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Energy Flexibility in the Chemical Industry

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Energy Flexibility in the Chemical Industry

by

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Executive Summary

The electrification of the production processes in the chemical industry is seen as a promising option to reduce its greenhouse gas emissions. This would result in a significant increase in the demand for electrical energy. The supply of electricity is becoming more fluctuating due to the variable nature of solar and wind energy. To ensure the stability of the grid, the consumption of electricity needs to equal the supply. Additionally, many countries are dealing with grid congestion, which means that there is insufficient transmission capacity for all consumers who want to receive power. One potential solution to these challenges is industrial demand response whereby companies adjust their electricity consumption to the available supply. The chemical industry might be able to provide this demand response through flexible operations of its production processes.

The goal of this research was to investigate whether companies have concrete plans to engage in energy flexibility with their production processes, and to determine the priority level they assign to it. This included examining how widely energy flexibility is incorporated into companies' ten-year roadmaps, identifying the obstacles to electrification in the chemical industry, and understanding the challenges of operating chemical production flexibly.

To answer these questions, interviews were conducted with participants who work at chemical companies in the Netherlands. The participants were recruited by compiling a list of all chemical companies in the Netherlands and using LinkedIn to approach suitable candidates within each company with a request for an interview. Those participants who responded positively were interviewed using a semi-structured interview methodology in interviews lasting 30-45 minutes. The interviews were processed into anonymous summaries which were then used to answer the research questions.

Participants from twelve different companies were interviewed, representing approximately a quarter of all companies active in the Dutch chemical industry. These companies are active in a mix of sub-sectors of the chemical industry. A possible response bias should be noted, as companies already engaged in electrification and energy flexibility may be over-represented among these twelve companies compared to the chemical industry as a whole. Moreover, as only one participants was interviewed per company, there is a significant chance of personal bias affecting the results.

The results showed that flexible energy use was included in half of the twelve interviewed companies. However, it was a priority for only two companies. For the remaining four companies, flexible energy use was a side benefit of using both natural gas as well as electricity as a source for process heat in the transition to fully electrified process heat generation. Although four more companies had tentative plans for flexibility, they did not expect these to be feasible within the next ten years.

The results also showed that for eight out of twelve companies, lack of sufficient grid capacity was a crucial obstacle to electrification. However, only two of those companies indicated that they would be willing to consider operating their process flexibly in return for accelerated access to the desired grid capacity. The benefits of quicker access to the grid do not outweigh the obstacles to operating flexibly for most companies. The most important obstacles were related to the high investment cost of chemical plants in the chemical industry. At this juncture, the financial benefits of demand response do not outweigh the increased investments costs needed to make flexibility possible for most companies.

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1 Introduction

1.1 Background

The amount of Green House Gases (GHG) emitted into the atmosphere needs to be reduced to limit their impact on climate change (H.-O. Pörtner et al., 2023). Significant developments are still needed to meet the goal of net zero GHG emissions by 2050 (Lu et al., 2022). To reach this goal, all sectors will need to reduce their emissions. The chemical sector is currently responsible for 10% of GHG emissions worldwide and is therefore a significant contributor and as such called upon to reduce its emissions (Bauer et al., 2023).

Reducing greenhouse gases in the chemical industry is challenging. The multitude of different and interconnecting chemical processes means that there is no single solution for making them carbon emission free (Chung et al., 2023). One of the potential solutions to this challenge is the electrification of chemical processes (Mallapragada et al., 2023). Here the energy which was previously provided by fossil fuel feedstocks to generate the heat required for a process is replaced by electrical energy. This will therefore result in a significant increase in the demand for electrical energy by the chemical industry. An estimate of the required electricity demand to ensure a 84% reduction of CO_2 emissions in 2050 concluded that the European chemical industry would require 135% of the expected available renewable energy in Europe that year (Alexis Michael Bazzanella & Ausfelder, 2017).

To reach the GHG emission reduction goals, industrial sectors which currently use fossil feedstocks will need to switch to alternative energy sources such as renewable electricity (Chung et al., 2023). To reach net zero emissions, the sources of this electricity will need to be generated by renewable energy sources such as wind and solar. However, renewable energy sources such as these are inherently variable. To guarantee a stable electrical grid, the input and output of that grid must be balanced (Pierri et al., 2021). As the input into the grid will be increasingly variable, more options will be required to match this with a similarly responsive uptake on the demand side of the grid (TenneT, 2023a).

An additional challenge that comes with the increasing demand for electricity by both industry and consumers is the issue of grid congestion (Mishra & Samal, 2023). In addition to the need to be balanced, the electricity flowing through any part of the network is limited by the capacity of that connection. Even if there is more power available and a consumer would like to use it, they will not be able to make use of this opportunity if the grid connection between the two is already at its maximum rated capacity.

This is an obstacle which a number of European countries are facing (Göransson et al., 2014). In the Netherlands, the grid congestion issues have become so dire that there is a waiting list of several years of companies waiting for a connection to the grid (Netbeheer Nederland, 2022). This forms an obstacle for companies in the process of electrifying and therefore limits their ability to reduce their GHG emissions. It is important to note that the maximum capacity of the electrical grids is only reached during certain peak periods (Autoriteit Consument en Markt, 2022). However, as the grid operator needs to ensure that the maximum grid capacity is not exceeded, the capacity during the peak periods is the limiting factor in allowing new companies on the grid.

A potential solution to both the variable nature of renewable energy sources, as well as the issue of grid congestion, is industrial flexibility through demand response (Heffron et al., 2020).

The principle behind industrial flexibility is that an industrial consumer will either increase or decrease their electricity consumption depending on the availability of electricity and grid capacity. This flexibility can either take the form of direct demand response whereby a company receives money from the grid operator in exchange for providing flexibility, plus compensation in case that flexibility is called upon, or indirect demand response whereby companies adapt their electricity demand based on the spot price of electricity price on the market (Baltputnis et al., 2019).

Although industrial flexibility has only been implemented on a limited scale in the chemical industry, companies are starting to explore its potential, as exemplified by a white paper exploring the flex potential of several companies written by *TKI Energie en Industrie* (TKI Energie & Industrie, 2022). This initiative consisted of a collaboration between various companies in the Dutch industrial sector, among which a number of chemical companies. Operating a process flexibly clashes with the traditional operating model in the chemical industry, and many companies have been hesitant to give it serious attention. However, the government of the Netherlands has indicated that it wants to strongly promote flexibility to combat grid congestion, with the possibility of making it mandatory if non-obligatory measures are not enough (Directoraat-generaal Klimaat en Energie, 2023).

For the chemical industry, this flexibility is a challenge (TKI Energie & Industrie, 2022). Most companies in the chemical industry operate continuously at maximum capacity (Seifert et al., 2014). Controlling the quality of a steady state process is easier than a process whereby intensity is constantly changing (Lashmar et al., 2022). Moreover, providing flexibility will result in unused production capacity, while the investments necessary for that capacity remain the same (Bieringer et al., 2013). However, with the need the reduce carbon emissions, it might be necessary for chemical companies to change their way of operating by embracing flexibility.

1.2 Practical Problem

This leads to the following practical problem. Although the use of flexibility is a hot topic in the relevant scientific literature (Howard et al., 2021; Santecchia et al., 2022; Xu et al., 2021), and among grid operators (Bundesnetzagentur, 2017; ENTSO-E Vision, 2022; TenneT & VEMW, 2021), it is unclear whether chemical companies agree on the potential of demand response for their energy transition plans. With the possible increase of electrical energy demanded by the chemical industry as it transitions to sustainable production methods, it is important to know whether chemical companies are giving priority to energy flexibility in their energy-transition plans, as well as the factors which underlie that decision. Initial research has been done on this topic by Bielefeld et al. (2023), who identified a number of obstacles such as technical and economic limitations. However, it remains unclear how representative these findings are for the chemical industry as the number of interviews conducted with representatives of the chemical industry was limited. Moreover, that research was conducted before the natural gas crisis following the full scale invasion of Ukraine in 2022. The spike in natural gas prices significantly affected the business case and the operation of companies in the chemical industry due to their reliance on natural gas (Liu et al., 2023). The potential for future price spikes may have influenced how companies view electrification and energy flexibility. Finally, it is unclear what role flexibility will play for companies who electrify their processes in the short to medium term. This thesis aims to fill in some of these knowledge gaps.

1.3 Research Objective

The research objective is therefore to identify the role industrial flexibility plays in the near-term energy transition plans of companies in the chemical industry, specifically whether it is a primary or secondary factor in energy transition plans. The work by Bielefeld et al. (2023) will be used as a basis to perform a more thorough investigation of energy flexibility within the chemical industry specifically, as well as whether events such as the gas crisis following the invasion of Ukraine have changed any of the found factors. To limit the impact of variables such as the industrial ecosystem and regulatory climate of various countries on the findings, the scope of the research was limited to a single country. The Netherlands was chosen as the scope for this research as it has a mature chemical industry spread out over a number of different industrial clusters. Moreover, as the work by Bielefeld et al. (2023) also limited its scope to the Netherlands, this will allow the results of this thesis to be compared to their work. It is assumed that the findings that are valid for the Netherlands will also be applicable to some extent in countries with a mature chemical industry and similar industrial ecosystem and regulatory climate as the Netherlands, such as other European countries.

Additionally, this thesis focuses on the role industrial flexibility plays in the energy transition plans for the next five to ten years. This is because companies are more likely to have thought concretely about their near-term energy transition plans, as opposed to their long-term energy transition plans. By considering whether a company places a technology in the near future on their roadmap or notes it as a possibility on their longer term roadmap, information about the priority of that technology for the company can be learned.

1.4 Research Questions

Main Research Question

Main Question: What role does industrial flexibility play in the near-term plans of chemical companies in the Netherlands for the transition to a sustainable chemical industry?

Sub-Questions

Sub-Question 1: How widespread is the inclusion of industrial flexibility in the near-term energy transition plans of companies in the chemical industry in the Netherlands?

To answer what role flexibility plays in the near-term energy transition plans of chemical companies, it is important to establish whether it plays any role at all in the Dutch chemical industry. Is it included in the roadmap of chemical companies in the Netherlands and if so, is it a priority or a secondary goal.

Sub-Question 2: What obstacles to the inclusion of electrification in their near-term energy transitions plans are encountered by the chemical industry in the Netherlands?

An important driving factor for the potential of industrial flexibility in the chemical industry is the potential electrification of its processes. This question will investigate what obstacles companies are encountering when considering electrification for their near-term energy transition plans.

Sub-Question 3: Are previously identified obstacles for chemical companies in the Netherlands to operate their processes flexibly still valid?

This question examines the obstacles faced by chemical companies that affect the degree to which energy flexibility plans are integrated into their energy transition plans. A few studies, most notably the study by Bielefeld et al. (2023), have already done some work in this field. this research investigates whether similar obstacles are found when a broader section of the chemical industry is sampled.

1.5 Relevance to MOT program

The goal of the Management of Technology (MOT) master is to understand technology as a corporate resource (TU Delft, n.d.). Specifically, the goal of this programme is to teach students to analyse technologies, their commercial impact for a company and how these can be implemented into the organisational context of the firm. The goal of this thesis is to analyse the impact of the technologies of electrification and flexibility on chemical companies in the Dutch chemical industry, and is therefore well suited to the skills which have been developed during the master. Moreover, to answer the research questions it will be necessary to apply skills from several modules of the MOT program, such as the need to take into account the impact of the various stakeholders in the industrial ecosystem on the roadmaps of companies in the chemical industry, which was covered in the course Technology Dynamics. Furthermore, aspects covered in the modules Emerging and Breakthrough Technologies, with its focus on analysing innovation opportunities, such as the one provided by the need to reduce emissions from chemical processes, as well as the module Inter- and Intra-organisational decision making, which among others looks at the decision making within companies such as what technologies to include in their energy-transition roadmaps.

2 Literature Review

To understand the rest of the report it is necessary to first establish some background information on the electrification of the chemical industry as well as to take a more detailed look at how demand response works. Moreover, two of the research questions look at the obstacles which companies in the Dutch chemical industry encounter with regards to electrification and industrial flexibility. To answer this question first the obstacles which are noted in contemporary research need to be established. To achieve both of these goals, a review of the scientific literature has been performed, the findings of which will be discussed in this chapter.

First, the methodology of the literature review will be described followed by a short discussion of the definitions of some of the terms used in this report. This will be followed by some background information on the different scopes of carbon emissions and a classification system of the chemical industry. Next, the literature review will be divided into a section on electrification in the chemical industry and a section on demand response in the chemical industry. At the end of each of these two sections the results of the literature review will be analysed and questions set out in this introduction addressed.

At the end of this chapter the results of the literature review will be analysed and the questions set out in this introduction will be answered.

2.1 Methodology

This literature review was performed in several steps. The first step consisted of a cursory search using a number of variations on the keywords 'Chemical Industry', 'Flexibility' and 'Electrification'. The aim of this initial search was to identify the jargon used in this research area and to identify key terms which could be used in a subsequent thorough review. Additionally, the key paper written by Bielefeld et al. (2023) was used as a starting point for this initial search as well. This was done both in a traditional way by examining the bibliography of this paper, as well as with a newer tool on connectedpapers.com. This tool creates a graph of the related literature to a particular paper. It determines how closely related a paper is using the concept of co-citation and biographic coupling. This concept assumes that papers sharing overlapping citations are most likely focused on similar topics. Based on this measure it clusters papers graphically. This results in a graph where important topics in the field can be identified by clusters of papers in the graph. Using these methods a number of prominent papers were identified which were read to get a feel for the topic and its nomenclature. Relevant sub-topics within the field were identified as well. An example of a graph generated by connectedpapers can be seen in Figure 1.

Based on the information gathered in the first stage, a more thorough search was performed. This was done by combining the relevant key words related to industrial flexibility and electrification, with the keywords 'Chemical Industry', 'Industry' and 'Chemical Manufacturing'. Additionally, searches were performed for each of the identified subtopics in the field. This was done both through keyword searches as well as using connectedpapers.com to identify all relevant papers for each subtopic. The literature identified using these methods will be discussed in the remainder of this chapter.

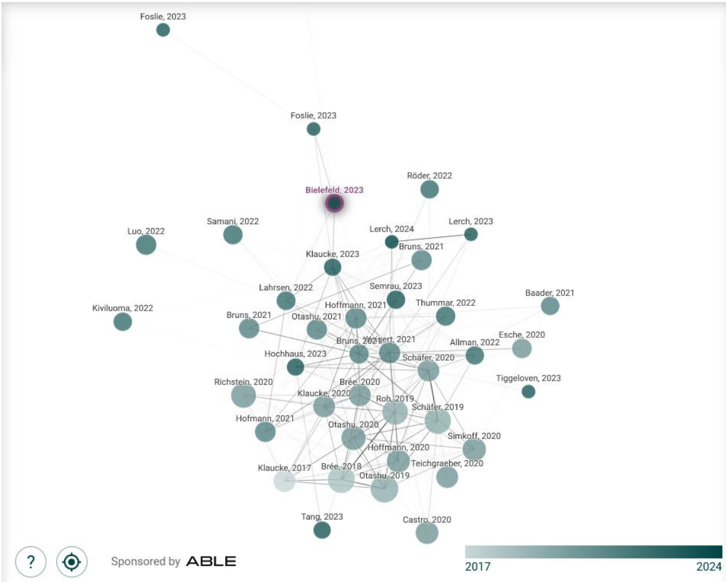

Fig. 1. An example of a graph generated by connectedpapers.com, based on the work by Bielefeld et al. (2023) as a seed.

2.2 Definitions

For a clear discussion on industrial flexibility in the chemical industry, it is important to define the different terms used in this report. This is especially important as there are several terms with similar meanings which are often used interchangeably among different papers in this field.

Although the term flexibility appears simple, within the chemical industry there can be several forms of flexibility. It is therefore important to define what we mean by industrial flexibility. The works by Luo et al. (2022) and Bruns et al. (2020) looked into the various definitions of flexibility in the chemical industry. Bruns et al. (2020) focused on the types of definitions in use in the literature. The most important types of flexibility identified by these studies were feedstock flexibility, which is the capacity of a process to use different types of feedstock without compromising the product; capacity flexibility, which is the ability to operate the process at different feed flow rates; product flexibility, which is the ability to make different products with the same feedstocks and/or production infrastructure; and operational flexibility, which is the ability of a process to operate under different process conditions and feed-flow rate without compromising the quality or quantity of the product.

All of these different terms should arguably be covered under the general term of industrial flexibility. In the literature reviewed and discussed in this thesis, the term industrial flexibility typically refers to industrial process's capacity to adjust its process in response to varying levels of electrical power supply. This is therefore a combination of capacity flexibility and operating flexibility, driven by changing levels of electrical power.

A related term also used in the literature is demand reponse. Demand response entails adapting the power use of a process depending on the availability of electricity (Valdes et al., 2019). It is also often grouped as one of the options of Demand Side-Management (DSM), which refers to measures to optimize energy use by consumers using existing infrastructure.

2.3 Background

To fully understand this thesis some background information is necessary which will be given in this section. First, the different scopes of carbon emissions will be discussed, which will aid in understanding where the carbon footprint of the chemical industry is coming from and how it can be reduced. Second, a classification of the chemical industry into several categories will be discussed which will help to understand the priorities of different types of companies.

2.3.1 Scope of Emissions

While emissions directly produced by a company, such as those from using natural gas for process heat, constitute the most obvious part of the carbon footprint, the chemical industry also contends with indirect sources of emissions. These sources can be divided into three different scopes (Teske et al., 2022).

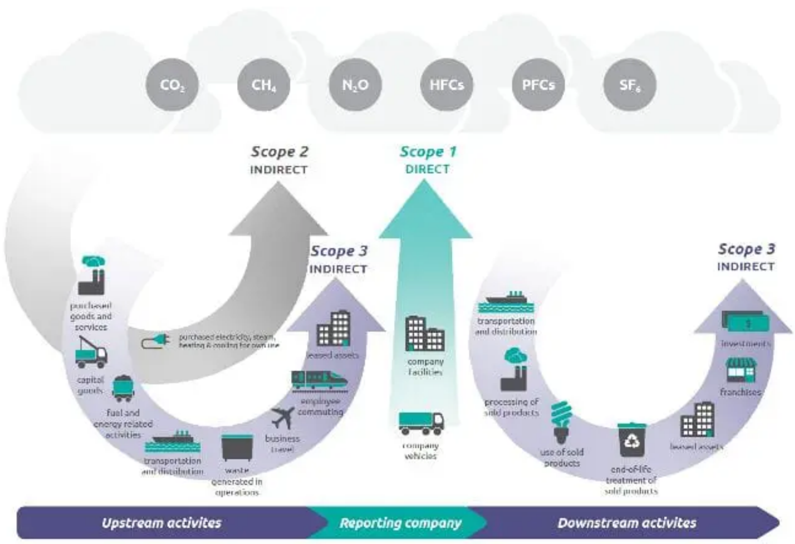

Fig. 2. An overview of the different type of scopes of emissions (EPA, n.d.).

Scope 1 encompasses direct emissions by the company. Examples of this scope are emissions from natural gas or any other form of fossil fuels used to produce heat at the production site. Related are emissions under scope 2, which entails indirect emissions from energy use. This refers to emissions resulting from energy use whereby the emissions themselves originate from a different company. An example of this is an energy company that emits greenhouse gases, while providing electricity that is then utilized by a chemical company. This scope also includes the emissions from steam generation, if this is done by a neighboring company, which is often the case for companies in a chemical cluster.

The final scope is scope 3, which is divided in an upstream and a downstream component. The upstream component of scope 3 encompasses all emissions that were involved in the production of the feedstock used by a company. This is very significant for chemical companies further along in the production chain as this includes all the energy used in earlier production steps. The downstream component of scope 3 refers to the emissions associated with the product after it leaves the company as a product. For example, if a company produces gasoline, the emissions from the cars that use the gasoline would be part of this scope. In Figure 2 a graphic representation of the different types of scopes can be seen.

2.3.2 Classification of the Chemical Industry

One of the challenges of investigating the chemical industry is the wide variety of different processes used, which also leads to significant differences between companies. This can make it challenging to find trends in the data gathered from different companies. For this reason, it is useful to divide the chemical industry into several categories, as companies in the same category are more likely to face similar challenges.

The classification is based on the commercial classification of chemicals into commodity, fine and specialty chemicals ("Industrial Chemistry Library", 1994). Commodity chemicals are chemicals which are produced in large volumes and which are single compound products. This means that the product that one company produces will be essentially the same as the product produced by a competitor. The means to most important distinguishing factor between competitors is the price.

Specialty chemical companies in contrast produce products which are a mix of several different compounds. These products are typically manufactured in smaller volumes and are marketed based on their functionality, granting them more pricing power compared to producers of commodity chemicals.

