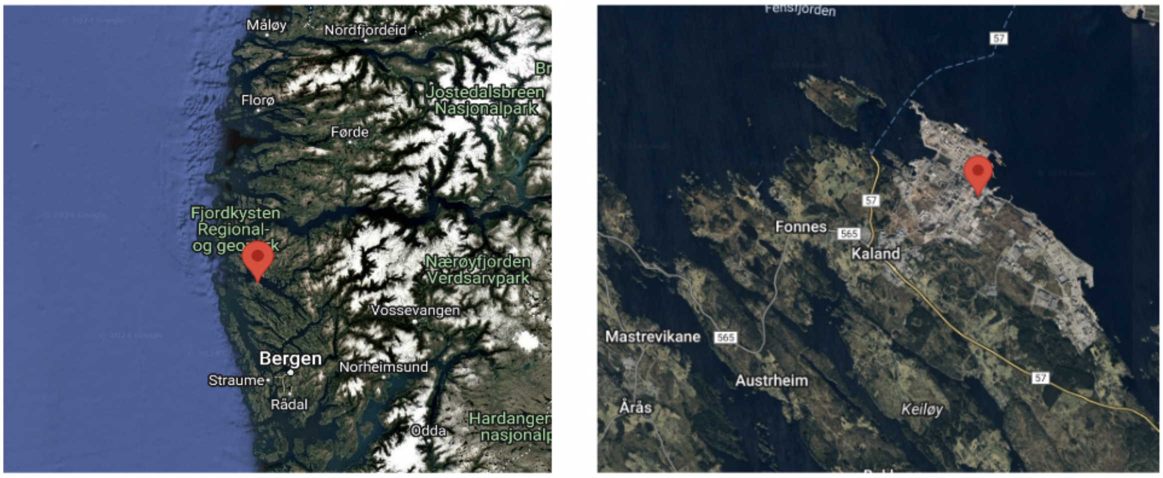

Figure 4.1: The images show the Mongstad industrial park in a larger Norwegian context. Images taken from Google Maps

Established in the 1970s, MIP has primarily focused on oil refining and energy production[17]. In recent years, the park has begun to address sustainability and environmental technology, specifically Carbon capture and storage. In figure 4.2, the industrial site is shown with areas marked explaining the park's layout. The blue and green areas are all managed by Equinor, which runs the refinery. The blue marks the area mainly reserved for activities relating to the distribution of the oil riggers. The orange area shows all other industries in the park.

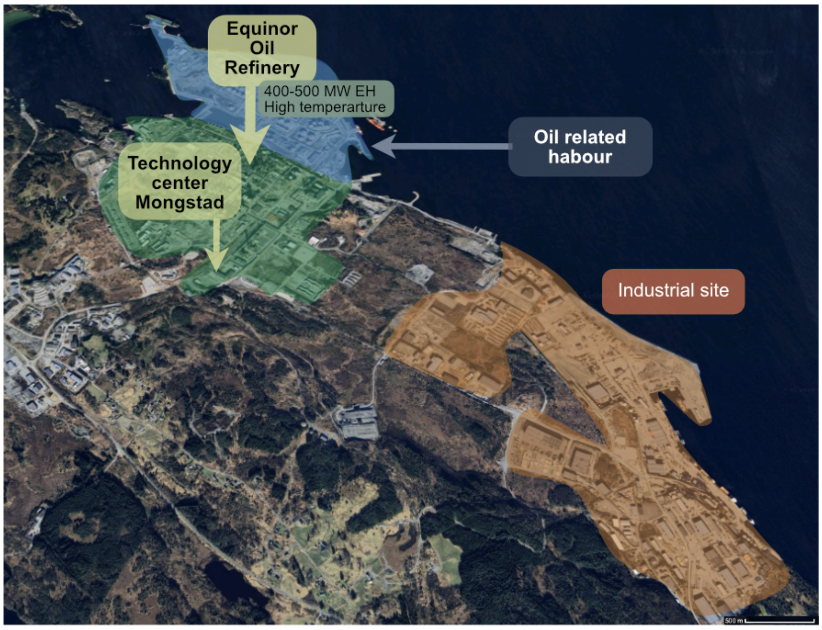

Figure 4.2: The image shows the placement of the industries. The park stretches approximately 5km. The map is taken from Google Maps, and modified to fit report

4.2.2 Power interest matrix

When conducting this analysis, all companies listed on the official Mongstad Industrial Park (MIP) website [59] were thoroughly researched to understand their operations within the facility. The focus was identifying to which degree they would need to be involved to ensure implementation. Therefore, the placement criteria rely mainly on whether the absence of their involvement would make the implementation impossible(power) and if they have an explicit reason for interest in the implementation(interest).