The final category is fine chemicals, which are single compound chemicals produced in small volumes. An example of this category are chemicals produced for the pharmaceutical industry.

Companies in these different categories will have differing priorities when reducing their carbon footprint. A commodity chemicals company will have more reason to focus on its scope 1 and 2 emissions than a specialty chemicals producer whose focus will be on the scope 3 emissions from the compounds it uses to produce its products (Taifouris & Martín, 2022).

As the commodity chemicals is a large category, it can be divided into several different subcategories which will be briefly described here ("Industrial Chemistry Library", 1994):

- Petrochemical: companies which refine petroleum based feedstocks into basic organic chemicals.
- Fertilizer: companies which produce fertilizer and other related nitrogen based products.
- Metal: companies which produce metals from raw feedstocks.
- Polymer: companies which use basic chemical feedstocks to produce monomers as well as the resulting polymers.
- Industrial gases: companies which produce gases such as hydrogen, oxygen, carbon dioxide and nitrogen.

Using the categories outlined in this section, the information presented in the remainder of the rapport can be placed in the appropriate context.

2.4 Electrification of the Chemical Industry

In this section, the scientific literature on the electrification of the chemical industry will be discussed. The industrial sector currently accounts for 37% of total final energy consumption worldwide (Wei et al., 2019). However, if we look at the chemical industry, only around 10% of direct energy used in the chemical industry is in the form of electrical energy (Wei et al., 2019). The remaining energy use takes the form of fossil fuel based process heating (Mallapragada et al., 2023).

However, only around 40% of fossil resources consumed by the chemical industry is used to generate that heat (Mallapragada et al., 2023). The remaining fossil resources are used as the feedstocks to produce basic chemicals, which in turn can be used to produce more complex chemicals. Although the use of these products do not impact the direct energy usage of the production process, and are therefore not included in scope 1 or 2, they do impact the scope 3 footprint. Although the demand for some of the resulting products is expected to decrease (such as gasoline for personal vehicles), the demand for many other products is expected to increase (Mallapragada et al., 2023).

To fully defossilise the chemical industry both the process heat as well as the fossil fuel feedstocks need to be replaced with sustainable alternatives. The potential to provide process heat with electricity will be discussed in Section 2.4.1. In Section 2.4.2 the potential of producing alternatives to fossil fuel feedstocks using electricity will be discussed.

2.4.1 Electrification of Heat

There are several options to defossilize process heat generation in the chemical industry, such as biobased fuels, heat generated from waste, or heat supplied by electricity (Thiel & Stark, 2021). Of these, electrification is seen as a promising option (Wei et al., 2019). Heat can be generated either through direct or indirect electrification. Direct electrification means that electricity is directly used to generate heat through resistive heating or a heat pump (Thiel & Stark, 2021). With resistive heating nearly all the electrical energy is converted into heat, and it can reach relatively high temperatures. This can for example be used to generate steam. However, given the price difference between natural gas and electricity, heat from resistive heating is still two to three times more expensive than heat generated using natural gas (Thiel & Stark, 2021). For resistive heating to be competitive, the low cost of fossil fuel would need to balanced against the expense associated with CO_2 emissions.

In contrast, heat pumps can generate more heat than the electrical energy used to generate it. An important obstacle though is that technologically mature versions of heat pumps can only reach temperatures up to 160 degrees Celsius (Thiel & Stark, 2021). Moreover, heat pumps require relatively high capital investments compared to fossil fuel or resistive based heat generation. A final obstacle is that heat pumps need to be integrated into the heat integration of a production process; they cannot simply be inserted as stand-alone boilers to generate steam (Schoeneberger et al., 2022).

A second way of generating heat is through indirect electrification. This means using electricity to produce an energy carrier, such as hydrogen, which can then be burned to generate heat (Bruns et al., 2022). As green hydrogen is produced with renewable electricity from water, this would result in a carbon free source of heat. An advantage of using an energy carrier like hydrogen is that it can be used to reach similar temperatures as natural gas. This means that if hydrogen were used to substitute natural gas there would not be a necessity for fundamental redesign of the production process (Bruns et al., 2022). Thus, hydrogen a poses less risky option for chemical companies compared to the extensive redesign that direct electrification might require. Yet, currently hydrogen is not cost-competitive to produce. Additionally, although hydrogen could reach similar temperatures as natural gas, its properties differ enough that specialized process control and burners would need to be developed (Thiel & Stark, 2021). These challenges make in unlikely that hydrogen will be used in the near-term as an energy carrier to replace natural gas.

2.4.2 Electrification of Processes

The defossilisation of the feedstock of the chemical industry can be achieved either by switching to bio-based feedstock, recycled plastic as feedstock, or by using electricity to drive the production of alternative feedstocks (Schiffer & Manthiram, 2017). This can be accomplished either through a thermochemical reaction, where heat is provided using one of the methods discussed in the previous section, or by employing electrochemical reactions. In electrochemical reaction, basic chemicals such as CO_2, nitrogen or water are used to directly produce more valuable chemicals using eletrical energy.

It is important to note that the feedstocks for both of these options contain less potential energy than feedstocks like oil. This means that electrical energy must be added to produce a feedstock that can be used replace that oil as feedstock. This means that if the chemical industry defossilises its feedstock using electricity, the electrical energy demand of the chemical industry would increase significantly.

A major obstacles to the usage of renewable feedstocks produced using electricity is that the technology is still relatively immature. While the electrochemical production of hydrogen, and to a lesser extent carbon monoxide, is becoming feasible, most potential processes are still in the early stages of development. Even the processes that are possible, such as hydrogen, are not yet cost-competitive, as was discussed in the previous section.

2.4.3 Conclusion

From the previous two sections it can be concluded that there are still significant obstacles to electrification. To fully defossilize the chemical industry, both the fossil feedstock used to produce heat, as well as the fossil fuel feedstock used as reaction feedstock need to be replaced. There are technologically mature options to generate heat using direct electrification, but both resistive heating as well as heat pumps face challenges due to their lack of cost-competitiveness. Additionally, heat pumps only have a limited temperature range and are more complicated to integrate into an existing process.

Though the replacement of fossil feedstocks through electrothermal or electrochemical means holds significant potential, most of these options are still in an early stage of development. The only feedstock that might be replacing fossil alternatives is electrochemically produced green hydrogen, although even this option faces challenges regarding its cost competitiveness.

Despite these challenges it is likely that many of these technologies will be used in the energy transition of the chemical industry. This means that the electrical energy demand of the chemical industry will most likely increase significantly. Successfully integrating this increased electricity demand from the chemical industry into the electrical grid poses a serious challenge for grid operators. Simultaneously, the growing reliance on electricity as an energy source means that electricity prices will become increasingly critical for their profitability. This increase in electrical energy demand therefore enhances the potential for demand response in the chemical industry. In the next section the literature on demand response in the chemical industry will be discussed.

2.5 Demand Response in the Chemical Industry

In this section the scientific literature on demand response in the chemical industry will be discussed. First, the electricity market will be addressed and how demand response gets integrated into it. Next, the literature on the technical potential of chemical processes to be operated flexibly will be examined. Subsequently, the financial implications of operating a production process will be considered, followed by the potential impact of grid congestion on the willingness of companies to participate in demand response. The impact of various government policies on the attractiveness for chemical companies to operate their processes flexibly will be discussed next. Finally, the obstacles that impact companies will be discussed based on a number of interviewed based studies. At the end of the section the most important findings will be discussed and conclusions will be drawn.

2.5.1 Electricity Market

Companies looking to participate in demand response will do so based on the electricity market. In this section, various forms of the electricity market will be discussed, along with balancing programs that support it.

Although the energy grids are organised differently in every country, the electricity market can generally be divided into three different timescales: day-ahead, intra-day, and frequency regulation. Expected capacity is traded on the day-ahead market until 24 hours in advance (Otashu & Baldea, 2018). The price will be based on the expected availability of electricity and the demand from companies for power during a particular time slot. However, the exact amount of electricity generation might vary due to factors such as changes in weather affecting renewable generated electricity, or companies needing more electrical power than expected. In this case, capacity can be traded until shortly before the actual time of use on the intra-day market. The day-ahead market is also referred to as the Long-Term Market (LTM), while the intraday trading is referred to as the Short-Term Market (STM). Generally the short-term market will experience larger peaks and troughs, hence requiring more flexibility in consumption to utilize. An example of this can be seen in Figure 3.

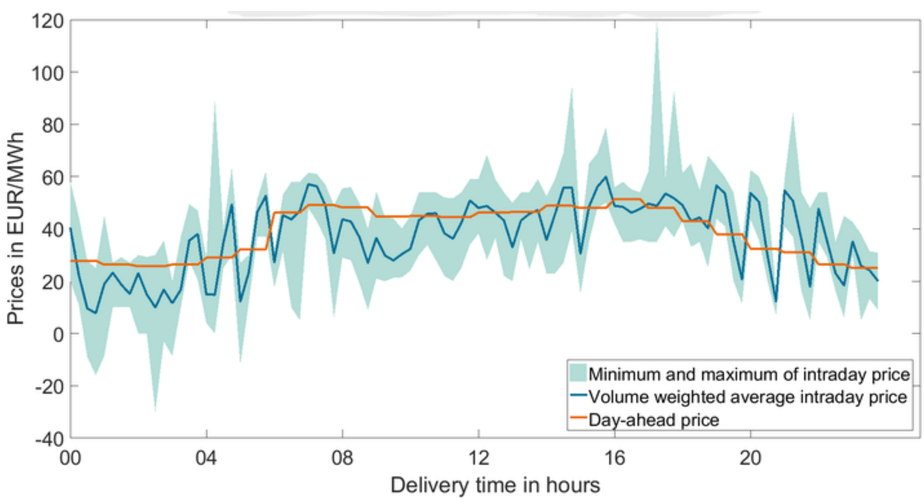

Fig. 3. An example of the difference in price between the day-ahead and intra-day markets (H. Martin & Otterson, 2018).

Adapting electricity usage based on the electricity markets is referred to as implicit demand response (Xenos et al., 2016). This means that the power-consumption of an industrial user depends on the price that they are willing to pay for a particular unit of power. An alternative form of this is explicit demand response, also known as a dispatchable program. In this approach the grid operator or aggregator sends signals to an industrial consumer to increase or decrease consumption as needed. Companies make their capacity available for demand response in return for a financial incentive as well as compensation when a dispatchable program is activated. Xenos et al. (2016) developed a model to estimate the cost of such explicit demand response programs. The benefit of this system compared to an implicit demand system is that it is financially less risky than operating on the electricity market.

A specific form of explicit demand response is frequency regulation. This is the form of demand response with the shortest time horizon. Electrical grids operate at a set frequency which represents the energy in the system (Tuinema et al., 2020). If the power input into the system does not exactly match the output, the frequency will either go up or down, depending on whether energy is gained or lost. Historically, the stabilisation of this frequency has relied on the inertia of generators in fossil fuel based power plants. However, as more of the power production is moving towards renewable sources such as wind and solar, which cannot fulfil this role, alternative sources of stabilisation are needed.

Some industrial processes could provide this stabilisation by very quickly scaling their usage up or down to increase or decrease the energy in the system. Potential processes which could do this are electrochemical processes, such as the production of hydrogen or the chlor-alkali process (Otashu & Baldea, 2020). As frequency regulation is necessary for the stability of the grid, companies which provide this explicit demand response receive financial compensation for this service from the grid operator. However, only processes with a very high responsiveness would be able to fulfil this role (Motalleb et al., 2016). The technical capacity for processes to operate flexibly will be discussed in the next section.

2.5.2 Flexibility of Processes

One of the main challenges with operating chemical processes flexibly is the need for these processes to adjust their power consumption rates, as noted by (Cegla et al., 2023). The standard practice within the industry is for chemical production processes to run continuously in a steady-state. Cegla et al. (2023), in their literature review focusing on the challenges of operating chemical processes flexibly, identified the difficulty of transitioning from steady-state operation to dynamic operation as a major obstacle. Chemical processes typically perform optimally when operating at a steady state (Otashu & Baldea, 2018). Different processes show significant variability in the speed at which they reach new steady state conditions following changes in process variables, such as changes in available heat from electrical sources(Cegla et al., 2023).

Some agile process might be able to quickly transition to a new steady state point that equates a new power level, which would make them suitable to participate in a form of demand response with a small time horizon (Otashu & Baldea, 2018). However, many processes are sluggish which means they will not be able quickly stabilise at a new stead-state point. Under dynamic conditions, while the process moves to a new steady-state condition, these processes might operate at lower efficiencies or produce lower quality products. The responsiveness of the responsiveness of a chemical process exists on a spectrum. For instance, reactions such as electrochemical production of hydrogen, are responsive enough to provide frequency stabilisation while others are not even responsive enough to participate in the day-ahead market. This means that every process will have a different optimal time-scale of demand response. To evaluate the best option for each process, models are needed which link the process control possible for a particular process with the economic incentives of the flexible markets. A number of studies have developed models with that goal in mind (Germscheid et al., 2022; Hoffmann et al., 2021; Xenos et al., 2016).

An additional challenge is that the equipment used in many processes has been designed to operate efficiently within a small window of process conditions (Cegla et al., 2023). Operating outside of this operational window can be damaging for the equipment and result in a lower efficiency of the process. For processes to be able to operate flexibly equipment needs to be redesigned to handle larger operational windows.

One potential avenue to make flexible operation possible for processes with a low responsiveness, is to use indirect demand response (Bruns et al., 2022). Indirect demand response means that part of the process will operate flexibly while allowing the rest to operate at a steady-state capacity. This would be accomplished by having a flexible pre-process which feeds into the main continuous process. The pre-process, for example the production of hydrogen through electrolysis, can easily ramp up or down in response to changing power availability. If more power becomes available, this process can scale up its production and any excess production is put into storage where it can act as a buffer for the process operating continuously at a steady-state. If at a later point power availability drops below the necessary level to sustain the main reaction, the main process can draw upon the pre-produced feedstock stored in the buffer. If the reduced power level is estimated to be of a longer duration, the storage of pre-produced feedstock can be the buffer, while the subsequent process, with its lower responsiveness, adapts to the lower power level.

This is also a potential hybrid solution for chemical companies to provide some flexibility during the transition towards an electrified chemical industry (Thiel & Stark, 2021). The chemical industry usually works with relatively long production cycles, and many processes are expected to remain unsuited for flexible operation for a long time (Wei et al., 2019). While implementing large scale demand response may be unfeasible for these processes, adapting pre-processes that can be used for demand response can enable enterprises to achieve a certain level of industrial flexibility regardless. However, indirect demand response does come with additional cost in the form of costs of the buffer storage cost. Bruns et al. (2022) present a framework for estimating the economic potential of using an indirect demand response method. This is an important factor because it needs to be financially attractive for companies to operate a process flexibly. This topic will be discussed in the next section.

2.5.3 Financial Considerations

Although there are numerous arguments in favor of industrial flexibility for its societal benefits, ultimately the decision to incorporate demand response is driven by financial considerations. The financial incentives for participating in demand response were already discussed in Section 2.5.1. However, adapting a process to demand response comes with a number of financial costs as well. Hoffmann et al. (2021) provide a good overview of the various costs associated with demand response. These costs can be split into provisional costs and load change costs. Provisional costs are the costs associated with making demand response possible. For example, equipment needs to be designed to contain a wider operating window, which then will have a lower efficiency compared to a process optimized for a small operating window. Moreover, a demand-response process requires more control equipment, storage and capacity to be built, compared to a process operating at a constant capacity. More capital investments are therefore needed to build a process capable of operating flexible, which means the financial incentives of operating flexible must be sufficient to earn back those investments.

There are also the operational costs of operating flexibly, referred to as the load change costs. (Hoffmann et al., 2021). An important part of this is the missed production if a process needs to be scaled down. Chemical processes are usually designed to operate continuously at a steady state. For a process to operate flexibly this will almost always mean lowering its production rate, which means that less product is produced. As the process cannot exceed the maximum capacity at which it usually operates this missed production cannot be compensated later. This is referred to as load shedding (Klaucke et al., 2017). However, the high investment costs for the process equipment need to be earned back in the same time-frame. Therefore, the financial incentives of demand response need to be higher than the cost of lost production.

An additional challenge is that operating flexibly can increase the wear and tear on the equipment, necessitating either designs capable of handling such conditions or accepting a reduced lifetime of the equipment (Hoffmann et al., 2021). Here as well, both options will lead to more capital investments being necessary, which need to be compensated by the financial incentives of demand response.

2.5.4 Grid Congestion

One potential issue which might have an impact on the willingness of companies to participate in demand response and which is not considered in the literature discussed above, is the issue of grid congestion. The general move towards electrification is increasingly pushing electricity grids to their limit (Plink, 2013). In the Netherlands, lack of transmission capacity in the grid means that enterprises often have to wait for several years to be connected to the grid or to increase the capacity of their connection (Netbeheer Nederland, 2022). As discussed in Section 2.4, many paths towards sustainability for the chemical industry are based on electrification. This means that the delays in expanding grid connection can be a significant obstacle to the transition to sustainable chemical production.

Besides playing a role in the balancing of the grid, demand response is also a potential tool to deal with grid-congestion (Stawska et al., 2021). Although both balancing and grid-congestion can be tackled using demand response, these goals do not always coincide. Balancing the grid with demand response sometimes causes more net-congestion. Grid congestion management methods need to be carefully considered by grid operators to ensure that these goals properly align. Stawska et al. (2021) investigated which congestion management methods are best able to deal with these competing aspects. The three most promising congestion management methods identified were a flexibility market, a peak tariff, or a tier tariff. The structure of the grid tariff can therefore significantly affect the use of electricity by companies. However, Stawska et al. (2021) also identified significant defects in each of the investigated congestion management methods and recommended further options to be investigated.

To the knowledge of the author, there is limited literature available on the subject of using industrial demand-response for addressing grid-congestion, and in particular, studies into whether grid-congestion might be a driver for the adaption of demand response in the industry. Although demand response for balancing may offer more immediate financial benefits, addressing grid-congestion could be the stronger driving force towards a more active flexibility market. This is because it might allow a company to expand their electricity use when they would otherwise be unable to.

In the Netherlands, most companies have contracts for firm transmission rights, which means that they have the right to a certain capacity which they can use at any time of the day as long as their peak usage does not exceed their maximum capacity (Authority for Consumers & Market, n.d.). The grid operator needs to ensure that this contracted capacity is available at all times. If the grid capacity in certain areas is near the total contracted transmission rights, the grid operator will be unable to connect new companies until the grid has been expanded. However, most often companies do not use the their full grid connection capacity. This means that during off-peak hours there is unused capacity on the grid. To be able to use this capacity, while still guaranteeing the firm transmission rights, the Dutch government will allow Alternative Transmission Rights (ATR) to be sold. This is a transmission right which is not continuously guaranteed, but which can for example be used during off-peak hours. A company which can engage in flexible operation of its processes might be able to obtain alternative transmission rights long before it would be able to get firm transmission rights. Grid congestion might therefore be an important driver for companies to include energy flexibility in their energy transition plans.

2.5.5 Policy Implications

The government can have a significant impact on many factors which impact the willingness of companies to operate flexibly, for example through regulations or its control over the grid operators, which in most countries are government owned. A study by Billings and Powell (2023) investigated what impact government policy had on the adoption of industrial demand response in the United States. They found that the American policies generally were not effective in promoting the use of demand response. The researchers identified the complexity of the industrial sector as one of the main reasons for this. Every type of industry has different considerations which leads to the policy remaining vague. However, the researchers also identified that effective policy could remove barriers that currently stand in the way of successful implementation of demand response.

A different study by Richstein and Hosseinioun (2020) modelled the impact of various tariff options used to incentivize industrial demand response. They found that the mechanics of demand response (explicit or implicit) and the type of tariff implemented significantly impacted both the willingness to adopt demand response as well as the type of demand response behaviour that was incentivized.

A review of the regulatory environment in the EU was provided by Lamprinos et al. (2016). Although their work mainly focuses on demand response as it relates to consumers and small businesses, most of their findings are also applicable to industrial demand response. In their work, albeit written in 2016, the authors indicate that regulatory frameworks had recently been introduced and that not all countries had incorporated these regulations into their domestic law. Given the increasing high pace of development in this field, it is very likely that the regulatory environment has changed since the time of publication. This is confirmed by a study by Leinauer et al. (2022) which found that there were conflicting regulations in Germany in the area of demand response which in fact disincentivized industrial companies from participating in demand response programs.

2.5.6 Obstacles and Motivations

The literature discussed in the sections above has been based on literature studies and models. However, these studies might also miss some of the obstacles and drivers that play a role within organisations that are considering energy flexibility. In this section, three papers will be discussed in which interview-based studies of the obstacles and motivations for companies to engage in engage in demand response were undertaken.