Considering the diverse range of industries represented at MIP, a preliminary categorisation was necessary to classify companies based on the nature of their operations at the site. This approach provides a clear structure, helping to identify the most relevant stakeholders for excess heat utilisation and to clarify their placement in the power-interest matrix. It is important to acknowledge that certain companies could reasonably belong to more than one category due to the broad scope of their services. In such instances, they have been assigned to the group most aligned with the goals of excess heat utilisation, ensuring that the analysis remains focused on the most relevant aspects of their operations. Additionally, given the large number of companies, it should also be noted that not all are directly relevant to the transition towards excess heat utilisation. These could have been placed in "low power / low interest" but do not drown out more relevant placements; they have been omitted from this figure. All company's operation is, however, listed in appendix A, where their operations are also briefly explained.

Table 4.2: Categorisation of Companies in Mongstad Industrial Park

Group	Description	Companies
Group 1: Energy Companies	Energy producers	Equinor [60]
Group 2: Companies Supporting Energy Company operation	Service providers and contractors offering specialised support to energy companies.	Aibel [61], Bilfinger, Flowserve [62], PSW Group AS[63], Halliburton, Schlumberger [64], NOV Tuboscope [65], WellConnection [66], West Piping AS [67]
Group 3: Data Centres and Technology Facilities	Companies operating data centres or technology facilities.	TCM [68]
Group 4: Industrial Building and Real Estate Companies	Companies involved in industrial infrastructure, building, and real estate within Mongstad.	Asset Buyout Partners [69]
Group 5: Waste and Environmental Services	Waste management, recycling, and environmental companies.	SAR [70]

In Figure 4.3, the placement of the stakeholders regarding the implementation of industrial excess heat utilisation technologies at Mongstad Industrial Park (MIP) is shown. In each square, the focus types are written out for easier overview.

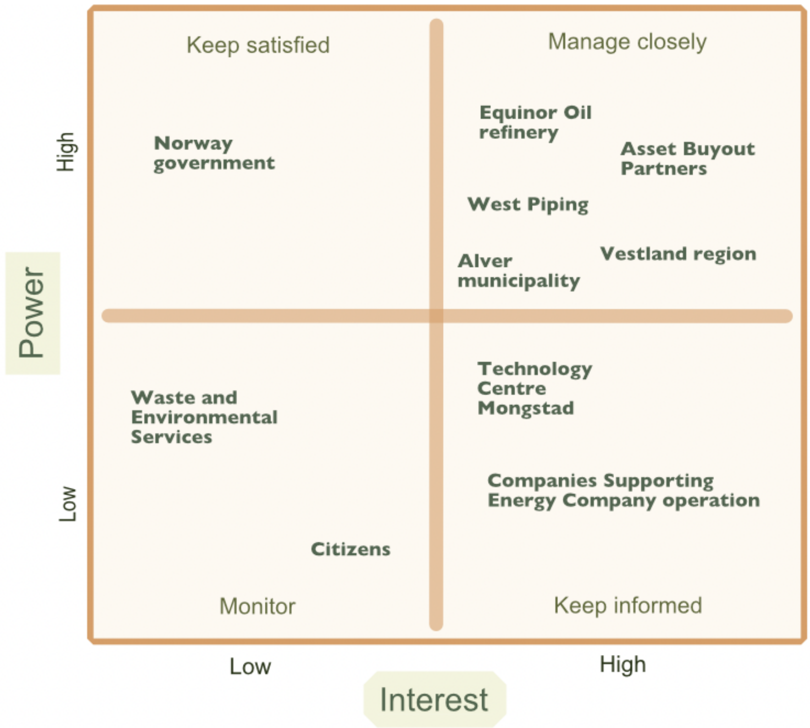

Figure 4.3: Figure showing the placement of different stakeholders in power interest matrix

High Power / High Interest

Equinor operates the main oil refinery at MIP, which plays a key role in the industrial park. The Mongstad refinery processes about 12 million tonnes of crude oil per year and converts this to various fuels [60]. Oil refineries generate large amounts of excess heat during their operations. Therefore, Equinor is one of the main stakeholders that could be providing excess heat for reuse.
Many companies at MIP support Equinor's operations, meaning their relevance depends on working closely with the refinery. This close connection gives Equinor a lot of power when it comes to decisions about changes in the system. Equinor is in the high power/high interest quadrant in the matrix. Its influence comes from its role as a major heat provider and its central role in the park's activities. Additionally, Equinor should be intensely interested in energy efficiency, as using excess heat could save costs, help meet regulations, and improve its sustainability profile.

West Piping is a service company that caters to technology related to the oil industry

both on and off-shore [71]. It is the only company from group two to be singled out and considered individually. They differ from the rest of their group by also having a manufacturing site at Mongstad. While the rest of the companies in group two mainly perform their services at Equinor's location, West Piping also produces some of their solutions at their workshop at Mongstad. As metal treatment and coating are heat- and energy-intensive processes, they are considered a potential off-taker of excess heat and are therefore placed in the high-power category. Their strong interest is assumed from the fact that obtaining energy from excess heat would reduce their emissions as a company.
Asset Buyout Partners is responsible for most of the buildings in MIP. Because they control the facilities, they can decide whether or not new technologies, like those for excess heat, can be implemented.. Their company aims to support sustainability by improving energy efficiency and promoting circular use of resources[69], which places them in both the high power and high-interest category for this kind of transition.