The first paper is by Lashmar et al. (2022) who conducted interviews among stakeholders in the commercial and industrial sector in Australia. Although this study does not focus on the chemical industry, its investigation of the industrial sector might be applicable specifically for the chemical industry as well. The aim of the researchers was to identify the barriers and motivations for participating in demand response programs as well as any enablers for participation. The authors found that the motivation for participation was largely financial with social and environmental factors playing only a small role. The most important identified barriers included uncertainty about revenue if companies chose to partake in a demand response program as well as concerns about the wear and tear on the process equipment associated with ramping in response to demand response signals. A final barrier was the lack of necessary knowledge within the company to implement demand response.

The study also identified a number of enablers that would reduce the barriers of entry to a demand response program (Lashmar et al., 2022). One of the biggest enablers was the provision of flexible options of ways to participate in demand response programs. This allows industry to tailor the program to the intricacies of their particular processes. This is a similar finding as in the work by Billings and Powell (2023) discussed in section 2.5.5. Moreover, if there are options with minimal obligations, companies can gain experience with the programs without assuming significant risks, making it a more likely that they will consider it.

A similar study was conducted by Leinauer et al. (2022), who combined a literature study with an interview approach amongst the industrial sector in Germany. This study focused mainly on the obstacles for participating in a demand response program. The financial and technical limitations that they identified overlap largely with the barriers identified by Lashmar et al. (2022). In addition to these types of obstacles, the authors also investigated regulatory, organizational and behavioral obstacles for adoption of demand response.

The study showed that amongst the stakeholders, the regulatory climate still poses significant obstacles, both because of the complexity of understanding the various regulations and frameworks applicable to demand response, as well as the existence of sometimes conflicting regulations (Lashmar et al., 2022). For example, some companies receive a discount on their electricity tariff if certain efficiency standards are met. However, using demand response can lower the efficiency of the plant even if the overall environmental impact of the plant is lower due to more efficient use of the electricity supply. Companies in response fear losing access to the lower tariffs if they implement demand response.

The study also identified a number of behavioral and organizational obstacles that prevented companies from considering demand response (Lashmar et al., 2022). One obstacle they identified was the shortage of individuals in companies knowledgeable about demand response. Additionally, those with relevant knowledge often do not have enough decision making power within the company to properly champion this topic. Moreover, employees of the stakeholders interviewed were skeptical of the automation that would be required for a successful integration in a demand response program, leading to resistance within the company. These findings show that beyond the technical and financial obstacles which many of the papers in this literature review identify, there are also less obvious obstacles that might hinder the implementation even if the technical obstacles are eventually solved.

The final paper in this section is by Bielefeld et al. (2023). This paper explored the benefits and limitations of industrial flexibility in the Dutch chemical industry through a combination literature review which compared the latest literature with industry publications, and with interviews with stakeholders in the industry. The limitations identified in this paper overlap partially with the findings of the previous two papers. An interesting additional finding was that due to the long investment cycles in the chemical industry, hybrid bridging technologies would be essential for the successful adoption of demand response programs. These technologies, such as e-boilers operating in parallel with traditional natural gas bases boilers, would allow companies to slowly invest in infrastructure suitable for demand response without requiring major changes in the middle of an investment cycle.

The study also identified that currently, demand response programs are not well suited to the integration of chemical companies (Bielefeld et al., 2023). An example of this is that grid operators mandate that companies offer at least a certain minimum capacity before being allowed to participate in demand response programs. Moreover, the time-horizon of the chemical process operators and grid managers often did not align, which as discussed in section 2.5.1, makes it unfeasible for some processes to participate. Organizational obstacles identified were the hesitance of companies to share data with third parties or to become dependent on third-party service providers who would be needed to predict the available capacity. This expertise is often lacking in companies, as the current purchasing of electricity is typically driven purely by the demand of the production process.

2.5.7 Conclusion

Based on the literature discussed in this section a number of obstacles to the implementation of energy flexibility in the chemical industry were found. One important technical constraint is the responsiveness of chemical processes, which makes it difficult for some processes to respond on time to the time frames which both explicit as implicit demand response require. The design limitation and the long investment cycles pervasive in the chemical industry also make many processes impractical for flexible operation in the near-term. A potential way to still achieve some flexibility is to implement indirect demand response, as this allows a responsive part of the process to operate flexibly while the rest of the process can operate as it was originally designed. This might also mitigate some of the financial concerns discussed in Section 2.5.3 as the indirect demand response isolates a large part of the production process from the financial cost of increased wear and tear and load shedding.

A potential driver of flexible operation in the chemical industry, a topic relatively unexplored in the the literature, is grid congestion. Given that companies often have to wait for years to obtain expanded grid connections, especially necessary if companies electrify their energy use, as outlined in Section 2.4. Operating flexibly in return for quicker access to more grid capacity might be advantageous. This is therefore an area where government policy can significantly affect the attractiveness for companies to engage in energy flexibility. Besides the control of the government over aspects such as the type of transmission rights and the tariff structure for grid fees, the regulations were also found to impact the willingness for companies to engage in demand response.

Some of these obstacles overlapped with those found in the interview-based studies discussed in Section 2.5.6. The increased wear and tear was noted by stakeholders in the industry, as well as the fact that the available options to provide energy flexibility are not suited for industrial processes. This is most likely because the responsiveness of certain reactions does not fit the time-schedule of those programs. Additionally, the financial concerns were noted in those studies as well which matches the literature discussed in Section 2.5.3. However, the literature discussed in this section also identified a number of obstacles which were not directly based on technical or financial concerns. All three interview-based papers highlighted organisation barriers such as the lack of necessary knowledge, organisational resistance to the automation required to participate in demand response and dependence on third parties to organise the balancing services. This shows that many constraints exist that are not immediately apparent from a technical or economical analysis of demand response. In the next chapter, the methodology for collecting data to identify these obstacles will be discussed.

3 Methodology

In the previous chapter the state-of-the-art scientific literature was discussed to establish what the known obstacles of electrification and industrial flexibility for companies in the chemical industry. To answer the research questions, this information needs to be combined with new data gathered as part of this master thesis. The methods used to collect that data will be based on those covered during the MOT module Research Methods which among others covered how to develop a qualitative research methodology. The developed methodology used to collect the data to answer the research question will be described in this chapter.

3.1 Overview

This research is exploratory in nature as its goal is to identify aspects of a topic which are not yet fully investigated. This means that the primary goal of the research is to identify new aspects, not to make definitive conclusions on the topic. There are a few data collecting methods which are suited to this task. Data can either be collected using published sources such as reports, roadmaps or other published documents by the relevant stakeholders, or by gathering the data directly from the stakeholders, in the form of either a survey or an interview. A survey however is not well suited to these research question, as the number of stakeholders which are relevant within the geographical boundary is relatively small. Moreover, participants are usually more willing to go into depth during an interview than while filling out a survey (Sekaran & Bougie, 2009). Finally, an interview will allow the researcher to respond and adapt based on the answers to earlier question, making this method well suited to exploratory research.

As Bielefeld et al. (2023) performed an analysis of the roadmaps of chemical companies active in the Netherlands as part of their work that was published in 2022, it was decided to focus on collecting the data to answer the research questions by directly interviewing the stakeholders.

3.2 Interviews

In this section the methodology for the data collection through interviews will be discussed. First, the choice of interview type will be discussed, followed by a section on the recruitment of interview participants. Subsequently, the interview questions used will be considered and finally the processing of the interviews will be examined.

3.2.1 Interview Type

The main method of data collection was through interviews. There are three different types of interview-based data collecting methods: structured, semi-structured and unstructured (Sekaran & Bougie, 2009). In a structured interview approach all the questions are determined beforehand which makes it easier to compare answers between different participants. However, as this research is exploratory in nature, an important aspect of the research was the ability to respond to interesting and unknown aspects mentioned by the participants and as yet unknown by the researcher. On the other side of the spectrum are unstructured interviews which tend to be very informal and guided by the flow of the conversation. The downside of this approach is that it is easy to forget to ask about certain aspects, making it more difficult to compare answers provided by different participants.

Semi-structured interviews lie between these two variants. There are a number of pre-determined open questions which the interviewer will ask. However, the format leaves room to dive more deeply into topics that arise during the interview itself. For this reason, it was chosen to conduct semi-structured interviews to achieve the research goals.

3.2.2 Selecting which Companies to Approach

Participants needed to be recruited from chemical companies operating in the Netherlands. Within the time constraints of this thesis, participants of only a subset of companies active in the Netherlands could feasibly be interviewed. For this reason it was important to be able to determine to what extent the final subset of companies where a participant could be recruited is representative of the Dutch chemical industry as a whole.

The selection of companies to approach was also important due to the challenge of recruiting participants. Although some participants were recruited through the network of the author, a large number of participants were approached through 'cold' communication, i.e. without having an introduction to the person approached. Initial exploratory experiments with cold approaches on LinkedIn showed a response rate of around 25% with around 10% of approaches resulting in an actual interview. To recruit sufficient participants it was therefore necessary to approach as many companies as possible.

To support both these goals, an attempt was made to create a list of all chemical production companies in the Netherlands. This would provide a comprehensive list of companies where participants could potentially be recruited, as well as serving as a benchmark against the final subset of interviewed companies could be compared to determine its representativeness for the Dutch chemical industry.

Although there are some websites which list chemical companies active in the Netherlands, no complete list is publicly available on the internet as far as this author is aware. The list therefore needed to be assembled by the author himself.

The term 'Chemical Industry' can be a broad term encompassing everything from production plants, storage locations, specialty transportation companies, to associated service companies such as engineering consultancies. For this research, only the companies directly producing chemical compounds are relevant. To this end the following selection criteria were established for a potential company to be included in the list.

1. The company produces a 'chemical' product such as a base chemical, plastic, specialty chemical or metal.
2. The company has at least one production facility located in the Netherlands.
3. The company does not use a biological means of production.

According to the *Koninklijke Vereniging van de Nederlandse Chemische Industrie* (VNCI), the association for the Dutch Chemical industry, there are six chemical clusters in the Netherlands. These are Rotterdam-Moerdijk, Chemelot, Noord-Nederland, Zeeland/West-Brabant, Noordzeekanaalgebied and the so called 'sixth cluster' ("Zes chemieclusters - VNCI Koninklijke Vereniging van de Nederlandse Chemische Industrie", n.d.). Under this sixth cluster, all companies are listed which are not located in one of the other five clusters. These clusters were used to give a structure to the attempt of creating an exhaustive list of chemical production

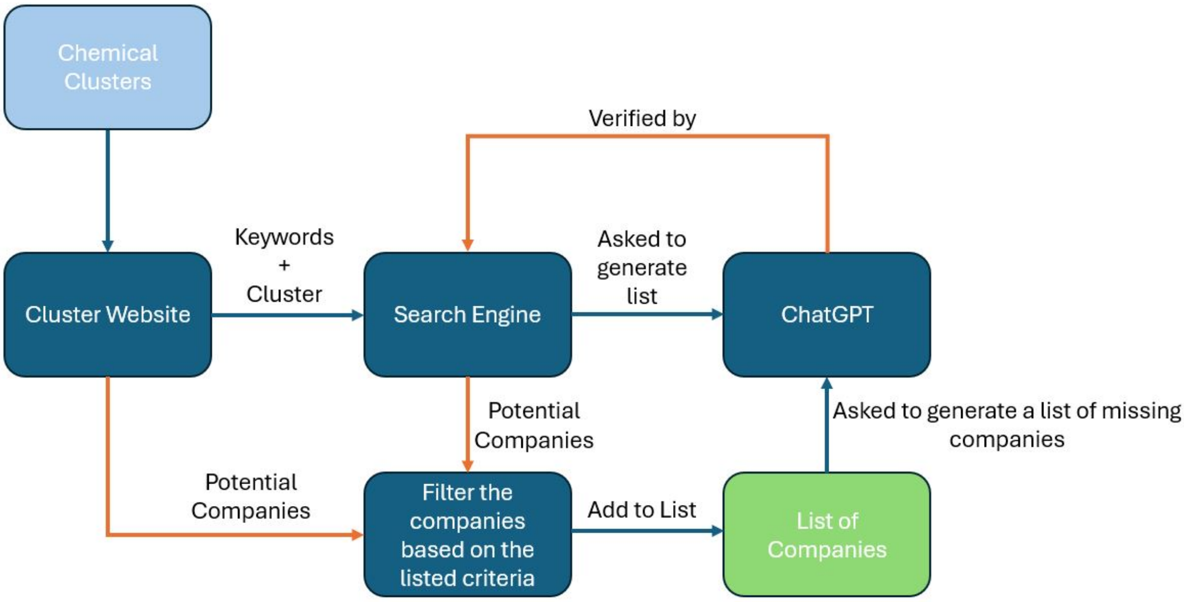

Fig. 4. A graphic representation of the process used to compile a list of chemical companies in the Netherlands

companies. A map of the locations of the various clusters is shown in Figure 5

Fig. 5. A map of the Netherlands with the approximate location of the five main chemical clusters in the Netherlands

For each chemical cluster, firstly the official website of the cluster was used if this existed, generally including all companies associated with that cluster. Using the selection criteria discussed earlier in this section, the appropriate companies were included in the list. Next an internet search was performed using the name of the cluster, or other names it sometimes might be known by, and various variations on the term 'chemical companies'.

Once the list had been generated using this method, the websites mentioned earlier in this section which have non-exhaustive list of companies in the Dutch chemical industry were checked to see if they included any companies not already included in the list of companies. Finally, ChatGPT was asked to generate a list of all the chemical companies in the Netherlands, as well as for each chemical cluster separately. A copy of the draft list was also given to ChatGPT with the question whether any companies were missing. Any company found through this method was manually verified using an internet search engine.

An overview of this process can be found in Figure 4. Using this process, a list of 51 companies was generated, which can be found in Appendix P. Although it is unlikely that this search managed to find all the chemical companies in the Netherlands which fit the selection criteria, the search was sufficiently thorough that the list can be assumed to be a reasonably comprehensive list of companies in the chemical industry of the Netherlands. This will allow it to serve as a benchmark for assessing the representativeness of the subset of interviewed companies.

function as an ideal standard to which the subset of interviewed companies can be examined to establish whether it is representative.

3.2.3 Selecting Potential Participants

With this list of chemical companies, individuals working at these companies could be approached. As companies generally do not make contact details of employees publicly available, the selection of who to approach was done through LinkedIn. Using the Sales Navigator function on LinkedIn, it was possible to filter individuals active on LinkedIn using as a filter the company they work for as well as the geographical area indicated in their profile. By filtering specifically on each company as well as on the Netherlands as geographical location, a list of employees associated with each company could be found.

The selection of who to send a message to was mostly driven by the estimated likelihood that someone would respond. For example, it was assumed that someone with no knowledge of the topic of energy flexibility would be unlikely to respond to a request for an interview on this topic. Because each company uses different titles for roles, finding the most suitable person to approach based solely on the information available on LinkedIn was not immediately evident. A list of priorities was therefore used to select the most promising employees for each company.

1. The person has 'Demand Response' (or synonymous term) in their job title, or listed as one of their responsibilities.
2. The person has 'energy' in their job title, or listed as one of their responsibilities (such as energy coordinator).
3. The person has sustainability in their job title, or listed as one of their responsibilities (such as sustainability engineer).
4. The person has an engineering role directly related to a technology with flexibility potential (such as hydrogen development engineer).
5. The person is responsible for innovation or improvement of their production process at their company (such as innovation manager or improvement engineer).
6. The person has a technical role (such as maintenance engineer or site manager).
7. The person is working in a non-technical role but with a technical background.

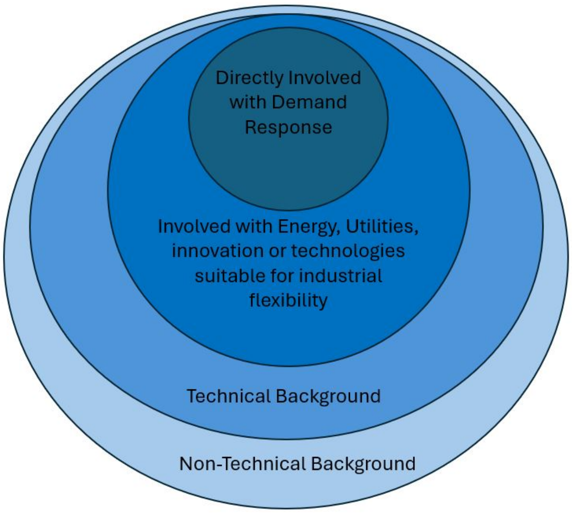

Fig. 6. A graphic representation of the different levels of preference when selecting potential participants

3.2.4 Selection Bias

A conscious selection bias in this selection procedure was the preference for potential participants having a technical background as well as having had academic education (university or HBO). The reasoning for this choice was the estimation that a person with a technical background would be more likely to know the reasoning behind the considerations to use energy flexibility or not, as the literature discussed in Chapter 2 showed that these are often driven by technical concerns from within the chemical industry. Participants with a university or HBO background were preferred because they were seen as more likely to have roles in which they have a comprehensive understanding of the entire production process. Consequently they were seen to be more likely to be able to provide information that addresses the research questions outlined in this thesis. Although it is possible that some potential participants without an academic education in appropriate roles were missed, it is assumed that the information they would have been able to share would not have significantly differed from those with an academic background.

An unwanted bias in the selection is that the gender ratio of the people who fit the selection priorities is significantly skewed towards potential participants who are male. Considering the topic of this thesis it is unlikely that the gender of the participants would affect the findings from the interviews. However, if possible it is still valuable to have a diverse participant pool. For this reason in the cases where there were two or more participants who fit the criteria sufficiently well, and one of them was female, the female was given preference.

A final, unintended bias in the selection process leaned towards potential participants who were Dutch, rather than individuals with an international background. This was a bias the author only became aware of towards the end of the selection procedure. The driving force behind this bias was the assumption that people would be more likely to respond to individuals similar to them. It was assumed that there would be an increased chance of a response from the approached individuals if the initial message from the author was in Dutch. Although it is unlikely this actually affected many decisions of whom to approach (with the listed priorities driving most of the decisions), in hindsight it cannot be ruled out that it did play a role in decisions with candidates who seemed similarly appropriate. Considering the topic of this thesis it is unlikely that the national background of the participants would significantly affect the findings from the interviews. However, it would have been preferable to have an unbiased selection of participants to exclude this possibility.

3.2.5 Approaching Potential Participants

LinkedIn

Initially one person per company was selected to send a message to, using the priorities discussed above. Once the potential participants had been selected, a message was sent on LinkedIn using Inmail, a function which makes it possible to send a message to someone who is not in your network. A standard template was used consisting of three paragraphs. The first paragraph introduced the author and explained his research. The second clarified the reason for approaching the recipient and extending the request for an interview. Finally, the third paragraph highlighted the most important details of the interview such as duration and how privacy would be protected. The second paragraph would be adapted to each participants that was being approached. An example of the standard template used for these messages can be found in Appendix N.

The type of response to these LinkedIn message can be categorized into four different categories. The first category are the people who responded positively to the request for an interview. With these individuals appointments were made for the interviews. The second category are people who responded that their company was not using demand response. These messages were followed up with a message stating that even if their company was not using demand response, their perspective would still be valuable to include in this thesis. The third category were people who did not accept the message. In this case LinkedIn does not allow any further messages to be sent to that person. The final category is people who never responded to the message. After two weeks a follow up message was sent as a reminder. The template of this reminder message can be found in Appendix N.

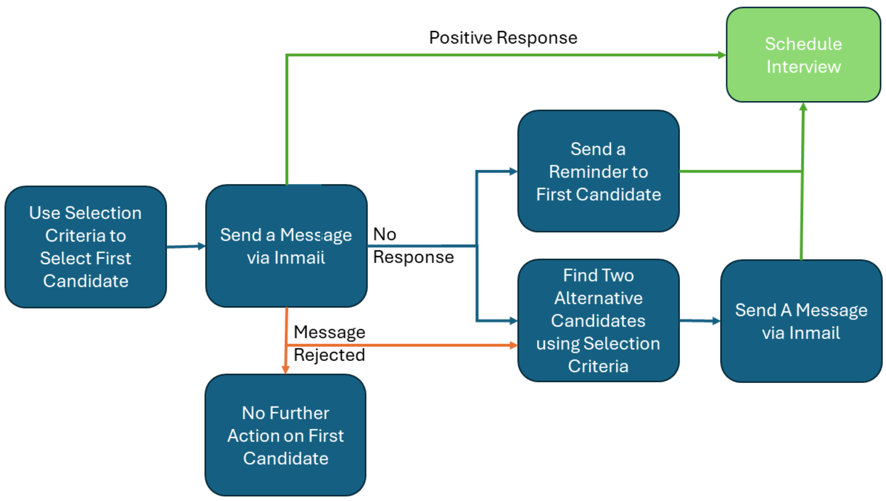

Fig. 7. A Schematic representation of the protocol used when approaching potentials participants via LinkedIn

In case no positive response had been obtained for a particular company after two weeks, two new people from the same company were approached, if suitable candidates could be found. Due to time constraints no subsequent messages could be send for these potential candidates. An overview of this protocol can be seen in Figure 7.

Social Network

Companies where someone worked who was in the social network of the author were approached either on WhatsApp, or by sending a regular message on LinkedIn (in contrast with the Inmail used for the cold approaches on LinkedIn). These relations were more likely to put in the effort to find the most suitable person to interview at their company.

Other Methods

Some other options were also investigated. Although the email of individuals working at companies can in general not be found online, there are publicly accessible email addresses, such as those of the company recruitment office. Some companies also have contact forms online, which were filled in with a similar message as was used for the LinkedIn approaches. Although some companies were approached using this method, this only played a limited role compared to the approaches through LinkedIn and the social network of the author.

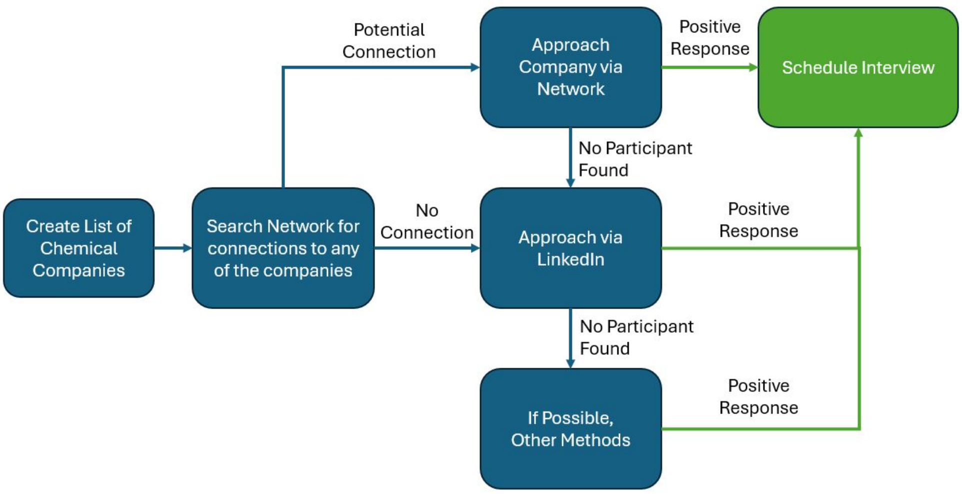

Fig. 8. An overview of the entire approach methodology

3.2.6 Effectiveness of Approach Methods

At twelve companies a potential connection through the network of the author was found. After approaching them this resulted in four interviews, with the others not succeeding due to not responding (1), the company being in the middle of a turnaround (1), not knowing a suitable connection with knowledge about this topic (4), or the interview not being possible within the time-frame of the thesis (2). Of the four companies were the network connection did not know a suitable connection, two companies were later interviewed through a LinkedIn approach (1) and an other method of approach (1). This method had a success rate of 25%.

Initially 52 messages were sent via LinkedIn which resulted in six interviews. Later, 35 reminder messages were sent, along with 70 messages to two new potential candidates per company. This resulted in eight positive responses, of which only four were possible within the time-frame of the thesis. A total of 167 message were send via Inmail resulting in 14 positive response, a success-rate of 8%.

One company was approached through a contact form for other companies, but which was used to send a message about the research. This approach was chosen after both a network approach and a LinkedIn approach had not been successful.

3.2.7 The Interview Process

Before the start of each interview, the participant's company was investigated using publicly available information on the internet. The aim of this was to be able to go further into depth during the interview itself, as well as being able to identify any potential aspects that would be interesting to raise during the interview.

At the start of the interview, the author introduced himself and briefly explained the purpose of his research. Next the participant was invited to briefly introduce themselves as well. Subsequently, the informed consent, including how the data would be used and their privacy guaranteed, was discussed. If there were no objections, the recording was started and the interview began, guided by the interview questions which will be discussed in the next section. Once all interview questions had been asked, or once the available time used, the interview was concluded and the participants were thanked for their help.

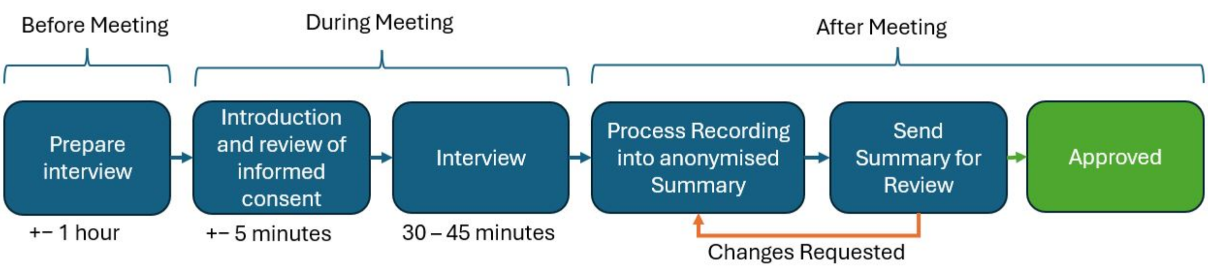

Fig. 9. A graphic overview of the interview process.

3.2.8 The Interview Questions

In this section the interview questions used will be discussed. As the interviews were semi-structured the actual questions asked, as well as their order, differed slightly from the questions and the order in which they are listed here.

Question 1: What is the core business of your company?

The aim of this question is twofold. Firstly it helps establish for the record what type of chemical company it is. Secondly it serves as a 'warm-up' question that will help make the participant feel more at ease.

Question 2: Does your company have greenhouse gas emission reduction targets?

Although this is another question that for most companies is easily found on their website, the way the question is answered can show how these goals are viewed internally. Is this a factor that is actively considered in decision making or is it seen as a politically correct action of the organisation?. This question also further serves as a warm-up and shifts the questions towards the next part of the interview.

Question 3: Does your company have a roadmap to achieve these targets?

Initially this question was only intended as a follow up to the previous questions. During the first few interviews it became clear that companies' approaches to roadmaps, varied considerably. Some had clear paths, while others lacked them altogether. As the interviews progressed, greater attention was given to this question, with follow-up questions aimed at understanding how these were viewed within the company.

Question 4: Can you estimate which part of the production process emits the most greenhouse gases?

This question established which part of the process would be their primary focus for decarbonization. It also helped establish whether there is potential for flexibility, while providing aspects to refer back to during subsequent questions.

Question 5 What measures is your company considering to reduce emissions originating from utilities?

This question established to what extent the participant's company uses electricity or natural gas, if that information had not already mentioned during the responses to one of the previous questions. It also determined the measures they were considering, the level of seriousness with which they were considering them, and the most important obstacles to implementing these measures.

Question 5 Follow up: Are you considering the decarbonization of process heat?

This questions was asked as a follow up if participants had only talked about reducing energy use. Did they omit mentioning decarbonization options because they have not considered them or because they consider them infeasible for their process?

Question 5 Follow up: Have you considered electrification?

Similarly, if participants mentioned a process emitting greenhouse gases and only discussed measures to reduce emissions from their current process set-up, this question was asked to establish whether they have also considered a significant redesign of their process.

Question 6 Is your company considering alternative feedstocks to replace fossil carbon feedstocks?

Some companies might have relatively low direct emissions but use feedstock which does have a significant climate footprint. This question established whether the participants' companies consider this kind of emission as 'their responsibility' and whether they exert pressure on supplies to address it.

Question 7 Does your decarbonization plan include a change in process technology, such as electrification (electricity-based processes such as electrolysis)?

This questions established whether the participants' companies were thinking from a continual improvement perspective or whether they were considering a major change in how the process operates.

Question 8: What problems does your company foresee that could arise from electrifying your processes?

This question allowed the interviewee to discuss the nature of their concerns regarding a significant process redesign. This was also focused on providing information which can be linked to the possible consideration of adopting flexibility in their process.

Question 9: Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

This question looked for information on whether participants were expecting the lack of grid availability in the Netherlands to limit the possibility of electrifying their process. During the interviews it became apparent that different companies have very different experiences dealing with the grid operators. This question was therefore used to dig deeper into how the participants' companies experience their relationship with their grid operators.

Question 9 Follow up: How are you planning to deal with those bottlenecks?

If a participant indicates that their companies do encounter bottlenecks, this question was meant to show how they plan to deal with this obstacle. This question also established information which could be referred back to for question 11.

Question 10: Would you consider running your process in a flexible way?

This is the purposely broad question where finally the main issue of flexibility is discussed. Many of the points of information collected during earlier questions could be used to deepen the follow up questions to the main question.

Question 10 Follow up: What are the main obstacles that prevent your company from doing this?

This question had usually already been answered during the initial answer but where this was not the case, this follow up question was asked.

Question 11: Would your company consider flexibility if it meant quicker access to more grid capacity?

Question 11 ties question 9 and 10 together. It became quickly apparent that companies are hesitant about flexibility due to the difficulty of ramping a production process up and down as well as due to the high costs of the infrastructure which needs to be earned back. This question tried to establish where balance lay for the participants' companies between these considerations on one hand, and the desire for more grid capacity on the other.

Question 12: Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility?

This questions attempted to delve into the question of the impact of regulations on their considerations. The answers to these questions tended to be fairly general although this might be explained by the fact that participants were generally individuals in technical roles who might not need to consider regulations in the context of their work.

Question 13: What role (if any) does flexibility play in your company's roadmap to GHG emission-free production?

Generally,this question also had already been answered by this point in the interview, although it acted a good reminder if this had not been the case.

Question 14 Is there a topic which was not addressed that you think would be relevant for this thesis?

This question was not initially part of the list of questions but was added as it became apparent that at the end of the interviews, interviewees were invested in the conversation and willing to engage in further discussion about these topic. The downside of prepared questions is that they limit the information provided. By asking this open question it was possible to get the interviewees to reflect on the interview and share information that generally tied into or deepened some of the questions already answered.

3.2.9 Processing the Interviews

All except one interview took place online. For the online interviews, the live transcription function of Microsoft Teams was used. For the in person interview the audio file was uploaded in Word, part of Microsoft Office 365, which has a function able to generate a transcript from an audio file.

Using the list of questions discussed in the previous section as a template the interview was summarized. All the information from the interview was grouped under one of the questions discussed above. Care was taken during this process to keep an open mind and not to let the summary be influenced by any biases the researcher may have. Upon completion, the summary was shared with the interviewee who had the chance to request the removal of any information as well as to clarify anything which might not be fully correct in the summary. Once the interviewee had given their approval, the summary became definite. Once the thesis has been concluded the participant will receive a copy of the thesis, after which all data related to the participants, except the informed consent forms and the approved anonymized summaries, will be deleted.

To identify the most important findings of the interviews, each summary was reviewed and interesting pieces of information were highlighted and added to an overview. The information in this interview was grouped into three main categories, each corresponding to one of the sub-questions of the research question. After this initial processing all the information in the overview was reviewed and similar observations within each category were grouped together. Subsequently all summaries were reviewed again in light of the observations made so far. Any observations in the summaries which either supported or contradicted these initial findings were noted in the overview. Observations which were not included in the first round, but were interesting in light of the initial findings, were also added to the overview. This process was repeated for several iterations.

This process resulted in a number of findings for each category. Next, these findings were analysed for their relevance to the topic and whether it was a valuable observation. Based on this a number of findings were removed from the overview. The remaining findings were ordered in a conceptual structure for the result section of this thesis. At this point a final read-through was done of all the summaries to see if the results matched the story in each of the summaries. The resulting conceptual structure was used to write the results chapter which can be found in Chapter 4

3.2.10 Data Management and Informed Consent

As this research collects Personal Identifiable Data (PID), the data management protocol and research set-up had to be approved by the Human Research Ethics Committee (HREC) of the TU Delft. To protect the data of the participants all recordings and other personal information were stored in Sharepoint account linked to the TU Delft account of the researcher. To ensure that participants cannot be identified based on their interview, any personal information was removed from the summary. Moreover, to ensure no information became publicly available which companies might not wish the share with their competitors, the interviewees had the right to remove any data from the summary of the interview, or to withdraw their consent. The full risk assessment as well as the Data Management Plan can be found in Appendix O.

4 Results

In this chapter, the findings from the data will be gathered using the methodology described in the previous chapter. This discussion will be divided into four sections. In the first section, Section 4.1, an overview of the interviewees and the characteristics of the companies they work for will be given. The status quo of their energy use as well at the use of energy flexibility will be discussed as well.

The will be followed by Section 4.2 which will analyze the roadmaps of the various companies, as described by the interviewees during the interviews. This will focus both on the importance of roadmaps in the organisation as well as on what is included in them. Finally, the impact of government policy on the roadmaps will be examined.

The third section will look at the roadblocks that the chemical industry in the Netherlands encounters in their plans to electrify their existing processes, and how these relate to the obstacles observed in the scientific literature which were discussed in Chapter 2.

In the fourth section, the factors that influence the decision to give energy flexibility priority in energy-transition roadmaps will be discussed. These will be compared against the factors which were observed earlier in the literature review on this topic.

The data supporting the findings discussed in this chapter can be found in the Appendix. Table 1 provides an overview of the anonymized name for each of the companies or participant, along with the appendix where the summary of the corresponding interview can be found. This table also includes the role of each interviewed participant.

Name	Appendix	Role Participant at Company
Company A	Appendix A	Engineering Manager
Company B	Appendix B	Energy Manager
Company C	Appendix C	Sustainability Manager
Company D	Appendix D	Energy Manager
Company E	Appendix E	Energy Manager
Company F	Appendix F	Energy Manager
Company G	Appendix G	Plant Manager
Company H	Appendix H	Plant Manager
Company I	Appendix I	Plant Manager
Company J	Appendix J	Engineering Manager
Company K	Appendix K	Process Engineer
Company L	Appendix L	Maintenance Engineer
Company M	Appendix M	Project Manager
Participant N	N/A	Program Director

Tab. 1. An overview of the interviewed companies and the appendix where the summary of the corresponding interview can be found

4.1 Overview of Interviewees

In total thirteen interviews were conducted for this thesis with participants working at companies. Twelve of these interviews were conducted with chemical companies in the Netherlands, while one was with a company currently working on setting up green hydrogen production plants in the country. Although this could arguably also be considered a chemical company, the challenges faced by such companies differ from those of the established chemical industry. However, due to the potential role of green hydrogen in the energy transition of the chemical industry, this perspective was included as well. The final interview was with a researcher at a knowledge institute, who was involved in projects relating to the potential of industrial flexibility in the Netherlands.

To facilitate the discussion of the results each of the twelve chemical companies has been categorized using the classification system described in Section 2.3.2. The classification for each of the twelve companies can be found in Table 2.

Another potentially significant factor which might influence the results is company size, as it can have implications for the resources available to the company. Finding a good way to measure size is difficult as the volume of production does not indicate how much value is produced, as was discussed in Section 2.3.2. Moreover, chemical companies are often part of multinational corporation, making it difficult to find accurate revenue numbers for a specific production site or country. The most effective way to measure this is basing it on the number of employees working for a particular company in the Netherlands, which can be estimated using LinkedIn. These numbers can be used as a rough indication of how substantial the presence of a company in the Netherlands is. An overview of these numbers can be found in Table 2. The numbers here are presented in ranges to preserve the anonymity of the interviewees and the company they work for.

Name	Category	Size (employees)
Company A	Commodity, Petrochemical	2500+
Company B	Commodity, Petrochemical	1501-2000
Company C	Commodity, Fertilizer	501-1000
Company D	Commodity, Fertilizer	501-1000
Company E	Commodity, Metal	2500+
Company F	Commodity	1501-2000
Company G	Commodity	201-500
Company H	Fine	201-500
Company I	Fine	1001-1500
Company J	specialty	201-500
Company K	specialty	2500+
Company L	specialty	2001-2500
Company M	Hydrogen	11-50

Tab. 2. A table with the category of the company, number of employees working for that company in the Netherlands, and role of participant at the company

As can be seen in Table 2,most interviewees work for companies in the commodity sector. These companies have been further categorized into the petrochemical, fertilizer, metal, inorganic, and polymer sub-sectors. The remaining three companies were classified as specialty chemicals. In the table it can also be seen that in there is no particular correlation between the size of a company and the category in which it is operating. The size of a company does function as a good indicator of the size of its scale of operations in the Netherlands.

4.1.1 Status Quo

Later in this chapter, in Section 4.2, the energy transition plans of the interviewed chemical companies will be discussed. To support those sections it will be useful to look at the status quo of the interviewed companies. First in Section 4.1.2 the current energy use of the interviewed companies will be examined. This will be followed by a discussion of the use of industrial flexibility among the interviewed companies.

4.1.2 Energy Use

There was a significant difference in the energy use among the interviewed companies, as well as in the primary source of their carbon footprints. The companies in the commodity chemicals category, with the exception of those in the polymer sub-category, generally reported much higher energy use than the companies in the specialty chemicals categories. Absolute energy use is dependent on the volume of production. To ensure a fair comparison, companies were asked to estimate the percentage of operational cost attributed to energy expenditure. An overview of their answers can be found in Table 3.

Name	Category	Main Source of Carbon Footprint	Percentage Energy of Overall Cost
Company A	Commodity, Petrochemical	Process Heat	Not mentioned
Company B	Commodity, Petrochemical	Process Heat	Not mentioned
Company C	Commodity, Fertilizer	Feedstock	60-70 %
Company D	Commodity, Fertilizer	Feedstock	60-70 %
Company E	Commodity, Metal	Process Heat	Not mentioned
Company F	Commodity	Process Heat	Not mentioned
Company G	Commodity	Process Heat	Not mentioned
Company H	Commodity - Polymer	Feedstock	<10%
Company I	Commodity - Polymer	Feedstock	<10%
Company J	specialty	Feedstock	<10%
Company K	specialty	Feedstock	Not mentioned
Company L	specialty	Feedstock	<10%
Company M	Energy, Hydrogen	Process Electrolysis	N/A

Tab. 3. An overview of the main source of the companies' carbon footprint, as well as the percentage of energy cost as part of the overall cost.

Although several companies did not share estimates of the percentage of energy costs, from the rest of the interviews it is clear that for companies A, B, E, F and G, energy costs constitute a large fraction of the overall costs. The specialty chemicals companies all indicated that energy costs accounted for less than 10 procent of their production costs. This is as expected as these companies mainly combines already produced feedstocks into compounds with a specific function. The two companies in the polymer sub-sector (Company H and I) also indicated that energy costs accounted for less than 10% of their production costs. The reason given by both companies was that their production process was exothermic, meaning that they generate energy internally and therefore do not require external energy input. Although both companies indicated that other parts of the process still required heat.

All commodity companies, except those in the polymer sub-sector, indicated that most of their footprint fell into scope 1, meaning they directly generated it themselves. Company F, where electrolysis is a key part of their production process, also had a major scope 2 footprint due to its high electricity usage. Additionally Companies F and G receive some of their steam from neighboring companies, which are therefore part of their scope 2 emissions. The most important feedstock to produce process heat was natural gas for companies C, D and F, and non-natural gas fossil feedstocks for companies A, B, E and G.

In contrast, companies in polymer (Company H and I and specialty chemicals (Company J, K and L) indicated that feedstock was the biggest component of their carbon footprint. This is because the feedstocks for companies in these sectors are typically several steps into the production chain, and therefore contribute significantly to scope 3 emissions (M. Martin et al., 2022). Combined with their relatively small energy consumption (see Table 2), this means that feedstock is the biggest contributor to their carbon footprint. This means that these companies will most likely have a different focus than the companies where the biggest contributors are the scope 1 and 2 emissions. This will be discussed further in Section 4.2.

The most significant source of scope 1 and 2 emissions for the companies in the polymer (Company H and I and specialty chemicals (Company J, K and L) sub-sector was process heat, taking the form of emissions from steam generation. All these companies reported that natural gas was used as the main source of energy for the generation of this process heat.

4.1.3 Flexibility

Among the interviewed companies three companies indicated that they were engaged in demand response. This section discusses the type of flexibility uses by the three of them.

will be briefly discussed for each of the three companies.

The first company is Company F. For this company electrolysis is a significant part of the production process. Electrolysis consumes a large amount of electricity and is comparatively easy to scale up and down. This makes it possible for Company F to scale their production up and down depending on the price of electricity, as well as allowing them to offer balancing services to grid operators.