Alver Municipality, like all municipalities, is required to track its carbon footprint and is very interested in reducing emissions and improving efficiency. The municipality also has considerable power to enforce or promote transitions by supporting new technologies.

Similarly, **Vestland Region** has a strong interest in lowering emissions and energy use, and its sustainability plan explicitly mentions the use of excess heat[16]. Other industrial parks within the region have already started implementing some excess heat technologies, further underlining the region's interest. The region also has significant power through regulations and policies, placing them in the high-power/high-interest quadrant.

High Power / Low Interest

The **Norwegian Government** is placed in the matrix's high power/low-interest field. While the government may have some interest in implementing excess heat technologies at MIP on account of the national climate plan promoting industrial circularity and supporting carbon capture technologies at Technology Centre Mongstad (TCM), there is no direct mention of industrial waste heat utilisation. Therefore, the government's interest is regarded as low. It still holds high power as it could enforce excess heat utilisation in future legislation.

Low Power / High Interest

Technology Centre Mongstad (TCM), despite being owned by Equinor [72], it will be considered a separate stakeholder due to its activities being focused on carbon capture and storage (CCS). As a leader in CCS, TCM is likely to be highly interested in sustainability efforts. Excess heat would benefit them in the future, as CCS technologies produce large amounts of heat during compression. However, TCM does not have direct control over the broader implementation of excess heat technologies, so it holds low power in this context.

This analysis considers the companies listed under the group **Companies Supporting Energy Operations** at MIP as a collective. This is due to their similar position regarding power or interest. Based on where precisely the excess heat would be used would mean the ones directly affected would change position. These companies are interested in excess heat utilisation because it could affect maintenance services and costs and potentially lead to lower energy prices. However, they do not individually have the power to push for or block the use of this technology. As such, they fall into the low-power/high-interest category.

Low Power / Low Interest

Waste and Environmental Services Companies form another group of stakeholders. Similar to the previous group, they have little influence over implementing excess heat utilisation. Their operations are unlikely to change significantly if the technology is adopted, so they are not expected to have much interest. As a result, they are placed in the low power/low interest section. They are mentioned here even while other groups were disregarded due to the potential of their interest and power shifting depending on the type of utilisation technology that might be implemented.
Finally, **Local Residents** near MIP have no direct influence on the decision-making process and are not expected to have much interest in the technology unless it results in lower heating costs through district heating. The implementation of excess heat technologies is not likely to cause any disturbance to the community. Thus, the local population is also considered to have low power and low interest in this case.

4.2.3 Findings

Write a summary here

4.3 Technical assessment and potential impact

This section attempts to clarify the energy potential of the excess heat found in the oil refinery. it does so by putting the energy amount found as excess heat into perspective of the potential savings it can help elevate.

4.4 Potential Utilisation of Refinery Excess Heat

The Equinor Mongstad refinery, located in rural Norway, consistently generates between 400 MW and 500 MW of excess high-temperature heat[73], which is a substantial and continuously unutilised energy resource. In a typical oil refinery, excess heat is generated at several different places in the refining processes, including distillation columns, heat exchangers, and cooling water systems[18]. These processes operate at high temperatures, creating significant opportunities for heat recovery and repurposing. While the specific details of which processes have the highest surplus at the Mongstad refinery, EH can be assumed to be produced in alignment with the common heat sources found in other refineries.

The multiple places that generate EH leads to substantial opportunities for capturing the thermal energy and repurposing it. The continuous generation of this excess heat indicates that over a year, there is an available energy resource that ranges from 3.5 TWh to 4.4 TWh, calculated by multiplying the excess heat power output by the total hours of operation in a year.

To put these numbers into something more tangible two calculation will be done. one that gives a rough estimate of the heat demand this would be applied to cover in the park, and one that looks at converting the thermal energy to mechanical energy and the impact of this.

4.4.1 Annual Excess Heat Energy

The annual excess heat energy (E_{total}) can be determined as follows:

$$E_{\text{total}} = P_{\text{excess}} \times t_{\text{year}}, \tag{4.1}$$

where P_{excess} is the excess heat power output, and t_{year} is the total number of hours in a year (8760 hours). This results in the following maximum and minimum energy amount available over the course of a year:

$$E_{\text{min}} = 400\,\text{MW} \times 8760\,\text{h} = 3{,}504{,}000\,\text{MWh/year}, \tag{4.2}$$

$$E_{\text{max}} = 500\,\text{MW} \times 8760\,\text{h} = 4{,}380{,}000\,\text{MWh/year}. \tag{4.3}$$

Given that the most effective way to use energy is often to keep it in its original form, using this thermal energy directly for heating purposes would be optimal. To assess the impact of using this energy directly, it is taken into cosideration that Mongstad is a rural area without significant nearby residential areas. Therefore, the impact is evaluated in terms of how many office buildings this could potentially supply with central heating.