The second company is Company E. Company E has a power plant associated with their production site, which partially runs on the byproducts of the production process. This power plant has the capacity to add more natural gas to the feedstock mixture in order to increase the power output of the plant. This allows the company to respond to electricity prices as well as to offer balancing services to the grid operators. In addition, some of the production units on the site of Company E can be temporarily shut down in response to electricity prices, or to avoid creating a large peak in electricity consumption.

The final company engaged in industrial flexibility is Company H. This is a company which uses a co-generation plant that produces both heat and electricity. These types of power plants often have the ability to vary the heat and electricity produced. At Company H both a co-generation plant as well as natural gas based steam boilers are present. This enables the company to adapt to price fluctuations between natural gas and electricity. The company is engaged in a limited amount of balancing services, although it has encountered issues when working with the grid operators. These will be discussed in Section 4.4.

An overview of the types of industrial flexibility by these companies is shown in Figure 10.

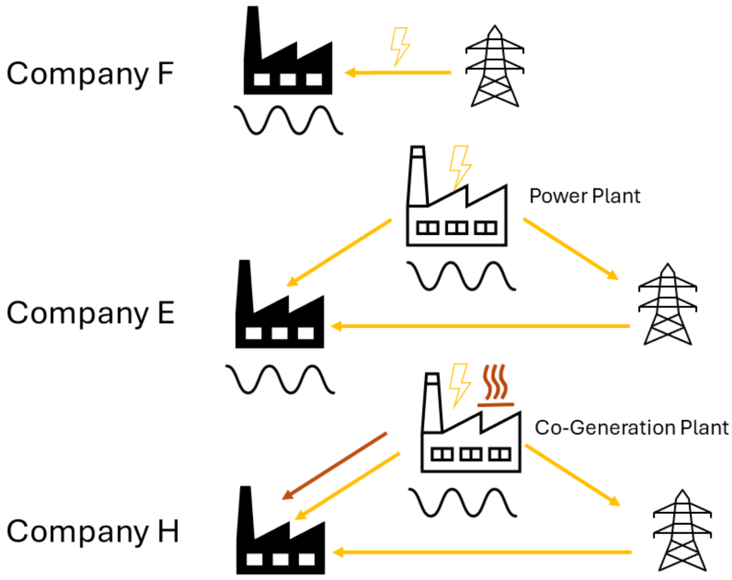

Fig. 10. A graphic representation of the different types of industrial flexibility used by company F, E and H.

4.2 Roadmaps

In this section the energy-transition plans of the interviewed companies will be examined, based on the description of these plans by the interviewees. These plans will be referred to as the roadmaps of those companies, although it is important that this does not refer to their publicly accessible roadmaps which some companies publish online. This section discusses first whether companies have roadmaps and what form they take. Next, the plans will be examined, focusing on companies' strategies to reduce their direct emissions, their plans to reduce the scope 3 emissions from feedstock and their initiatives for industrial flexibility. Finally, the influence of governmental policy on the roadmaps will be discussed.

4.2.1 The role of roadmaps

Every company interviewed reported having climate goals. Most of these goals were focused on the year 2030, as there is a government mandated goal for that year ("Verduurzaming van de industrie | Duurzame economie | Rijksoverheid.nl", n.d.). Which scopes were included in these goals differed per company with some companies only focusing on scope 1 and 2, while others mentioned that they intended to include scope 3 as well (company C and J).

As part of the interviews, participants were also asked whether they had roadmaps associated with their climate goals, and whether they played a role in the decision making of the company. There were significant differences in the level of detail of the roadmaps different companies interviewed, varying from detailed plans (Company A and Company C) to having no official roadmap at all (Company G).

The least developed plans were those of the small commodity chemicals company (Company G). The stated reason for this was the small financial margins in the business, making the available possibilities heavily dependent on the economic situation. According to the interviewee, this made it not useful to write a roadmap plan as 'a 5-year plan would be of limited utility in this business, I would probably need to rewrite it after four months' (Company G). The given reason for the small margins was the nature of commodity chemicals, where there is practically no difference between the company's product and that of their competitors. This competition based on price means that companies in this market are under pressure to produce for as little cost as possible. Although the production site in the Netherlands is part of a global company, only a limited amount of budget for sustainable improvements was allocated to each site. This meant the necessary resources had to be raised based on plant's performance.

This did not mean that Company G was not considering ways to reduce emissions from the production process. For example, they indicated having asked an outside consultancy to analyse options to reduce emissions from their processes. They also mentioned several steps which could be undertaken to improve their sustainability. However, these plans were not structured into a roadmap but rather had a focus on what might be the next nest step.

Although the other companies interviewed generally indicated having more developed roadmaps in place, or at least indicated the presence of one, the level of detail varied between companies. For some companies the necessary steps were clear (Company H, K, L), with mature technologies being available and no need for a fundamental redesign of the production process. These companies indicated having no certain timeline, with implementation of these plans depending on the economic situation.

Meanwhile, the remaining company in the specialty chemicals category, Company J, had clear plans for their energy-transition, with detailed plans to reach net-zero which were ready to be implemented. The constraint keeping these plans from being implemented was the lack of available grid capacity.

Finally, the remaining commodity, fertilizer and petrochemical companies reported having the most detailed roadmaps (CompanyA, B, C, D, E and F). These companies were also comparatively larger energy consumers than those in the specialty or polymer categories, as was established in Section 4.1.2. Most of these companies (A, B, C, D, E) indicated that their production process would need to fundamentally change in order to achieve the necessary reduction in carbon emissions. However, only company E indicated that this fundamental change in process was planned to start in the next few years. The remaining companies indicated that although these changes in process were included in their roadmap, they would only be able to implement them on the longer term.

An additional factor in the role of roadmaps is the practice of 'Maatwerk' (Custom Approach) by the Dutch government ("Maatwerkaanpak verduurzaming industrie: 8 getekende intentieverklaringen goed voor circa 10 megaton CO2-reductie | Nieuwsbericht | Rijksoverheid.nl", n.d.). Motivated by the need to achieve the climate goals for 2030, the government is negotiating with the largest carbon emitters amongst industrial companies in the Netherlands to help them reduce their emissions. Several companies which were interviewed as part of this research have signed, or are negotiating about singing, joint letters of intent with the government (Company C, D, E and F). They indicated that these were negotiations aimed at accelerating their energy transition plans in return for financial aid for the required investments. None of the other companies indicated that they had been approached by the government about a 'Maatwerk' approach.

4.2.2 Content roadmaps

In this section the content of the energy-transition plans at the companies of the interviewees will be discussed. First, the plans of the various companies to reduce emissions from direct energy use, targeting their 1 and 2 footprint, will be discussed. Next, the plans to reduce their scope 3 footprint by changing the feedstock used will be examined. This will be followed by a discussion of the plans to engage in energy flexibility. Finally, plans to reduce the environmental impact unrelated to the carbon footprint will be considered.

Scope 1 and Scope 2 Emissions

As discussed in Section 4.1.2, most the scope 1 emissions for companies arise from generating process heat for their production process. A number of companies (A, H, I and J) indicated currently being engaged in reducing their emissions through the reduction of energy use. Company A reported achieving this by replacing existing production units by more modern and efficient units. Both interviewed companies in the polymer category (Company H and I), as well as company J, said to be working on the recovery of heat which is released as part of their exothermic production process.

Energy reduction and recovery of heat was something that companies were either actively engaged in, or were planning to start on in the next few years. Another near-term plan reported by Companies B, I, J and K was to reduce the emissions from steam production. All companies interviewed in this category produced steam using natural gas. No company in this category indicated seriously considering heat-pumps to replace their steam production, even though it is more efficient than resistive heating used in an e-boiler (Thiel & Stark, 2021).

A potential reason for this, as was noted by Company J, is that integrating e-boilers would not require any significant redesign when asked if they anticipated any problems with electrifying their process. Similarly, Company B indicated that the heat integration of a production process would not need to change when replacing natural gas powered steam with e-boilers. In contrast, the literature discussed in Chapter 2 showed that heat pumps would require a redesign, as they would need to be connected to the heat integration of a production process. This makes the e-boiler attractive because it removes the up-front capital expenditure and risk associated with a significant redesign.

An additional benefit of using an e-boiler which was noted by several companies (B, I, J and K) was that it could be installed to function in parallel with natural gas based steam production. Company B and K indicated that this would allow them to adjust the source of their steam based on relative prices of electricity and natural gas. Company I noted that having two energy sources operating in parallel would mean that they would enable them to continue operating if one of the energy sources became inaccessible.

None of the companies from the polymer, or specialty chemical category indicated that a fundamental redesign of their production process was necessary or being considered, with only the source of their heat needing to be replaced to reduce their emissions from direct energy use. In contrast, almost all of the remaining companies in the commodity category (Company A, B, C, D, E and F) indicated significant redesigns of their process being necessary to reach their climate goals.

The timeline at which they anticipated this fundamental change would take place did differ between companies. Company F, already actively engaged in large-scale electrolysis, was already beginning to slowly replace natural gas based heating with heat pumps. The company in the metal sub-sector, Company E, reported having plans to start replacing production units in their near-term energy transition roadmap as well.

In contrast, the petrochemical (Company A and B) and fertilizer (C and D) companies indicated that their fundamental redesign would occur in the longer term, and only had rough indications when this would be. Company A and B indicated that this was due to the technology needed for that redesign still being technologically immature. Specifically, Company B indicated still being in the early development phase of the design of an electronic furnace and Company A was not yet actively engaged in the development of a similar unit, only noting it in its long term energy-transition plans. The second reason given by Company A was the focus on actions that are more cost-effective in the near-term, such as reducing energy consumption by modernizing production units and replacing appliances currently operating on steam such as compressors and pumps, with electronic alternatives.

Both fertilizer companies (C and D) indicated that although a redesign was necessary, the technology was not yet mature enough to make a final decision between the different options. They instead indicated that they were focusing on making the process more efficient and making improvements which do not yet require a fundamental redesign of the process. Both companies were considering replacing their production methods either with green hydrogen, or by employing Carbon Capture and Storage (CCS).

Feedstock

All companies except Companies F and G, which use non-fossil based raw materials, and K which did not share any information about their feedstock, expressed the intention to replace feedstock with sustainable alternatives to reduce their carbon footprint. The details of this differed by category, and each will be discussed in this section.

Companies I and J indicated that replacing their feedstock with renewable alternatives was an important focus. These companies are placed farther along the production chain and therefore impacted by the emissions generated in the production of the feedstocks they use for their processes. Both companies indicated having no interest in producing a sustainable feedstock alternative themselves, opting instead to either work with their suppliers in developing sustainable alternatives, or looking for alternative suppliers who could deliver such alternatives.

Besides the need to reduce their footprint, the two companies in the polymer category (Companies H and I) indicated that pressure from their customers was a significant factor in the decision to consider sustainable alternatives to their feedstocks. These companies indicated that this was likely primarily due to regulatory pressure on the packaging industry (Company H) and the automobile sector (Company I) which was then transferred to them as suppliers. Company J also indicated working on replacing its fossil fuel feedstocks but indicated that this was most likely due to the consumer preference of having sustainable products.

Petrochemical companies (A and B) currently use feedstock derived from fossil resources. Both interviewed petrochemical companies indicated that they were investigating alternative feedstocks for the crackers, namely biological and recycled plastic. Company A also indicated that in the design of their future furnaces, the capability to handle different feedstocks was going to be included. This would allow them to engage in feedstock flexibility, which was discussed in Chapter 2. However, company A also indicated that they expected that even in the long term fossil fuel derived feedstocks would still be used to some degree as a feedstock.

The two fertilizer companies (C and D) currently use natural gas as their main feedstock in their production process. The companies indicated that they were considering two different options to reduce the reliance on natural gas. The first was to use natural gas to produce hydrogen and CO_2, with the emission of the CO_2 being avoided using carbon capture and storage. The second option noted by the companies was using hydrogen to directly replace natural gas as a feedstock. In the long term, this would be green hydrogen produced by electrolysis. Company C indicated that they were considering hydrogen themselves (Company C). A critical decision factor for this is the grid capacity necessary for such a production, which will be discussed in Section 4.3.

Industrial Flexibility

Industrial Flexibility was included in the energy transition plans of ten of the twelve interviewed companies. This section will explore these plans and the level of flexibility aimed for by these companies will be discussed. Firstly, the flexibility offered by operating different forms of energy in parallel will be examined. Then, the companies considering flexible operation of chemical processes will be discussed.

The first form of energy flexibility which companies are considering is indirect demand response through the production of process heat. As discussed in the previous section there are several companies (B, I, J and K) which are considering installing e-boilers in parallel to natural gas based steam production. Two of these companies, B and K, indicated that they would run the e-boiler whenever this was cheaper than natural gas based heat, which would be a form of implicit demand response. A graphical representation of this can be seen in Figure 11. This is a similar form of flexibility which is already being practiced by company H. It is likely that companies implementing this would also consider offering balancing services to the grid if it was financially beneficial, although none of these companies explicitly mentioned it. Company H, already engaged in a similar form of energy flexibility, expected that upon decommissioning the natural gas based heat, they will no longer have the capacity for flexibility. The other companies did not mention whether they expected to be able to offer flexibility once they have decommissioned their natural gas based heat, with the exception of Company J who was considering the installation of a battery to function between the grid and their electricity usage. Although not mentioned by these companies, there would be the potential for flexibility through batteries or heat storage (Thiel & Stark, 2021).

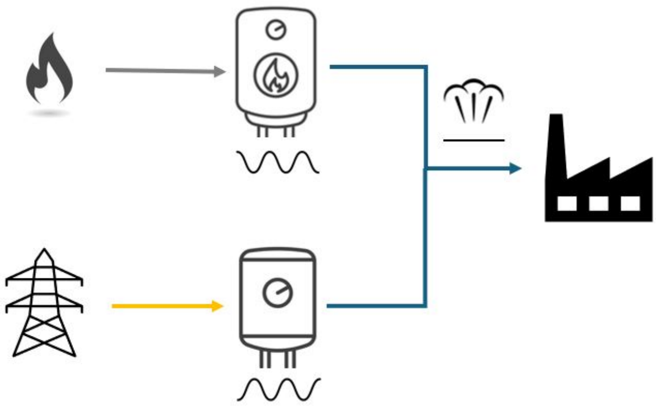

Fig. 11. A graphical representation of the plan to operate both natural gas powered steam production along with electronic steam production, allowing the company to engage in industrial flexibility

The companies already engaged in flexible operation of their processes, Company E and F, indicated that they would seek to increase their flexibility potential. Company F reported already being in the process of slowly replacing production units operating on natural gas based heat with heat pump based heating which would enable them to increase their flexibility capacity. Company E, which is planning to change to hydrogen as one of their main feedstocks, indicated that if they produce hydrogen themselves this would allow them to increase the amount of energy flexibility they could engage in as well. Company C, which indicated that they were also considering producing green hydrogen as a feedstock for their process, also noted that it would allow them to engage in energy flexibility. However, this was only noted as a theoretical option, with a number of obstacles noted that would make implementation difficult.

Company A, B, D all indicated that a wider turn-down ratio would be included in the design criteria of future electricity (A and B) or hydrogen based production (Company D), although these would only be possible once they had redesigned their production process, which all three indicated would only occur in the longer term. Although the flexibility being considered by company D would be flexibility of hydrogen usage, this would still constitute a form of energy flexibility. Although Company D did not indicate whether they would produce hydrogen themselves, it would allow them to indirectly respond to electricity demand, as electricity would most likely be used in hydrogen production.

Finally, company G, despite not having a detailed technology roadmap, indicated that they might be able to offer a limited form of flexibility in the long-term, by adapting to a day-night rhythm with a lower capacity at night. However, this was only noted as a theoretical possibility in the long term.

Environmental Concerns

Companies C, J and M indicated that besides emission goals, reducing the impact of waste products on their local environment also played figured prominently in their roadmaps. Company J and M indicated that this was even a more important aspect of their technology roadmaps compared to the need to reduce their carbon footprint. Especially for companies who have a relatively little emissions from direct energy use, other factors might have more of their focus than reducing their carbon footprint.

4.2.3 Government Influence on roadmaps

Governmental policy was mentioned multiple times during the interviews as a significant factor affecting energy-transition plans. Almost all interviewed companies indicated being under pressure by the regulatory environment. Companies C, D, J even indicated that shifting investments to other locations outside the Netherlands due to the impact of those factors. In this chapter the different reasons mentioned by the interviewed companies will be discussed.

The first reason is the lack of an equal playing field between countries, mentioned by companies F, E and D. They specifically indicated that the relatively high grid fees in the Netherlands compared to other countries were an important factors in reducing the competitiveness of the Dutch chemical industry. Due to grid congestion and the anticipated increased need for grid capacity, many new grid connections are being built (TenneT, 2023b). Company F reported that while in other countries companies were partially compensated by the government for this cost, that this was not the case in the Netherlands. An example given by Company F to illustrate the impact of this was the fact that zinc producer Nyrstar, a large electricty consumer, was forced to shutter its production in the Netherlands in early 2024, while being able to continue production in Belgium (“Nyrstar Budel’s zinksmeltactiviteiten worden op care & maintenance gezet | Nyrstar”, n.d.). This observation by Company F is supported by Nyrstar’s contribution to the government consultation on the removal of the discount for large energy consumers (ACM, 2023).

Another important impact of government policy is the lack of necessary infrastructure such sufficient capacity on the electrical grid, as mentioned by Company J. This is also an important obstacle to electrification, which will be discussed further in Section 4.3. Company C and J both indicated that this lack of infrastructure might even result in them shifting investments to other countries. The interviewee of Company J indicated choosing between the Netherlands, where infrastructure constraints pose significant constraints, and an alternative location with no such restrictions, would be difficult for the Netherlands location.

that an investment decision might be between the location in the Netherlands, which is heavily constrained by a lack of infrastructure and a different location with no such constraints would be difficult for the location in the Netherlands.

The competitive field outside of the European Union was reported to be an important factor as well by Companies A, D and K. Although regulations concerning carbon emissions are largely the same across the European Union, this is not the case for all countries outside the European Union. Companies A, D and K indicated that competing with companies which do not face the same level of regulations can be difficult, and Company K indicated that this threatened the feasibility of chemical companies operating in the European Union. CBAM, which is a tariff on imports into the European Union to compensate for the lack of a carbon tax, protects the competitive position of chemical companies within the European Union, but does not enhance their global competitiveness (Zhong & Pei, 2024). Company D indicated considering moving to other countries to avoid the regulatory pressure of the EU.

Finally, another factor is the unpredictability of policies, indicated by Companies G, J and D. These companies indicated wanting clarity about what they are up against while the focus of the government can differ significantly depending on the political views of the current government at any given time. Company C indicated not wanting to commit to certain plans until a final policy had been decided by the government.

4.2.4 Discussion

The results from this section show that the level of detail varied significantly from company to company, with greater emphasis on it for companies which use more energy. The companies with more detailed plans also generally indicated that a change of production process would be necessary, while the companies in the polymer and specialty chemicals industries generally only needed to replace the source of process heat for their steam, for which mature technologies, such as the e-boiler are available.

The technological maturity and cost-competitive were the most important criteria for technologies to be included in the near term plans. Technologies such as the e-boiler, intended to replace steam production, or heat pumps to electrify the extraction process at company E, are scheduled to take place in the coming years. Meanwhile, the more fundamental changes in process operations considered by several commodity companies, are planned to take place farther into the future.

Plans to reduce the emissions related to direct energy use were mainly focused on electrification, with only the petrochemical industries considering biological feedstocks as well. This matches the results by Kloo et al. (2024) which studied the public energy transition roadmaps published by industry associations. This implies that the potential significant increase discussed during the literature will most likely occur, strengthening the need for industrial flexibility.

Some form of energy flexibility was considered by ten out of twelve interviewed. However, only for two of those ten was it given priority in their near-term plans. These were the companies which were already engaged in flexible operation of their production processes. For four companies, mainly those in the polymer and specialty chemicals sub-sectors, the switch to electronic boilers provided an opportunity to engage in implicit demand response by switching between energy sources. However, these appeared to be secondary reasons to implement these technologies, with the ability to engage in flexibility noted as a nice bonus. An important factor in this is most likely the small part of energy in the overall production costs, making it less attractive to make this a priority in the companies' energy transition plans. Moreover, some of these companies indicated that feedstock or environmental concerns were a more important focus of their roadmaps, diminishing the priority given to energy flexibility in their plans.

The remaining companies, all of which are larger energy users, acknowledged the benefits of incorporating energy flexibility into their energy transition plans. However, since the technologies enabling this were placed in their long term energy-transition roadmaps, they are most likely limited by the technological immaturity of the processes necessary for participation.

These results do conflict somewhat with the study of industry publications performed by Bielefeld et al. (2023) which showed that flexibility was mentioned by almost no companies. This might be because in the interviews, participants were willing to share more than was published in their online roadmaps. It might also indicate that the use of energy flexibility has a relatively low priority compared to the plans which are noted in their publicly facing energy transition plans.

One important caveat which needs to be kept in mind when considering these findings is that many companies reported that although the roadmap was an important guideline, it was not set in stone. Especially with the lack of grid infrastructure, challenging investment climate, and uncertainty related to government policy, it is possible that these energy transition plans could change, or even become defunct if companies decide to close production locations in the Netherlands.

There is another potential weakness to the findings discussed in this section, and that is the way the data was collected. The results are only based on what the participants reported during the interviews, with no validation from their own published roadmaps. This was not possible as participants were promised anonymity to allow them to speak more freely during the interview. However, this means the reported energy-transition plans cannot be compared to the publicly facing roadmaps that some companies publish. The results from the interviews are more likely to reveal the true plans than a publicly accessible roadmap which might be used as window-dressing. For example company G, which indicated not having a roadmap, did have a publicly accessible roadmap available online. Despite cases such as these, published roadmaps would make it less likely that certain information was missed. As the interviews were semi-structured, not all participants were asked the same questions in the same context. Although this was taken into account during the interviews as well as during the analysis, it is possible that differences reported here actually do not exist as a participant simply did not mention it during the interview.

4.3 Obstacles to Electrification

In this section the obstacles encountered by chemical companies in the Netherlands when exploring the possibilities of electrification in their technology roadmaps are considered. First the technological constraints due to immaturity of the technology will be considered. Next the challenge presented by the necessity for a redesign of processes will be discussed. Subsequently, the role of the electrical infrastructure will be examined and finally the role of the dependence on a different energy source.

4.3.1 Technological Challenges

Many of the technologies being considered for electrification are new and not yet technologically mature. This can form an obstacle for chemical companies as the capital intensive nature of production equipment makes it risky to implement new technologies. In this section the role these technological challenges play in the decision to implement electrification in the roadmap of a company will be examined.

Certain technologies such as e-boilers and electrical appliances (e.g. compressors or compressors or pumps), were mentioned by companies as being mature technologies which could metaphorically be ordered 'off the shelf' (Company J and K). These were often mentioned in the near-term energy transition plans of those chemical companies which were planning to implement them (Company J and K). Heat-pumps were also mentioned by Companies B, F and H as being currently being used or as being in their near-term energy transition plans, indicating that the technology is mature.

Company I indicated that there were no electric alternatives that could reach the temperatures that were required in their production process. Although the literature shows that heat pumps are currently limited in their heat range, resistive heating should be capable of reaching most temperatures used in the chemical industry (Thiel & Stark, 2021). However, most likely this is not considered as a serious option as it is not cost competitive with natural gas. A solution which was mentioned by this company as a potential hybrid solution was to initially heat the process using electrical means, and then completing and adding the remaining heat using natural gas as is currently done.

One of the options discussed in the literature is the use of hydrogen to replace natural gas in the burners (Thiel & Stark, 2021). None of the interviewed companies saw this as an option, one citing the price as being too high to be used in such a fashion (Company B). At the current technological level, hydrogen, let alone green hydrogen, is not competitive enough to be considered for such a role. This leaves a temperature gap which no emission free alternative can cost-competitively fill.

For three companies, hydrogen production would be essential for their energy transition roadmaps (Company C, D and E). Companies C and D are active in the fertilizer sub-sector while Company E is a metal producer. All mentioned the cost competitiveness of green hydrogen as a significant critical obstacle for their energy-transition plans. Company C indicated that a significant scale-up would be necessary compared to current plants, needing several times the capacity of the Holland Hydrogen I, one of the largest green hydrogen production plants in Europe currently being built by Shell, to create enough hydrogen for a single factory. The uncertainty regarding whether the scale-up required cost reductions can be achieved increases the risk for companies like this to successfully reduce their emissions.

Company E mitigates this uncertainty by designing a hybrid phase into the redesign of their factory, thereby allowing natural gas to be used until hydrogen is at a mature enough level. Companies C and D were also contemplating blue hydrogen, a process that involves converting natural gas to produce hydrogen while capturing the resulting carbon dioxide, with company C noting it as a potential hybrid solution until green hydrogen can be scaled up to a sufficient level.

Another technological challenge is being faced by the companies operating in the petrochemical industry, Company A and B. As discussed in section 4.1, these companies process a feedstock in furnaces which subsequently is used to produce various base chemicals. Electrical variants of these furnaces are in a very early stage of development but the development for this would still take until at least the middle of the 2030s. Both companies noted a challenge associated with this technology: its significantly different role in heat integration with the rest of the production site, which would require a redesign of process. This will be discussed further in the next section.

4.3.2 Process Redesign

Another obstacle which companies reported during the interviews was the need to redesign their processes. Chemical companies are often heavily integrated, with waste-heat of one process being used to heat another part of the process (Dunn & El-Halwagi, 2003). Technologies which require a redesign of this integration are riskier and costlier (Company A).

An example of this is the preference of Companies B, I and J to use an e-boiler instead of a heat pump, even though a heat pump is much more efficient than an e-boiler (Thiel & Stark, 2021). One of the reasons, already discussed in Section 4.2, was that it would allow them to use both the e-boiler and the older natural gas powered steam boilers take advantage of the most attractive price. The second reason noted was the ability to install the e-boiler without any redesign of the heat integration of the production process. This might be preferable to the reduced energy costs of a heat pump as it would require less investment up front and would entain less risk as most of the process would remain the same. Moreover, it might be easier to convince other stakeholders in the organization to go for a less invasive technology, allowing the company to get used to the new technology while retaining the natural gas powered alternative as a fallback.

Companies where the production process is less integrated, as is the case for Company E, which has multiple units not directly linked to each other, and Company F, which indicated that production steps were spread out over several locations, reported fewer issues with the redesign of the process. This allows them to build new production units while the old units are still running.

These challenges associated with the redesign were most significant for the two petrochemical companies, Company A and B. These companies are considering using electrified furnaces. However, both companies indicated that this would require a redesign of the heat integration of the production process To integrate this technology into the production process, the heat integration would need to be completely redesigned and rebuilt. The interviewee representing Company A compared this to conducting open heart surgery, as production cannot be shut down for a long time. These challenges make alternative technologies, such as implementing CCS, more attractive. Company B indicated the comparative ease of this by referring to the implementation as no more than a bolt-on unit.

Name	Category	Grid Congestion an Obstacle?	Impact or Motivation
Company A	Commodity, Petrochemical	Yes	Rearrange roadmap Postpone plans that require electricity
Company B	Commodity, Petrochemical	Yes	Limiting factor for energy transition plans
Company C	Commodity, Fertilizer	Yes	Limiting factor for energy transition plans Postpone investment decisions
Company D	Commodity, Fertilizer	Yes	Postpone plans that require electricity
Company E	Commodity, Metal	No	Grid connection recently expanded
Company F	Commodity	Yes	Limiting factor for energy transition plans
Company G	Commodity	No	No increase in electricity demand expected
Company H	Fine	Yes	Limiting factor for energy transition plans Scale down energy-transition plans
Company I	Fine	Yes	Not mentioned
Company J	specialty	Yes	Limiting factor for energy transition plans Postponement of energy transition plans
Company K	specialty	No	Not mentioned
Company L	specialty	No	No increase in electricity demand expected
Company M	Hydrogen	Yes	Critical factor in location selection

Tab. 4. An overview of the impact of grid congestion on the energy-transition plans of chemical companies.

4.3.3 Grid Congestion

A potential obstacle for electrification in the chemical industry is the ability to obtain the electricity necessary for electrifying. As discussed earlier in Chapter 2, the Netherlands is currently facing a serious shortage of electrical grid capacity, leading to grid congestion. In this section, the impact that this grid congestion has on the electrification plans of chemical companies in the Netherlands will be considered. Next, the increased importance of location will be discussed. This will be followed by an examination of the impact of uncertainty in this regard for companies. Finally, the relationship of the interviewed chemical companies with the grid operators will be explored, as well as how this affects the energy-transition plans of those companies.

Impact on Electrification Plans

All but four of the interviewed companies, Company G, E K and L indicated that grid congestion was a significant obstacle to the implementation of their energy-transition plans. One of the most immediate effects is the delay of projects. An example of this is Company J, which indicated having to postpone a plan which would get their production location to net-zero because the company's inability to obtain an expanded connection until 2031. Even larger companies such as Company A had to rearrange their energy-transition roadmap to push forward projects which did not require additional electricity while pushing backwards electrification plans.

The four companies which did not report anticipating issues with getting a grid connection either use virtually no energy (Company L), recently received an expansion of their grid connection (Company E) or assumed that by the time they would electrify the net congestion will have been solved (Company G). Company K only noted that there was no grid congestion present in their area.

Location

Increased use of electricity by industry makes the location of production sites more important. Company E is planning to use hydrogen to decarbonize their production process. The interviewee noted that producing hydrogen themselves is being considered as an option as the company is well located on the coast of the Netherlands. A lot of green energy in the Netherlands is generated in wind-parks at sea. If that electricity is used near the coast, no grid infrastructure is needed to move it further inland, providing relief to the grid. Company A expressed similar sentiments about the possibility of producing hydrogen at their location. This shows that grid congestion can also be an opportunity for companies, not only a roadblock.

An interesting side-note regarding location is the experience of the future hydrogen producer, company M. Their main production process is using electricity to produce hydrogen out of water, leading to significant electricity needs. However, the company indicated having no issues with grid connection at the sites where building will occur. This is due to choosing locations where there is enough space in the grid. In contrast to established chemical companies, which have a lot of existing production infrastructure at specific sites, this company is able to select greenfield locations with no grid capacity issues. The company indicated that grid capacity is one of the most important factors in the selection of locations for their production site.

Increased Uncertainty

Grid congestion was still considered the most significant roadblock to electrification plans by most companies. Several companies (A, B, C, F) indicated that their technology roadmaps depended on getting a large enough connection. The uncertainty about whether they will be able to obtain a grid connection for their electricity means that companies cannot execute their energy transition plans as they would want. This results in energy transition plans being delayed.

Noteworthy in this context are the companies which are in talks with the government and have signed joint letters of intent (Company D and F) to reduce their emissions. Company F indicated that they expect help from the government in obtaining a sufficiently large grid connection. Companies which are large energy consumers might be able to leverage the desire of the government to accelerate the reduction of emissions into assurances about sufficient grid connections.

Two companies also cited this uncertainty as a possible reason to shift investments to another country, where infrastructure is not a constraint to the electrification plans (Company D and J). This means that beside the other obstacles to electrification plans, the lack of sufficient infrastructure might also result in a smaller chemical industry in the Netherlands, as companies choose to invest elsewhere or leave.

Relationship with Grid Operators

The process of obtaining an increased grid connection depends significantly on the size of the company, with large commodity producers generally reporting better relationships with grid operators.

Smaller companies in the fine and specialty chemicals sectors reported having bad or neutral experiences with grid operators. Two companies indicated having had applied for more capacity than they needed (Company H and J). If electrification plans change, companies would not want to move to the back of the waiting list again, which leads to applications for more capacity than would be needed under their current plans. This results in inflated applications, which make it unclear to the grid operators where new grid connections are needed most.

One company also indicated currently having more capacity than needed (Company H). Although giving up this increased capacity temporarily would not be considered a problem, the company would want to maintain their right on the original capacity for their future electrification plans. Under the current legislation it is not possible to temporarily 'rent' capacity to another company. As legislation considers a grid connection a right, it is not legal to sell it to others. Some companies indicated that the ideal situation did not match reality, thereby leading to the situations described above. One counteracting pressure against this type of hedging is the fixed grid fees that companies need to pay for their connection. Although Company H indicated that in their estimation it was beneficial to keep the connection, this hedging of unused capacity does come with a financial cost.

Another aspect highlighted by Companies B and D, is that grid operators only want to build new grid connections if they have the assurance that the capacity will be used. In contrast, companies only want to commit if they know that the grid connection will be there (company D. This results in dead-lock in negotiations, leading to further delays in the building of new grid connections.

4.3.4 Discussion

A number of obstacles to the electrification of the chemical industry were identified in this section. The obstacle which was mentioned most often by participants was the lack of available grid capacity. This is an obstacle which is especially relevant for the electrification plans in the near-term as companies report having to postpone electrification plans or to adapt their plans. However, companies did not report that this was a reason to consider alternative emission reduction plans. This implies that companies do not see the alternative options as viable. A lack of available grid capacity primarily causes the postponement of plans and not the cancellation of plans. However, as was discussed in Section 4.2, many companies reported considering shifting investment to other countries, due to factors such as the lack of necessary infrastructure.

Although lack of infrastructure is mentioned as an obstacle to electrification in literature (Wei et al., 2019), it has not been identified as a major obstacle in the scientific literature. However, the fact that grid congestion is a less significant issue in other countries as compared to the Netherlands, could be an explanation for the lack of significant attention to this matter in the scientific literature.

The second most important obstacle identified are the technical challenges associated with the potential technologies that can help companies electrify their chemical processes. This is not a surprising finding as there is a lot of focus in the scientific literature on assessing the technological maturity of different technologies (Wei et al., 2019). Only one of the twelve interviewed companies was planning to implement a significant change in process in the near-term, while several others have only mentioned it on their long term energy transition roadmaps. Companies that only needed to replace their source of process heat faced fewer obstacles, as most of them anticipated that current mature technology would facilitate the transition.

This conclusion was reached based, partially, on whether companies had placed specific technologies into their near or long term energy transition roadmaps. A potential weakness to this method is that it might overstate the impact of this factor. Companies might see a certain technology as viable but choose to focus on lower hanging fruit such as energy recovery or the replacement of steam powered appliances. While this is likely a contributing factor, it is worth noting that the technologies needed by these companies, such as large-scale hydrogen production and electrified furnaces, are still highlighted in the literature as needing further development (Mallapragada et al., 2023).

A final factor in the decision making to electrify is the need to redesign existing processes. Although this factor did not appear to be a significant factor in this research, the results show that companies prefer electrification technologies which do not require a redesign of the integration of their production processes. Interestingly, even though this would appear to be a logical preference of companies this was not a factor which was identified in the literature discussed in Chapter 2. This is most probably because it is not a fundamental barrier, but anticipating it could make efficient technologies such as heat pumps more attractive to chemical companies.

4.4 Industrial Flexibility

During the interviews, industrial flexibility was an important focus. In this section the obstacles that companies reported hindering the implementation of industrial flexibility will be discussed. Throughout this section the results will be compared to those found in the key papers considered in Chapter 2 by Bielefeld et al. (2023), Lashmar et al. (2022) and Leinauer et al. (2022). An overview of the obstacles that companies encountered and which companies reported them can be found in Table 5. In the rest of the section each of the obstacles will be discussed in more depth.

	Obstacle Mentioned by:														
Obstacle	(Bielefeld et al., 2023)	(Lashmar et al., 2022)	(Leinauer et al., 2022)	A	B	C	D	E	F	G	H	I	J	K	L
High Capex, Low Margins	X				X	X	X			X	X				
Increased Wear & Tear	X	X				X			X					X	
labor Costs		X								X				X	X
Design Limitations	X	X	X	X	X	X	X				X	X			
Production Schedule	X	X			X					X	X				X
Operational Flexibility													X		
Instability of the Value of Flex		X	X		X										
Automation Concerns			X					X	X		X				
Third Party Balancing Service Manager	X														

Tab. 5. An overview of the different obstacles mentioned by interviewed companies, as well as the works by Bielefeld et al. (2023), Lashmar et al. (2022), and Leinauer et al. (2022).

4.4.1 Obstacles

High Capex, Low Margins

One of the obstacles that was mentioned most frequently was that production equipment was a very high investment which needed to be earned back. This was mentioned by company B, C, D, G and H. According to the interviewees the only way to do this is would be to run the production process at maximum capacity as much as possible. Incorporating flexibility would involve operating the equipment below maximum capacity, while still accumulating wear towards its end of life. Even if the maximum capacity were to be expanded to enable similar average production while allowing for scaling up or down, the capital expenditure of this increased capacity may not be earned back. This obstacle was also identified in the work by Bielefeld et al. (2023).

labor Cost

Another related objection mentioned by three companies (K. G and L), is the cost of labors. For these companies, one of the main objections to flexibility is that the labor cost of the operators would still need to be paid even if the process were to be scaled down. Company K and L noted that this did not weigh up against the financial benefits that might be gained by operating flexibly.

Another impact on labor, noted by company K, was that they expected that it would be more difficult to retain operators. If the schedule of operators were to become flexible the interviewee from company K expected that a rapid turnover of operators would occur. According to the interviewee this would be a problem, indicating that it is currently difficult to find operators on the labor market.

Labor as an obstacle was also noted in the work by Lashmar et al. (2022). However, since their work focused on the industry in general, the interview results confirm that similar obstacles exist in the chemical industry. This appears to be mainly an obstacle for small energy consumers for whom there is little to gain by operating flexibly. In such cases, additional costs can quickly outweigh the benefits. Interestingly, the fact that this was noted by company G, a larger energy consumer, suggests that this might also play a role for larger companies.

Increased Wear and Tear on Equipment

Another important impact mentioned by Companies F, C and K was the increased wear and tear on equipment. Many processes in the chemical industry are designed to operate continuously at a constant capacity. The interviewee from Company F indicated that scaling a process up and down puts more wear and tear on the equipment than keeping it at a constant level of operation. Despite this Company F already started operating their process flexibly, although it is not yet clear to what extent this wear and tear will reduce the lifetime of the equipment. This obstacle is linked to the first identified obstacle of high capital expenditure. Increased wear and tear would necessitate earlier equipment replacement, resulting in the need for additional revenue generation. This also adds an uncertainty factor for companies to engage in industrial flexibility as the rate at which the equipment degrades faster in such circumstances is unknown.

While the paper by Bielefeld et al. (2023) mentioned the obstacle that non-optimal use would degrade the equipment, it did not discuss the impact which simply scaling up or down would have on the lifetime, and therefore on the required investment of the production equipment.

Design Limitations

Another noted objection mentioned by several companies is the fact that their processes are not designed to operate at lower capacities (Company A, B, D, H) which means that this cannot be done safely. This is called the turn-down ratio. Although it would be possible for some processes to design the equipment to handle a wider operating window, most indicated that the additional effort to do this would not be outweighed by the financial benefits gained from flexibility, as it would be difficult to earn back the necessary capital investments.

Another design limitation is the high level of integration in the production process of many chemical companies. Companies stated that it would be infeasible to design flexibility into the equipment without losing the benefits of such an integration (Company A and B). A potential way to deal with this, as suggested by Company A, was to engage in a form of indirect demand response. The example given by Company A was to design its furnaces with a larger turn-down ratio, while designing the follow up processing of the cracked feedstock to handle a constant load. For companies with highly integrated production equipment, indirect demand response is the most likely way in which they would be able to engage in industrial flexibility.

This is related to the obstacle identified by Bielefeld et al. (2023) who found that interdependencies between different companies in the same cluster could make adopting industrial flexibility difficult. Although this obstacle was not mentioned by interviewees in this research, similar interdependencies also exist within the production process of a single company, if it uses advanced heat or other kind of integration. Process interdependencies was mentioned by Lashmar et al. (2022), although only briefly.

Production Schedule

The impact that industrial flexibility would have on the production schedule is also a frequently mentioned obstacle (Companies B, G, K). Companies indicated often having specific deadlines or monthly quota's. Although engaging in industrial flexibility might offer some financial rewards, the penalties associated with missing those deadlines are more significant. An interesting alternative example for this obstacle is Company M, which is planning to produce hydrogen. The contracts with their customers include clauses that take into account the impact on the schedule of engaging in industrial flexibility. Customers are willing to do this because the hydrogen gets mixed in with grey hydrogen, which is currently their primary source of hydrogen, and any decrease in the production from Company **??** can be compensated with more grey hydrogen.

Similar objections were noted in the paper by Leinauer et al. (2022) and Lashmar et al. (2022). Leinauer et al. (2022) focused on the potential in the industry in general but both chemical companies which were interviewed as part of that study indicated the production schedule as an obstacle.

Another aspect of this obstacle was mentioned by Company J, where production occurs via batch production. This means that their energy use is not steady throughout the day. Although the interviewee admitted that it would theoretically be possible to schedule the production in such a way that these peaks occurred during hours when electricity was cheap, this was judged not to be beneficial compared to the loss of flexibility in their production schedule. If something were to delay start of a batch, the production window would be lost.

Instability of the Value of Flex

Company B noted that it was difficult to make a business case as the value of flexibility was not stable. The reason for this is that flexibility is organized based on a bidding system, whereby the grid operators opt for the cheapest offer for flexibility. However, as the company would need to make substantial investment to be able to offer flexibility, it would be important to have a stable value of flexibility to make the business case possible. A contract with implicit demand response, whereby flexibility would have a fixed value, would make engaging in industrial flexibility more feasible.