4.4.2 Potential Direct Use for Heating

The energy output from the refinery's excess heat could be used for district heating, but due to the rural location and the absence of an existing district heating system, it would need significant infrastructure investments to make it viable. The number of office buildings it could heat is calculated to put this thermal energy use into a more tangible number. Assuming an average annual heating requirement of 200.000 kWh per office building, we can estimate:

Minimum Number of Office Buildings

$$N_{\text{offices,min}} = \frac{E_{\text{min}}}{E_{\text{office}}} = \frac{3{,}504{,}000{,}000\,\text{kWh/year}}{200{,}000\,\text{kWh/office/year}} = 17{,}520\,\text{office buildings}. \tag{4.4}$$

Maximum Number of Office Buildings

$$N_{\text{offices,max}} = \frac{E_{\text{max}}}{E_{\text{office}}} = \frac{4{,}380{,}000{,}000\,\text{kWh/year}}{200{,}000\,\text{kWh/office/year}} = 21{,}900\,\text{office buildings}. \tag{4.5}$$

These calculations show that the excess heat from the refinery could theoretically provide heating for between 17,520 and 21,900 office buildings per year. In figure 4.4, the office or otherwise industrial buildings that might need heating are marked. Seventy locations are assumed to need heating. This was estimated based on satellite photos of the area. The energy supply in the form of heat available is of magnitudes higher than the need. It is assumed that thermal storage units will be implemented to create a more flexible system. However, the heat supply compared to the demand is so significantly higher that it could be assumed a lot of the energy would be wasted. If a local heat distribution grid were to be established, losses in the distribution are expected; however, due to the vast amount of available energy, it would still not be a problem to support the area.

Figure 4.4: Figure showing the placement of office or industrial buildings that need heating. The red dots indicate a building expected to need heating. Map from Google Maps.

Central heating of offices is, of course, not the only way the heat could be used however, as identified in section 4.2.2, the only company with on-site manufacturing is West Piping, and while their exact need for energy has not been available, it is assumed that this large amount of heat would not be needed for their operation.

4.4.3 Conversion to Mechanical Energy

Considering the rural location of the Mongstad refinery and the absence of a district heating network, another potential application of the excess heat is to convert it into mechanical energy, which can then be used to power the different businesses in the area. As the available EH is high-temperature, the conversion process would involve using technologies like steam turbines, Organic Rankine Cycle (ORC) systems, or waste heat recovery boilers as introduced in section 4.1.2. For high-temperature excess heat, typical steam turbine conversion efficiencies range between 65% and 70% [74]. Using an efficiency of 65% as a lowest case value, the electrical energy produced would be:

$$E_{\text{electricity}} = 0.65 \cdot 450\text{MW} = 2,925,000\text{MW} \cdot 8760h = 2,562,300\text{MWh/y} \tag{4.6}$$

This is a substantial amount of energy. To make it more case-relevant, an industrial park case is calculated. Industrial parks can differ in nature, and therefore, energy consumption amount. Given the low amount of manufacturing happening and a focus on maintenance, it is assumed that the energy consumption is comparable with the case of an industrial office site. Here it is stated the annual energy consumption for an industrial park spanning 200,000sqm is 12.000.404kWh[75]. Mongstad zoned area is 2.677.000 sqm [76], so the energy consumption is scaled to fit this.
First the scaling factor is found by use of the areas:

$$Scale = \frac{2,677,000\text{sqm}}{220,000\text{sqm}} \approx 12 \tag{4.7}$$

Then the approximated anual energy consumption can be determined

$$12 \cdot 12,000,404\text{MWh/y} = 146,023,098\text{MWh/y} \tag{4.8}$$

Lastly to see how much this covers, the total energy is divided by the supplied energy from the excess heat:

$$\frac{146,023,098\text{MWh/y}}{2,562,300\text{MWh/y}} \approx 57 \tag{4.9}$$

This shows that by converting the thermal energy into electrical energy the assumed demand could be covered approximately 57 times over. Even with a loss of conversion, the surplus heat is still sufficient to cover the energy demand. The scale of electricity generation makes it a viable option for supporting industrial activities. The implementation would require some retrofitting to send the electricity into the local energy grid. It should be mentioned that these are evidently simple calculations, and should be regarded with insecurities.

4.4.4 Benefits and Challenges of Different Technologies

The main benefit of converting the thermal energy into mechanical energy is that it could be used by the various businesses in the industrial park, such as *West piping*. These businesses require a reliable and consistent electricity supply, which could be met through the

refinery's waste heat. Using steam turbines for high-temperature heat is ideal because of their relatively high efficiency at converting thermal to mechanical energy.
Alternatively, an Organic Rankine Cycle system could be used, which is more suitable for lower temperature heat, but this would result in a lower conversion efficiency (typically around 10% to 25%) and would therefore produce significantly less electricity. Waste heat recovery boilers could also be employed.

Consideration of Energy Losses The energy losses inherent in converting from thermal heat to mechanical heat should be noted. Direct use of the excess heat for heating would retain a much higher proportion of the original thermal energy (typically up to 90% efficiency). In contrast, converting this thermal energy to mechanical energy using Waste heat recovery boilers results in significant losses, with conversion efficiencies reaching up to 65% in ideal circumstances. This means that more than half of the energy would be lost as low-grade waste heat, reducing the overall energy efficiency significantly.

4.4.5 Summary

In summary, while using the excess heat directly for district heating would be the most efficient energy conservation option, the rural setting of Mongstad and the lack of an existing district heating network make this approach challenging. Converting the heat to mechanical energy and then using it locally presents a viable alternative, though it involves considerable energy loss during conversion. Given that the industrial park has only one company with significant manufacturing (West Piping), investing in steam turbines for electricity generation may be the most effective solution for utilising the high-temperature excess heat in this specific context.

Scenario	**Technology**	**Efficiency**	**Application**
Heating	District Heating	80% - 90%	Office or Industrial Heating
Electricity Generation	Waste Heat Recovery Boilers	65% - 70% [74]	Local Power Supply
Electricity Generation	ORC	7% - 16% [77]	Moderate Temp Power

Table 4.3: Comparison of utilisation scenarios for excess heat at Mongstad refinery

Chapter 5

Discussion & reflections

Presented with a wide variety of information throughout this report, how the results relates and helps inform the case as a hole is presented in the following discussion.

5.1 Ambitions and Industrial Context

Norway has set ambitious goals to achieve carbon neutrality by 2030, which necessitates a cohesive national effort involving adopting novel technologies, system optimisation, and implementing carbon offset mechanisms for sectors that have not yet reached carbon neutrality. The industrial sector, the largest contributor to Norway's carbon emissions, demands particular focus. In Vestland County, where there is a significant concentration of heavy industry, achieving these goals poses a substantial challenge. The region's roadmap highlights seven strategic focus areas designed to overcome these challenges, emphasising the need for technological advancement and strategic planning to reduce emissions.
It is evident from the literature review that the Mongstad site, home to Norway's most advanced carbon capture and storage (CCS) facility, has monopolised the focus of both political initiatives and academic discourse. While CCS is crucial in achieving emission reductions, limited attention has been given to optimising existing facilities beyond CCS. When conducting a literature review using keywords such as "Mongstad" and "circularity," only two articles explicitly addressed circularity within the Mongstad site. The broader search, including just "Mongstad," yielded over 200 articles, yet only two focused on improving resource efficiency through circularity, despite both suggesting that there are emissions and cost savings to be gained by such initiatives. Moreover, one of these studies dates back to 2009, before significant developments at the site, including changes

to its industrial composition. This highlights a lack of a system savings approach and underscores the need to also focus on improving energy efficiency measures and reducing emissions at their source rather than relying solely on mitigation strategies.
While engaging the stakeholders with both high power and interest is essential to realise this project, another stakeholder, such as TCM, should be utilised. While they might not hold the power for implementation collaboration could prove beneficial. Due to their work on emission mitigation, energy efficiency measures could perhaps be implemented into their systems, and when a CCS site is built, it would have the potential to mitigate emissions even further for a refinery case. Should utilisation of the excess heat be successful, knowledge sharing about best energy efficiency measures through EH utilisation could be broadened to cases such as ASTRON Refinery in South Africa, the largest single-point emitter globally.

5.1.1 The Role of Government and Industry Stakeholders

Three key Norwegian government entities are identified as drivers of change in emission reductions and industrial efficiency. Yet, there is no explicit requirement or policy focused on reducing industrial excess heat. While Equinor and the Norwegian government have invested in CCS infrastructure at Mongstad, the focus has remained mainly on direct emissions reduction, overlooking the broader potential for energy efficiency initiatives that could enhance the energy system's resilience. In a context where the electrification of industrial operations is increasing, these energy efficiency measures are essential for environmental sustainability and securing a resilient energy supply in the face of growing demands.
The region and municipality should also be more engaged in the case of energy efficiency measurements. While they both have circularity goals in their action plans, further rigour and specification of the use of excess heat from industries are needed to ensure as high energy efficiency and as low emissions as possible. this is especially true in the case of the region as it houses multiple large industrial sites. by promoting industrial ecology they can create ground for knowledge sharing of these practises and the implementation of them. In both cases presented in this report, either for heating or converted to energy, the municipality should help foster these practises and aid in the establishment of needed grids to funnel the surplus. As key stakeholders they should employ planning engineers to help guide a successful transition into a more circular industrial site.
The increasing energy demand, both globally and in Norway, partly due to widespread

electrification, makes implementing all possible energy-saving measures imperative. The current presence of a Combined Heat and Power (CHP) plant, which has been decommissioned and will eventually be shut down, indicates that the site may currently have sufficient heat and energy. However, it is important to note that this decision appears to be primarily financially driven, rather than one made considering energy efficiency or long-term resilience. The decommissioning process has been ongoing since 2018 without reaching completion further suggests that this decision was not solely based on efficiency assessments.