This is an obstacle that was also found in the paper by Bielefeld et al. (2023) as well as Leinauer et al. (2022) who noted that the payback time would be difficult to determine due to the electricity savings and benefits from providing grid balancing services not being fixed.

Automated Controls

There are some companies that have the ability to offer industrial flexibility on the market but have noted obstacles in the way grid operators prefer to do this (Company E, F and H). When offering grid balancing services, Companies E and H noted that the grid operator expressed a preference for systems to respond automatically based on a digital signal. Interviewees expressed reservations about this as they would like to retain control over the process, preferring to respond via a phone call to the operators. While this was possible for company E, the plan to offer balancing service by company H was blocked by their grid operator, leading to not being able to offer that service.

This shows a difference in culture between the grid operators on one hand, wanting everything to respond automatically, with the culture at chemical plants on the other hand, where operators want to retain control of the process to ensure the safety of the plant.

Third Party Balancing Service Managers

In the paper by Bielefeld et al. (2023) one of the mentioned obstacles to participating in industrial flexibility programs was that companies would be hesitant to become reliant on a third party service provider to manage their demand response. However, during the interviews two companies indicated that they were offering flexibility services through third party providers (Company E and F), and that this was not an obstacle to engaging in it. This was also not mentioned by one of the other companies, not currently engaged in industrial flexibility, as an obstacle to offer it.

Grid Congestion

With the large effect of grid congestion on the electrification plans of companies, it was also investigated whether the decision to engage in industrial flexibility was influenced by grid congestion. The interviews showed that grid congestion was not a significant decision making factor in engaging in industrial flexibility for the interviewed companies.

Of all companies asked only two indicated that they would consider industrial flexibility to get quicker access to an increased grid capacity (Company J, F). However, these companies were either already engaged in industrial flexibility, or were already considering a business case to do so. Although grid congestion is not a reason by itself for companies to consider flexibility, companies considering electrification in their roadmaps and planning to use that opportunity to engage in industrial flexibility, need to wait. Grid congestion therefore acts as a delaying obstacle for companies who want to engage in industrial flexibility.

An interesting side-note is Company M, which is planning to produce hydrogen. This company has indicated having been approached by grid operators to engage in industrial flexibility to mitigate the effects of net congestion. Although this is not officially a requirement, it does make it possible for the company to operate in this area, as well as benefiting from an additional financial incentive.

Grid congestion was not noted as an obstacle for industrial flexibility in the scientific literature. This research shows that although it is an indirect obstacle, it does delay the implementation of flexibility for companies that are open to it.

Grid Fees

In the Netherlands companies are charged grid fees to be able to use their capacity on the grid. This is separate from the energy prices that companies need to pay to use electricity which is transported over the grid. These grid fees consists of a fixed monthly amount that corresponds to the amount of firm transmission rights that a company has a right to, and a variable tariff depending on the peak usage of that capacity that month.

Company E reported that the presence of a variable peak tariff was the most important financial incentive to engage in industrial flexibility. A benefit of other financial incentives for industrial flexibility, such as fees for grid balancing services, is that the variable peak tariff allows the company to retain full control of how it responds to a predicted peak in consumption. Although this results in a beneficial financial result for the company engaging in industrial flexibility, it is an undirected form of industrial flexibility. The results show that peak grid tariffs can be effective measures in promoting industrial flexibility, which matches the findings by Stawska et al. (2021). However, only one of the large energy-consuming commodity companies was able to make use of this (Company E).

Another factor affecting companies' willingness to engage in industrial flexibility is the impact on those who want to operate natural gas powered steam generators alongside e-boilers. This allows them to switch energy sources depending on price fluctuations. However, the downside is that even if the e-boiler is not being used in a particular month, the grid connection cost will still need to be paid. Company K indicated that this complicated the business case for such a dual set-up.

Mindset

An additional potential obstacle is the mindset in the industry towards flexibility. As the chemical industry has traditionally operated mainly with continuous production, it is possible that there is a fixed mindset at some companies which might mean that they do not seriously consider industrial flexibility.

Although there were some signals during the interviews about mindsets being a factor, the methodology of only speaking to a single person at a company, without additional internal sources, makes it infeasible to make reliable statements about the mindset on industrial flexibility within the companies.

Sustainability Label

An interesting driving factor for the engagement in industrial flexibility was indicated by Company M, which is planning to produce hydrogen. One of the main driving factors for this company to engage in industrial flexibility is to maintain their status as a 'Green' hydrogen producer. To do this, only sustainably produced electricity can be used, leading to a scaled down production whenever there is little to not sustainably produced electricity available. The financial benefits of engaging in industrial flexibility were only of secondary concern. Being able to use fully sustainable electricity (and branding the company as such for marketing benefits) was not noted as one of the benefits in the key papers on this topic.

4.4.2 Discussion

This section has identified a number of obstacles faced by chemical companies in embracing energy flexibility. Most of the reasons not to engage in energy flexibility were related to the high investment costs necessary for process equipment. This factor, combined with the strong competition of commodity markets, highlights that production equipment needs to earn its investment back over long periods. Factors which increase the necessary investment costs such as the increased wear and tear or the increased capacity necessary to make use of cheap electricity without resorting to load shedding therefore make redesigning process equipment unattractive for companies. For flexibility to be feasible, the financial benefits need to outweigh additional costs. Factors such as labor costs, or the decrease in operational flexibility can be enough to deter a company, for whom energy only makes up a small part of production costs, from engaging in energy flexibility. Large energy users have more to gain by reducing their energy costs, but are hampered by factors such as the uncertainty of the value they will be able to extract from operating flexibly. To make long term investment decisions companies need clarity.

A factor discussed in the literature review in Chapter 2 that might motivate companies to engage in flexibility is the possibility of receiving earlier access to increased grid capacity through mechanisms like alternative transmission rights if they can operate flexibly. However, only two of the interviewed companies would be willing to consider this, one of which was already engaged in energy flexibility. This is surprising as in Section 2.4 it was found that lack of grid capacity was the obstacle that was noted most often during the interviews. This shows that either the costs of postponing electrification plans do not outweigh the costs of implementing flexible operation, or the process itself was not responsive enough allow for such flexibility. Although responsiveness was mentioned in several papers discussed during the literature review, this not explicitly mentioned as a factor during the interviews, with interviewees pointing to the financial aspects or simply stating that it would not be possible for their process. However, it is possible that due to prevalent beliefs about flexibility there is a factual knowledge gap about this topic within the chemical industry. Due to the structure of this research it is not possible to draw useful conclusions about this but it might be a potentially interesting area of further study.

The interviews did show that the mindset within a company can also be an obstacle, as was shown by the resistance to the automation of process control for demand response, as was reported by two companies. This shows that a clash exists between the priorities of chemical companies and grid operators. Flexibility in this regard might make it more attractive for companies to engage in demand response. However, this is a relatively small obstacle and as such unlikely to affect the priority energy flexibility receives in energy transition plans. Other organisational obstacles such as the unwillingness to rely on third party balancing service providers, identified in the literature by Bielefeld et al. (2023), were not encountered in this work with two companies currently engaged in demand response indicating that this had not been an issue.

Throughout this section the obstacles found have been compared to those identified in the works of Leinauer et al. (2022), Lashmar et al. (2022) and Bielefeld et al., 2023. Most of the obstacles identified in this section had already been identified by one of the other papers, as can be seen in Table 5. Most of the obstacles observed in this thesis had already been identified by (Bielefeld et al., 2023), with the exception of a few smaller obstacles such as labor costs and the instability of the value of flex. These two factors were identified by the other two papers, which focused on industry in general. Although not new, these findings therefore constitute good confirmation that these factors also play a role in the chemical industry. An additional value of these findings is that they provide more nuance to the findings by broadening the interview pool. In Chapter 1 the possibility of a change in the willingness of companies to consider flexibility after the gas crisis associated with the invasion of Ukraine was hypothesized, but little to no effects were found with only two companies noting it as a benefit of relying on electricity or a dual system.

Although in this discussion all obstacles have been discussed, it was clear from the results in this chapter, that the exact obstacles that a company encounters are highly dependent on the specific circumstances. In this chapter, attempts have been made to identify trends in obstacles companies face, but it is highly likely that some trends have still been missed. This is another potential avenue of future research.

5 Discussion

In the previous chapter the interview findings were discussed. To make the outcomes of this thesis valuable, the limitations of the results also need to be understood. In this chapter these will be discussed. First it will be evaluated whether the subset of companies interviewed for this thesis forms a representative sample for the chemical industry in the Netherlands, assuming no bias in the companies which participated. In the next sections these assumptions will be discussed, with Section 5.2 looking at the response bias of companies and Section 5.3 discussing the impact of any bias of participants. In the final section, the results will be examined in a wider context and the applicability to the chemical industry outside the Netherlands will be explored.

5.1 Representativeness of Interview Sample

An important question is to which extent the twelve interviewed companies represent the chemical industry in the Netherlands as a whole. In Appendix P the list of chemical companies in the Netherlands can be found, which was discussed in Chapter 3. Although it is possible some companies are missing, it is assumed that the list is inclusive enough to be provide a representative sample of the entire chemical industry in the Netherlands. Each company has also been categorized based on the categories explained in Section 4.1. The relative size of each category in the interview sample compared to the total list is shown in Table 6.

	Specialty	Commodity Polymer	Commodity Petrochemical	Commodity Metal	Commodity Fertilizer	Commodity Inorganic	Commodity Industrial Gases
Interview Sample	28%	17%	17%	8%	17%	17%	0%
Total Industry	25%	25%	14%	10%	6%	10%	4%

Tab. 6. The relative size of each category in the interview sample and the list of chemical companies in the Netherlands in Appendix P.

As shown in Table 6, most categories are relatively equally represented in both sets. The polymer category is relatively underrepresented in the interview sample compared to the actual industry, while the fertilizer category is over represented. The absence of companies in the industrial gases category is unfortunate as their perspective is not represented in this study. However, given that they only constitute a small fraction of the Dutch chemical industry, this does not significantly affect how representative the interview sample is.

Seeing as the interview sample represents roughly a quarter of all chemical companies in the Netherlands and most categories are represented proportionally to the number of companies active in the chemical industry, it can be assumed that the results found in this thesis are representative for the Dutch chemical industry. However, it is still highly likely that some obstacles present in the industry were not identified during this research. This is due to the highly heterogeneous nature of the chemical industry. This study can therefore not be considered definitive for the Dutch chemical industry.

5.2 Response Bias

The analysis in the previous section assumed that the companies interviewed represented a random selection of all the chemical companies in the Netherlands. However, it is possible that there is a response bias in the selection. In this section the possible reasons for such a bias and the effect it would have on the results will be considered.

Companies already engaged in a form of industrial flexibility are assumed to be more likely to reply to the interview request, as some of the participants mentioned this as being a reason to reply. This suggests a possible overrepresentation of companies which are already engaged in, and therefore have less hesitation towards, flexibility. It is therefore likely that the overall view of the chemical industry on flexibility is more negative than the results discussed in the previous section would suggest.

Similarly, companies which use, or are thinking about using, electrification will be more likely to respond to a request for an interview on this topic. This would suggest that companies which have no plans of implementing electrification are underrepresented in this interview sample, and that companies which are considering electrification are over-represented in the interview sample.

Additionally, size may also play a role. In a larger company it is more likely that a more suitable candidate was identified, approached and included in the final interview group. However, the effect of this bias was mitigated by including the size of the companies in the recording of the results.

Finally, when making the list of companies to contact it is possible that despite the protocol followed, some companies were missed and therefore not included in the list. If this has been the case, this is more likely to be a smaller company. Similar to the previous limitation this would bias the sample towards larger companies.

In conclusion, if a response bias is present, it will have shifted the bias of the results to that of companies which are more open minded about electrification and industrial flexibility. However, in spite of this potential bias, as the sample size was made of approximately 20% of all chemical companies in the Netherlands, the results from this thesis would still be representative of a large portion of the chemical industry in the Netherlands.

5.3 Participant Bias

The second type of bias which can influence the findings is inherent in the participants themselves, both in terms of who responded to the interview requests as well the extent of their knowledge within their respective companies.

As many of the obstacles against electrification and industrial flexibility in the chemical industry are driven by technical constraints, people with a technical background were given priority in the selection of who to approach. As can be seen in Table 7, this has resulted in almost all participants being in an engineering role. Although this has provided many valuable results, it is also possible that in some areas covered, participants may not have known the full story. Examples of areas in which this might be the case is the influence of governmental policy or the negotiations with grid operators.

This concern is mitigated by the observation in Table 7 that most of the interviewed participants were in a management role, which means it is more likely that they had sufficient knowledge about these topics as well. Moreover, the indication that participants gave was that they were up to date on the topics discussed, making it likely that this factor did not significantly bias the results.

Name	Category	Size (employees)	Role Participant at Company
Company A	Commodity, Petrochemical	2500+	Engineering Manager
Company B	Commodity, Petrochemical	1501-2000	Energy Manager
Company C	Commodity, Fertilizer	501-1000	Sustainability Manager
Company D	Commodity, Fertilizer	501-1000	Energy Manager
Company E	Commodity, Metal	2500+	Energy Manager
Company F	Commodity	1501-2000	Energy Manager
Company G	Commodity	201-500	Plant Manager
Company H	Fine	201-500	Plant Manager
Company I	Fine	1001-1500	Plant Manager
Company J	specialty	201-500	Engineering Manager
Company K	specialty	2500+	Process Engineer
Company L	specialty	2001-2500	Maintenance Engineer
Company M	Hydrogen	11-50	Project Manager

Tab. 7. A table with the category of the company, amount of employees working for that company in the Netherlands, and role of participant at the company

Easily the most influential factor in determining which companies were included was the personal interest of the people that were approached. Similarly to the potential biases noted in the previous section, a participant with more interest in electrification and industrial flexibility would have been more likely to respond to a request for an interview on that topic from a stranger. One participant even admitted that he agreed to an interview because their company values getting new perspectives on their process. It is therefore likely that individuals with a personal interest in these topics were more likely to respond, leading to companies which are engaged in the topic to be over-represented.

The diversity of the group of interviewees was also relatively low. Of the 12 participants who were interviewed all were male and only one person had an international background. The most important reason for this is that men and people with a background in the Netherlands are by far the largest group within the chemical industry in the Netherlands. It is unlikely that this affected the results of this thesis.

One other influential aspect is the personal bias of the participants who were interviewed. As only one person was interviewed per company, the bias of each participant will color their contributions to the interview. Although participants generally spoke directly to matters of the company, occasionally they would contribute their personal opinion. Especially concerning the impact of regulatory policy as well as the consideration of flexibility this had the potential of significantly affecting the results. For all results, care should therefore be taken to acknowledge that findings which were only reported at a single company, and which are open to personal bias, might not be fully representative.

5.4 Validity of the Results

Taking all of this into, what can the validity of these result be said to be? The results are representative of at the least a significant portion of the chemical industry in the Netherlands. Due to the nature of the methodology, the results cannot be used to draw firm conclusions, but they can be used to identify general trends and to serve as a departure point for future research.

It is likely that some of the results point to factors which are found in other countries, especially within other countries in the European Union, as the regulatory climate is more likely to be similar. However, obstacles or other findings relating to regulatory climate, or lack of infrastructure such as the issues surrounding grid congestion, cannot with any degree of certainty be said to be applicable outside of the Netherlands as these are aspects which are highly specific to each individual country. Especially as the results showed that companies experienced the regulatory climate and availability of infrastructure in the Netherlands as more limiting than in other countries.

The findings which are not related to these aspects such as the technological obstacles, or economic considerations related to the capital investment of the production equipment are more likely to be applicable globally for the chemical industry as well.

6 Conclusion

In this final chapter, the research questions will be reviewed in light of the results on the basis of which conclusions will be drawn. First each of the sub-questions will be discussed followed by the main question being addressed. At the end of the chapter a number of recommendations for future research will be made.

6.1 Conclusions

Sub-Question 1: How widespread is the inclusion of industrial flexibility in the near-term energy transition plans of companies in the chemical industry?

Six of the twelve interviewed companies indicated that they had some form of energy flexibility included in their plans for the near future. However, only two of those companies indicated that it was a priority for them. These were companies who were already engaged in flexible operation of their processes. The remaining four were planning to combine natural gas powered process heat with electricity based process heat, allowing them to engage in a type of implicit demand response by adjusting which energy source they use based on the relative prices. However, this was not a priority for them but more an opportunity that was made possible by their electrification plans.

Four other companies indicated that flexibility was noted as an option on their roadmaps, but that it was dependent on plans that would only occur on the longer term. This was because first they needed to transition to sustainable production processes, which they expected would not be completed in the near future. Flexibility also did not seem as a priority for these companies, although that might be because the decision point for the inclusion of flexibility was still several years in the future.

These therefore show that although the awareness of industrial flexibility is reasonably high, and companies will make use of it if possible, only a small fraction is giving it priority in their near- term energy transition plans.

Sub-Question 2: What obstacles to the inclusion of electrification in their near-term energy transitions plans are encountered by the chemical industry in the Netherlands?

Based on the results it can be concluded that the most important obstacle to the electrification of the chemical industry in the Netherlands is infrastructure constraints resulting from limited grid capacity, with eight of the twelve companies noting this as a crucial factor. This obstacle mainly leads to the postponement of electrification plans, with none of the companies indicating that this had caused them to prioritize a different technology. However, it did lead to more uncertainty and was also noted as a potential factor shifting investments to a different country.

Technological maturity also was found to be a major factor, with the near-term energy transition plans only focusing on a small number of technologies which are mature. Other more fundamental changes in processes are also included in energy-transition plans, but with the exception of one company none would take place in the near term. An additional factor is the preference for electrification technologies which could be implemented without affecting the rest of the production process integration.

Sub-Question 3: Are previously identified obstacles for chemical companies in the Netherlands to operate their processes flexibly still valid?

From the results it can be concluded that most of the obstacles for the participation in industrial flexibility programs are still valid. Most of the obstacles for the chemical industry were related to the high investment costs that are necessary to construct chemical production equipment. The financial gains from energy flexibility are often too small or too uncertain to justify the increase in capital investments necessary to make it possible.

Despite its substantial impact on the electrification plans, grid congestion only played a small role in the consideration of the inclusion of industrial flexibility in energy-transition road-maps. Only two companies, both already considering or engaged in demand response, noted that they would consider an option to get quicker access to more grid capacity. This signifies that although the lack of grid infrastructure is delaying the implementation of electrification plans for many companies, it is not enough of an obstacle to overcome the obstacles relating to operating flexibly for most companies.

Only a few obstacles identified through the interviews had not been noted previously in the scientific literature. Organisational resistance to automating the controls of processes at chemical companies is one of them. An obstacle noted in the literature about reluctance to rely on third-party balancing service providers was not found during the interviews. Two companies specifically indicated that this had not been a hindrance for them. The results from this research have therefore mainly validated the results found in earlier studies and provided them with more context.

Main Question: What role does industrial flexibility play in the near-term plans of Chemical companies in the Netherlands for the transition to a sustainable chemical industry?

In conclusion, industrial flexibility is only a priority for a small fraction of the chemical industry, with only two of the twelve indicating it as such. Although half of the interviewed companies around half had some form of flexibility planned in the near term, for four of them this was a side benefit possible in their transition to electricity based process heat. The obstacles of electrification did play an important role, as the four remaining companies indicated that they would only be able to utilize flexibility once they had switched to new production processes, which were not yet mature at the moment.

Industrial flexibility did not play an enabling role in any of the energy transition plans of the interviewed companies. This is despite the fact that most of the companies indicated that grid congestion was a significant factor affecting their energy transition plans. This implies that while grid congestion presents a hindrance to their energy transition plans, the obstacles associated with operating flexibly outweigh it.

Therefore, role of industrial flexibility differs between companies. It is a priority for large energy consumers with processes that can already operate flexibility. It is a side benefit for companies needing to replace the source of their process heat and for the remaining in does not play a role in the near-term.

6.2 Recommendations for further Research

Based on the findings of this thesis, a number of recommendations can be made for further study. The first is that a study looking at the obstacles observed in another country could provide confirmation whether or not the observed results can be extrapolated to other countries. Given that many companies also highlighted the differences in infrastructure and investment climate across different countries it would be valuable to map those differences, for example across the European Union. Such a mapping would provide policy makers with a tool to find the balance between mandating certain measures while preventing emissions from being 'exported' by companies relocating

Another interesting avenue of further study is how roadmaps are used within companies. The interviews revealed a wide variation in the detail across companies, as well as a case where the official roadmap and the internal roadmap differed. In light of many companies needing to make significant changes it would be interesting from a Management of Technology perspective to study how roadmaps are used within technological companies and what role they play in decision making.