5.1.2 Opportunities for District Heating and Potential Collaboration

A critical finding of this study is the permission granted by the Norwegian Water Resources and Energy Directorate (NVE) to ABP Fjernvarme to establish a district heating network within Mongstad Industrial Park[73]. This document, available only in Norwegian, was overlooked during the research due to the limitations of the language barrier and the lack of academic or public reporting highlighting the development. Nevertheless, the permission granted by NVE validates the feasibility of using surplus heat from the refinery, as identified by this research. The district heating network's focus was likely limited to evaluating the viability of heat for residential or commercial purposes, whereas this study expanded on a broader set of possibilities, including power conversion, to maximise the utility of the excess heat. it should be noted though that the calculations presented in this study was updated to incorporate the findings of the energy amounts and high temperature of the excess heat.
While a district heating network is an important step towards energy efficiency, it may not represent the optimal use of the excess heat available at Mongstad. The decommissioning of the CHP plant, reportedly due to a lack of demand for the generated power, further raises questions regarding the best utilisation of this energy resource. Thus, it is essential to consider other high-value applications of the surplus heat.

5.1.3 Insights into Excess Heat Utilisation at Mongstad and Beyond

The results of the technical analysis indicate that the available thermal energy can be most efficiently used in its current high-temperature state. Yet, there seems to be insufficient demand to utilise this heat within the site. Conversion of the heat to mechanical energy for electricity generation could be a more versatile application, especially if integrated with the local energy grid. Although this would require considerable investment, including

implementing private distribution networks, transformers, and inverters, it could provide a valuable energy source for the grid, contributing to the broader electrification efforts. A cost-benefit analysis would be required to determine the economic viability of such an approach, both for Equinor and for the local energy infrastructure.
Establishing direct contact with the various companies and municipal authorities involved in Mongstad would also provide a clearer understanding of the actual energy and heat requirements, as well as the stakeholders' interest in implementing changes. Unfortunately, due to the limitations of this study, this information was not fully accessible. Nevertheless, engaging with these stakeholders could uncover significant opportunities for collaboration, and provide a more informed recommendation to the use of the excess heat.

5.1.4 Challenges when carrying out the study

During the industrial park survey, the oil refinery's presence and operation were obvious. In contrast, verifying the operations and type of presence of the other industries and companies presumably located within the park proved considerably more challenging. A significant portion of the time allocated for this study was therefore devoted to confirming the physical presence of all the listed industries. Complicating this task was the fact that, despite being listed on the official MIP website, not all companies disclosed their presence in the park on their sites. This inconsistency applied to Bilfinger, Halliburton, and Baker Hughes. Furthermore, for nearly all the companies classified under the group "Companies Supporting Energy Company Operations," even those asserting their presence in the park, determining the nature of their involvement proved difficult. Many of these companies are large international firms that offer a diverse array of services and solutions so their operation at MIP was not obvious.
Given that many of the companies provide maintenance, it is presumed that much of this activity occurred solely at the refinery rather than at their locations. Additionally, as no actual manufacturing activities could be confirmed at MIP as such, the estimation of the energy, and heating demands typically associated with such companies is based on the assumption that it is comparable with another case in which total energy demand was disclosed. Therefore, the results bear considerable uncertainty regarding the potential need for heat and energy. Consequently, the next level of analysis should focus on establishing the energy, heating and cooling demands of all industries to ascertain the most beneficial applications of the excess heat energy. This should be done through contact with each of the firms. First, establishing contact with the stakeholders found in the high power / high

interest would be beneficial. *Asset Bouyout Partner* would be able to provide energy and heat data for all the companies as they are the building managers of the entire industrial park. Early contact with them would also mean a discussion on their support for implementing the necessary technologies required for the building to be recipients of heat and power. When this data is provided, a better estimation of the potential benefits in energy savings could be carried out before engaging the rest of the stakeholders.
This type of strategic energy planning, coupled with the capacity-building perspective outlined by Van der Steen (2018) [78], would facilitate adaptive planning and preparedness for unforeseen challenges, such as policy changes or restrictions on the release of heat to the environment.

5.1.5 Recomendations

Concluding this study a cautious recommendation would be to consider the energy scenario the most beneficial to ensure energy use, however this should be regarded with a considerable amount of uncertainty. Perhaps a hybrid scenario where the needed thermal energy is sent into a local heating grid and the rest is converted to energy supply would be the optimal solution. However this would require more installation of technology and costs for the involved stakeholder whom does not have heat and energy supply as their core business.

5.2 Methodological Reflections

In conducting this research, a range of methods could have been employed to achieve a more comprehensive understanding of excess heat utilisation at Mongstad. Had there been closer collaboration with Equinor, the focus of this study would likely have shifted towards a techno-economic analysis, thereby evaluating the potential business case for investment in energy efficiency measures. Such an approach would have provided greater insight into the economic feasibility and profitability of the proposed solutions.
The literature review also presents certain limitations regarding the terminology used to search for relevant studies. While this report mainly focused on excess heat, it became evident that the term is variably referred to as "waste heat" or "surplus heat" in academic literature. The latter term was inadvertently overlooked, resulting in a narrower scope of the literature review. given more time future studies would benefit from a broader approach to terminology, ensuring a more comprehensive understanding of existing research

on the topic.
A larger focus on establishing contact with the relevant stakeholders would have strengthened several parts of this report. It would have given more insight into the synergies at place at the industrial site as well as concrete data on the demand of the local industry.
had the study spanned longer it would have been beneficial to establish a large cost benefit analysis of all possible scenarios. This should also expand to cooling and societal benefits to make a full feasibility study. Further a collaboration with TCM would have been interesting to examine the combination of industrial ecology principles along with their CCS facilities.
Furthermore, not only looking at heat exchange and utilisation, more symbiotic relationships could be explored in depth.
The strength of this study would also be tightened by completing a comprehensive cost-benefit analysis to strengthen the feasibility of the study and to present tangible implementations and long-term savings to the relevant stakeholders.

5.2.1 Data Limitations

It is worth noting that certain operations at Mongstad may already use some of their own excess heat, although no information was made available on this matter. Therefore, this study was conducted on the assumption that limited excess heat recovery was taking place, which may have led to an incomplete understanding of the site's existing practices. Additionally, there appears to be a lack of advanced planning simulation tools available that are specifically designed for the benefits of industrial excess heat utilisation.

5.3 Reflections

when considering this case from a broader perspective, with the background of knowing other cases of industrial symbiosis, it can perhaps be discussed to what degree this study can be considered symbiotic relationships. As this study's time and resource constraints meant only delving into excess heat as recirculation, can it still be considered industrial symbiosis? When conducting the literature review, no lower limit of what is considered industrial symbiosis is established. While the refinery is simply providing a resource it is still a waste product from their core operation, and implementation would require investment and collaboration. As it stands, with no lower limit of what is symbiotic relationships in industries, implementation of excess heat recovery for use in other local industries will

be considered a form of industrial ecology, albeit maybe a lower one.
It is undeniable that the world is still dependent on fossil fuels, but the irony of trying to heighten the sustainability of a oil refinery has not escaped the author. The study was not conducted as a way of lowering Equinors emissions, however the culmination of the found information remains based around energy reduction for them. While the world is still dependent on the fossil fuels, creating the least energy intense scenario is still imperative to the sustainable transition.

Chapter 6

Conclusion

The central research question guiding this study was: *What opportunities exist for the optimal utilisation of excess heat at Mongstad Industrial Park employing industrial ecology principles, considering stakeholder engagement, technological options, and political barriers?*
Mongstad Industrial Park offers a challenging and somewhat unique case for applying industrial ecology principles. The presence of an oil refinery, coupled with industries with activities mainly aiding its operation, has not often been explored with the goal of applying industrial ecology principles.
To better understand this case, technologies, stakeholders, and policy landscape have explored the possibility of creating circular pathways through excess heat utilisation.

On a global scale, there is a push for establishing industrial ecology practices that promote optimised resource usage and reduced consumption, as explored in the literature review. This is evident in the introduction of policy frameworks aimed at promoting circularity and energy efficiency. However, there is a notable vagueness in these policy efforts, specifically concerning industrial excess heat.

While Mongstad is home to a significant source of excess thermal energy, the specific demands of various local stakeholders and industries remain uncertain. This uncertainty is furthered by the site's rural location, which limits the potential for integration into larger systems such as district heating. Therefore, The optimal strategy for using excess heat at Mongstad must consider both technical efficiency and practical feasibility. From a technological standpoint, retaining the energy in its heat state represents the most efficient pathway. However, an alternative approach is proposed, given the mismatch between the high quantity of high-temperature heat available and other businesses' relatively modest demand for industrial heating. Utilising a waste heat recovery boiler to convert this thermal energy into electricity may be the solution that wastes the least amount of energy.

In conclusion, this study has sought to identify potential methods for utilising excess heat at Mongstad while addressing the various technological, organisational, and policy-related challenges. Key stakeholders at Mongstad, including Equinor, Asset Buyout Partner, and local authorities, must be engaged to determine the specific energy requirements and ensure successful implementation. Although several promising opportunities for excess heat utilisation have been identified, realising these opportunities will require further investigation through comprehensive stakeholder engagement, a robust cost-benefit assessment, and detailed strategic planning surrounding cost and technology implementation.

Mongstad shows great potential for energy efficiency through the utilisation of the oil refineries excess heat. Two preliminary industrial ecology opportunities are presented but can only be realised through the collaboration of present stakeholders, considering their power and interest. Furthermore, the correct constellation of technologies must be employed based on the still uncertain demand of the industrial park. It will necessitate a concerted effort involving various stakeholders, enhanced data transparency, and a shift in policy focus to ensure the optimal use of available resources. By leveraging industrial ecology principles, Mongstad could exemplify how efficient energy use contributes to local sustainability and broader climate goals.

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Appendix A

Table A.1: Categorisation of Companies in Mongstad Industrial Park

Group	Description	Companies
Group 1: Energy Companies	Energy producers	Equinor, Aibel
Group 2: Companies Supporting Energy Companies	Service providers and contractors offering specialised support to energy companies.	Baker Hughes, Bilfinger, Flowserve, PSW Group AS, Caverion AS, Halliburton, Schlumberger, NOV Tuboscope, WellConnection, West Piping AS
Group 3: Data Centres and Technology Facilities	Companies operating data centres or technology facilities.	TCM
Group 4: Industrial Building and Real Estate Companies	Companies involved in industrial infrastructure, building, and real estate within Mongstad.	Asset Buyout Partners
Group 5: Waste and Environmental Services	Waste management, recycling, and environmental companies.	Norsk Gjenvinning, SAR
Group 6: Equipment and Material Suppliers	Suppliers of industrial equipment, tools, and materials for operations and maintenance.	TESS, Tools
Group 7: Health, Safety, and Environmental Services	Companies providing HSE services.	Salutis HMS, Hoover Ferguson
Group 8: Companies in the Chemical Sector	Companies specialising in chemical distribution and services.	Brenntag
Group 9: Logistics and Recruitment Operations	Companies providing logistics, transportation, and recruitment services.	Swire Oilfield Services, Bring (Posten Norge), Grieg Logistics, Ocean Recruitment and Competence, Wilhelmsen
Group 10: Software Provider Companies	Companies providing software solutions and IT services.	COSOL, Compute
Group 11: Core Operations Off-Site	Companies whose primary operations are conducted off-site.	Stena Drilling, Kystverket (Norwegian Coastal Administration), Modex, Deep Sea Mooring, Transocean

Appendix B

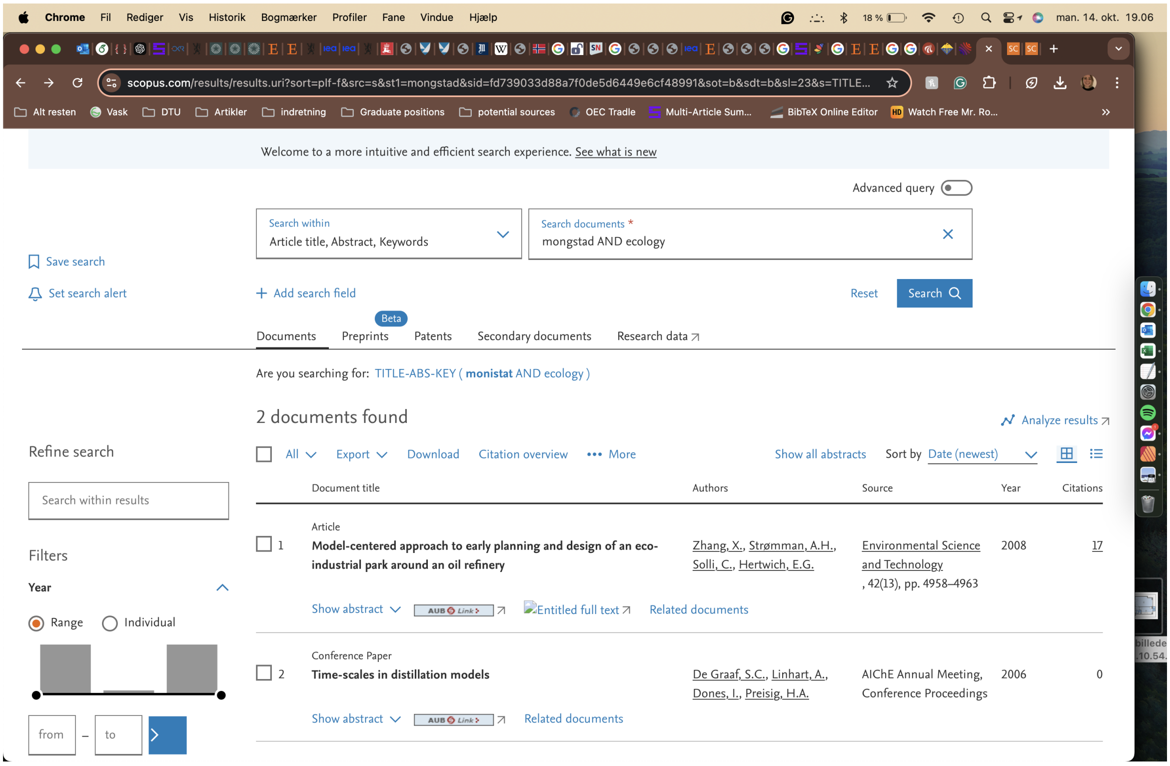

Figure B.1: An example figure demonstrating how to insert an image in LaTeX.