Finally, this study focused on the obstacles that companies were willing to share during interviews, but it remained unclear what the mindset regarding flexibility was within organisations. One interview-based studies noted conservatism within organisation as an obstacle against considering flexibility (Lashmar et al., 2022). However, with only single interviews per company, it is difficult to accurately estimate the significance of this factor. A more in depth study into a limited amount of companies might provide clarity on this topic.

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A Summary Company A

Company A

Category: Commodity Chemicals / Petrochemicals

Role interviewee: Engineering Manager

Summary Interview

What is the core business of your company?

We produce basic chemicals.

Does your company have greenhouse gas emission reduction targets?

Yes, we have extensive climate reduction goals.

Does your company have a roadmap to achieve your emission targets?

Yes, there is a detailed plan for the next few years, and a less detailed roadmap leading all the way to 2050. It includes estimated levels of emissions at various points on the roadmap. Some projects and technologies further down the line are still uncertain.

Is your company considering alternative feedstocks to replace fossil carbon feedstocks?

We are implementing the ability to use plastic as a feedstock, which would be chemically recycled.

If instead plastic is recycled mechanically, it does not have the same mechanical strength, and it keeps certain pollutants making it unsuitable for pharmaceutical and food industry.

In the end we expect that the feedstock for our process will be a combination of recycled plastic, bio-based feedstock, as well as still a surplus of fossil fuel resources. An important design criteria would be the ability to be flexible in the type of feedstock that is used.

What measures is your company considering to reduce emissions originating from utilities?

We are currently implementing some projects to improve the efficiency of the system. Cracking units are being replaced with larger, more modern, and more efficient units. These units recover more energy which means less energy leaves through the chimney. This will result in a 10% reduction of energy for the entire production site.

In the next step we are looking to replace pumps and compressors, which currently run on steam, with electric alternatives. This is more efficient than steam and it allows us to use sustainable electricity. We are also looking into heat pumps as a possibility to upgrade recovered heat to a level where it can be used in a different part of the process.

One options to eventually fully eliminate the emissions from the cracking unit is to install CCS units onto the chimney of the cracker units. If we can get a connection to a wind-park, which is feasible because of our location, we might also build a hydrogen electrolyzer. In the longer term we are also looking into electrical cracking units.

Electrification is one option, but an alternative would be to run the process by mixing biological feedstock together with natural gas. This biogas can be extracted from animal waste, which produces biogas and dry fertilizer, which can be used in greenhouses.

For some of the technologies it is not yet clear whether they will be financially feasible. Increasing the CO_2 tax would not be the solution as we would price ourselves out of the global market. There is no silver bullet to these challenges. Every step you tackle a bit of the problem.

The transition to sustainable technologies is very complicated. Generally the factory has very good heat integration, which increases its efficiency. However this means that this heat integration needs to be untangled and then re-integrated into the production process. It is like performing an open hart surgery on your factory.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

The external infrastructure is a critical factor. If we want to become sustainable, our electrical consumption is going to increase significantly. We are in negotiation to build a new high voltage station which would connection us directly to the wind parks at sea.

We started negotiating very early with the grid operator. We would like to have the increased capacity in 2028 but we will get it no earlier than 2031. We are looking at how this will impact our roadmap. For example by bringing some projects which do not need more electricity forward, at the expense of projects which do require electricity.

Other types of infrastructure would be necessary too, such as hydrogen and CO_2 pipelines. These infrastructure are very difficult to organize due to the many stakeholders involved.

Would you consider running your process in a flexible way?

We are investigating whether we could design turn-down ratio into our electric cracking units, as it would allow us to respond to the availability of electricity, We have a co-generation plant which we could use to offer balancing services. Additionally, we are planning to install batteries in combination with a solar park, so this will give us a limited amount of flexibility as well. We are investigating whether we can use these options to deal with grid congestion as well.

Another potential source of flexibility would be to store heat, which can later be used to generate steam. This would make it possible to adapt to a day night cycle based on the availability of sustainable electricity.

An obstacle to flexibility is that you lose efficiency if the process does not run at full capacity. However, this can be mitigated if a unit at the front (such as the cracking unit) runs flexibly while the rest of the process runs at a constant and full capacity.

In the future we expect that we will become much more flexible, both in the type of feedstock, as well as the type of energy used to run the process. One option to become more flexible would be to have some of our cracking units be electric based, while others remain traditional cracking units but fitted with CCS units. This would allow us to adapt to differences in price of the competing energy sources.

Implementing flexibility remains a big challenge as the impact on the heat integration would be significant.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

As one company you do not have a strong platform, so we have banded together with other companies in the chemical industry, to lobby for infrastructure projects which are needed for the energy-transition in the industry.

B Summary Company B

Company B

Category: Commodity Chemicals / Petrochemicals

Role interviewee: Energy Manager

Summary Interview

What is the core business of your company?

Our core business is using a cracking furnace to produce basis chemicals. This is split over two production locations in the Netherlands.

Does your company have greenhouse gas emission reduction targets?

Yes, they can be found online in the sustainability report.

Can you estimate which part of the production process emits the most greenhouse gases?

The temperature inside the cracking unit needs to be very high which requires a lot of energy. At the second production location process heat is the most important source of emissions. A large part of the footprint of the products we produce is in the scope 3 emissions.

Is your company considering alternative feedstocks to replace fossil carbon feedstocks?

Yes, we are looking at replacing the naphtha with recycled plastic (both mechanically and chemically), as well as biological feedstock.

What measures is your company considering to reduce emissions originating from utilities?

There are three different potential options to reduce emissions from the cracking unit: electrification, using hydrogen or using carbon capture and storage. All three options are being investigated.

The emissions from process heat for the rest of the production process can be reduced by using either biological feedstocks instead of natural gas, or by electrifying the process of generating process heat.

What problems does your company foresee that could arise from electrifying your processes?

Heat integration would be a challenge. A cracking unit is the central point of the production process in which a lot of heat is produced. If you switch to an electric cracking unit you don't get convection anymore, which would be a fundamental change in the process design. The heat integration would need to be redesigned. All the separate pieces of technologies already exist, but it would be a challenge to combine them all.

If you use hydrogen some redesigns would also be needed but, but the process would largely remain the same. If instead CCS were to be implemented, that would basically only require a bolt-on module onto the production equipment.

If it would be decided to use hydrogen in the production process we would most likely look for a third party to produce the it. No one is yet looking at using hydrogen to generate process heat, as it is still way too expensive.

The rest of the production process uses steam, and it does not matter how you make the steam. The integration of steam would not change if the steam is generated using electricity (e-boilers) or biological feedstock.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

It is a critical factor. If we want to electrify on a large scale, more high voltage transport would be needed.

Discussions with grid operators always end up going nowhere. They are still very stuck in the old mindset. It is difficult for them to offer enough financial incentives to make flexibility feasible for us, as they are a regulated company. Moreover, the value of flexibility is not stable as it is sold using a bidding system. That means that if more flexibility becomes available its value will decrease. This makes it risky for us to invest in offering flexibility. If the rules of the system change, so does the value. From our perspective it is an unclear and nontransparent market. If more certainty could be offered about the value of flexibility it would be more attractive.

Would your company consider flexibility if it meant quicker access to more grid capacity?

We don't think it is realistic that the grid operators would give priority to companies which embrace flexibility.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

Through various sector associations we are talking to grid operators about issues such as grid congestion. The infrastructure problem in the Netherlands is a very tough problem, with a lot of different tensions and priorities for each of the different stakeholders.

The grid operators only want to build infrastructure once they are sure that it will be used, but companies are not sure yet which decarbonization options they will use, partially because they do not know whether they will be able to get enough electricity. Everybody is waiting for each other, it is a chicken and egg dilemma.

It is difficult for the government to support us given the current political climate. Everywhere they are constantly changing the regulations, they are trying to make us move using sticks. For example the grid fees have risen significantly the last few years. On the other side the infrastructure that we need to make my process more sustainable is not available. We can see the carrots, but we can't reach them due to infrastructure constraints. And in the meantime the sticks are still hitting us.

Would you consider running your process in a flexible way?

We are in a commodity business, you can only be successful if you run your factory at maximum capacity. Moreover, the units are not designed for flexible operation. The electrified options might have the possibility to design a 30-40% turn-down into them, but flexibility is not part of the mindset in this industry. Our competitive position is already under pressure, so our potential to engage in flexible operation is very limited. To some extent this is an outdated mindset, but our equipment was designed with that mindset. To be competitive you want your process to run continuously at maximum capacity.

At the other production location some flexibility might be offered by operating a hybrid system, where an electrical boilers operators in parallel to a natural gas based boiler. There are many hours where electricity is cheaper than natural gas, so this would allow us to make use of whatever energy is cheapest at each particular moment.

If hydrogen is used indirect demand response would also be possible. This would require storage but that would not be a significant obstacle.

Some companies have embraced flexibility, but that is only because they have leftover capacity, any company would prefer to make more product. The production quotas are important so flexibility for us would mean consuming more electricity, not less. This means we would need a larger grid capacity under flexible operation as compared to constant production.

C Summary Company C

Company C

Category: Commodity Chemicals / Fertilizers

Role interviewee: Sustainability Manager

Summary Interview

What is the core business of your company?

Our core business is producing fertilizer.

Does your company have greenhouse gas emission reduction targets?

Yes, at corporate and local level. the exact numbers vary by country. We have already reduced our emissions significantly, and we have additional goals for next year and 2030.

Netherlands is ahead comparatively to the global level with a reduction in carbon emissions by two thirds. Additionally the corporate target for 2030 is an absolute reduction (Scope 1 & 2), which means that it is independent of further growth.

The goal for 2050 is carbon neutral, evaluating the possibility to be at net-zero in 2050. Scope 3 downstream will also be considered in that goal.

Does your company have a roadmap to achieve your emission targets?

Yes, although this does not solely look at the carbon emissions. The environmental impact of our production process is also an important factor. Sometimes these aspects can conflict with each other. The roadmap includes both measures to reduce carbon emissions, as well as plans to reduce the impact on the environment through other emissions.

A healthy business on an unhealthy planet is unsustainable. We want to move our company to an as high as possible level. But the challenge is we along the transition need to remain a positive financial balance sheet to be able to make the investments that are needed.

One of the challenges in that regard is that we earn money based on the volume, as product margins are relatively small. However, if you don't reduce your carbon emissions you become irrelevant as a company. Climate change itself also brings different risks, which need to be accounted for in future plans. Taking climate change into account in your decision making is not just because you want to do good, it is a strategic imperative for companies.

Can you estimate which part of the production process emits the most greenhouse gases?

The feedstock necessary for the production process, natural gas, is responsible for the largest part of the energy consumption. Natural gas is converted into hydrogen and CO_2. Most of the carbon emissions are captured and used either for further production, sold to the beverage industry, or sold to agricultural greenhouses. The downside of these uses is that they are considered non-permanent use, as the carbon in those products does get emitted on the short term. These emissions are therefore included in our carbon footprint.

What measures is your company considering to reduce emissions originating from utilities?

There are three options that we are considering. The first is to capture and store the carbon permanently, using CCS. We have developed plans to implement this option in the next few years.

The second option is the replacement of the natural gas feedstock with a biogas.

The third option would be to remove the natural gas cracker, which is currently used to produce hydrogen, and replace it with a hydrogen electrolyzer. This would require huge amounts of electricity, which itself would also need to be green. Renewable electricity generation is generally depended on weather conditions, and we would therefore need access to almost double the capacity of renewable energy that our process requires, so that there is always enough sustainable electricity to run our process continuously. This would therefore be very expensive. The inability to get a larger grid connection would also be a critical obstacle. Another obstacle is that the scale of hydrogen production necessary for this would need to be on another order of magnitude compared to what is currently possible.

It is very hard to get a finalized business case for a hydrogen production site. The main reasons for this are the grid limitations, the large capital investments necessary, and the not fully mature status of the technology.

A lot of stakeholders underestimate the challenge of scaling up the hydrogen production and related infrastructure to the necessary level for the energy transition. Many challenges still need to be overcome.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

Yes this is a big obstacle for our energy transition plans. Many steps have already been taken to resolve infrastructure constraints, but it will still require massive investment to solve them. To implement our energy transition plans we need assurances that we will be able to get the energy that we need.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

This is difficult to say as the government is in a difficult position. The government has different drivers than the business world does. To complete the energy-transition the government will need to become more agile with less bureaucracy.

The government waited too long with building the necessary infrastructure by adding too many regulations. This has resulted in the current, very disruptive, situation for the market. One of the most important things that the industry wants from the government is clarity.

Would you consider running your process in a flexible way?

Flexibility in hydrogen production would be a possibility. However, it would require hydrogen storage which is very expensive, which would impact the feasibility of the business case. Storage would also bring safety risks. You would need to have at least a few days buffer in case a shortage of sustainable electricity were to occur.

A hybrid hydrogen production approach would be feasible initially, combining green hydrogen with other types of hydrogen. However on the long term you would need a constant stream of either green hydrogen or electricity,

The main production process would not be able to operate flexibly. This is because at a constant production level the process is more efficient. Moreover, ramping the process up and down significantly increases the wear and tear on the equipment, which can reduce its lifetime. As the equipment is very expensive this would not be economically viable.

Ideally we would be able to make use of the opportunity that the financial incentives of operating a process flexibly provide. However we are in a capital intensive industry. Under-performance of equipment has a large financial impact.

If governments forces flexibility on companies, it would be another driver to make the decision to move production to a different picture. Even when companies are engaging in demand response, they are only doing so because they are forced due to a lack of available grid connection capacity.

D Summary Company D

Company D

Category: Commodity Chemicals

Role interviewee: Energy Manager

Summary Interview

What is the core business of your company?

Within the Netherlands our core business is producing fertilizer and other related basic chemicals.

Can you estimate which part of the production process emits the most greenhouse gases?

A lot of energy used in the production process ends up in the product itself. The production process itself has been optimized to the extent that not a lot of energy savings can still be achieved in the production process through classical means. Two thirds of the natural gas that we use is used as feedstock, the rest is used to generate process heat.

The energy costs make up well over 50% of the total production cost. This also makes us very vulnerable to price swings such as during the natural gas shortage after the Ukraine invasion. Although fertilizer is mainly sold locally, and the price could therefore be adjusted, some of our other products which are sold on the global market became uneconomical to produce. Ammonia and fertilizer markets are global markets

What measures is your company considering to reduce emissions originating from utilities?

We use a lot of natural gas. We are responsible for a few percent of the total Dutch consumption. The natural gas used in the production process can be replaced with hydrogen. Hydrogen is relatively straightforward to decarbonize through either green or blue hydrogen. The total energy used in the production process would not differ a lot between a process run on natural gas and one run on green hydrogen.

Follow up: Are you planning to produce the green hydrogen yourself?

To produce enough hydrogen to provide all fertilizer companies in the Netherlands (not just our production sites) with green hydrogen, several GW of electricity would be needed, compared to the current average electricity production capacity in the Netherlands of 17 GW.

Would you consider running your process in a flexible way?

In the bulk chemical production margins are very low, and profits need to be made by producing larger volumes of product to decrease the investment cost per ton of product. The incentive is therefore to run at maximum capacity as much as possible.

Flexibility would be considered as a last resort, such as during the initial invasion of Ukraine, when some of the production sites were shut down. This was because the required natural gas was so expensive than money was lost if it was used to produce product.

We assume that the hydrogen price will be flexible, but not as flexible as electricity, as it is possible to store it to a certain extent. The price flexibility will be in between that of electricity and natural gas. We will take this into account by including the ability to turn down the production capacity of the process. This is currently not the case.

We would design the process to run on a certain base-load of hydrogen, supplemented with additional flexible hydrogen. It is yet unclear what relative levels of base and flexible hydrogen could be achieved. If this is possible, it could function as a method to respond to hydrogen prices.

However, it is yet unclear whether enough hydrogen production facilities will be able to be built on time. Tens of times the capacity of the hydrogen production facility Shell is building, Holland Hydrogen I, would be necessary to cover the hydrogen for the fertilizer industry.

Flexibility in our electricity usage would also be possible, although it is a relatively small part of the overall energy usage of the production process. If we electrify our process heat this would offer some flexibility potential. For example by having both the option to heat steam through both electricity as well as natural gas. Those would be relatively easy to implement.

The downside of this option is that there are a lot of fixed costs associated with an increased grid connection, which are necessary due to the high cost of building the infrastructure and the costs of stabilizing the grid. This means that relatively low prices of electricity need to occur frequently enough to make this set-up worthwhile.

Does your company have a roadmap to achieve your emission targets?

There is a roadmap, a combination of different measures already discussed in this interview. A roadmap is important, but you need to be able to adjust based on developments. However, this needs to be balanced against the fact that building chemical production sites takes relatively long. At some point a decision needs to be made.

The uncertainty surrounding natural gas has impacted our energy transition plans. Europe is way too uncertain for large scale projects at the moment. That does limit the available options for reducing carbon emissions. If you don't act on time you might end up with only a single option, such as closing the production site.

One of these uncertainties is whether we can be competitive in the future while producing green hydrogen, or whether it will be produced elsewhere and transported here. There are still a large number of uncertainties.

Another important consideration is the level of support from the government. For example the USA passed the inflation reduction act two years ago, which made it more attractive invest over there, leading to factories being built with the goal of producing for export. This impacts our decision making as well.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

Our company has signed a joint letter of intent to accelerate its energy transition plans. Initially it was primarily about reducing carbon emissions, but supporting Dutch industry now also plays a role.

The challenge is that there are a lot of different stakeholders, even within the government itself. It is a challenge because every decision comes with a trade-off, and there will always be at least on stakeholder within the government who opposes the decision.

Political uncertainty also makes investment decision more difficult. The political climate has a lot of impact on negotiations, such as the one we are currently engaged in with the joint letter of intent.

We try to influence policy in the EU as well by means of a lobbying organization for our sector. This is vital because many regulations are decided at that level.

Is there a topic which was not addressed that you think would be relevant for this thesis?

The government has been too late with expanding infrastructure and now everyone is running into problems. The procedure to build a high voltage grid connections takes decades. Even without those procedures it still take at least five years before the construction of a new grid connection can be completed. As a company you are in somewhat of a limbo at the moment.

E Summary Company E

Company E

Category: Commodity Chemicals

Role interviewee: Energy Manager

Summary Interview

What is the core business of your company?

Our core business is producing metal.

Does your company have greenhouse gas emission reduction targets?

Yes we do. More information about this can be found on our website in our sustainability report.

Does your company have a roadmap to achieve your emission targets?

Yes, we have a detailed road-map for the next several years, as well as a less detailed roadmap for the longer-term.

The goal for 2045 is to produce the same amount of product but without carbon emissions. But even if you have a roadmap, many challenges such as the financing and permits can impact the final implementation of those plans.

Can you estimate which part of the production process emits the most greenhouse gases?

The reduction process, the conversion from ore to metal, results in most greenhouse gas emissions. In addition, heat which is required for our production process is also an important source of emissions.

What measures is your company considering to reduce emissions originating from utilities?

Reducing our emissions is a complex challenge because the production process consists of several different units in series. Every time you change something in the system the rest of the whole still needs to continue working.

One of the plans on our roadmap is using hydrogen instead of fossil fuel based feedstock that we currently use. We have not yet decided whether we will produce the hydrogen ourselves or purchase it from somewhere else in the Netherlands. Hydrogen is still very expensive so the business case to use it to reduce our carbon footprint would only be possible with the support of the government at this moment.

An earlier transitional step in our roadmap is to switch to natural gas, which would already significantly reduce our emissions, as it is more carbon efficient than the feedstock we are currently using.

One other option which is being considered is capturing the emitted CO_2 using CCS. The business case for this might be achieved without support from the government.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

This is an important factor but we are fortunate that our grid operator is working at connecting us to a new grid station, which will be enough for the near future. An additional benefit of our location close to the coast is that we can use wind energy without it having to use the land-based grid, therefore reducing the load on the grid in the rest of the county. This also means that it would be interesting for us to produce hydrogen to alleviate pressure on the electrical grid.

Follow up: How is the relationship with your grid operator

We have a good relationship with our grid operator. We are talking with them about additional connections to future offshore wind parks, as it would reduce the strain on the grid if the electricity produced in the wind parks was used near the coast to produce hydrogen.

We are also working on strengthening our relationship with Gasunie because we want to be connected to the hydrogen backbone that they are building.

Would you consider running your process in a flexible way?

We are already engaged in flexibility. Our site has its own power-plant which uses waste gas combined with natural gas as a feedstock to produce electricity. We can ramp up our the power production of that plant to offer electricity to the grid. For example by producing surplus electricity during the evening peak.

In addition, some of our production units sometimes need to shut down for maintenance or other reasons. This has an impact on the amount of electricity we can produce or consume. Grid fees have risen very strongly the last few years, and the discount for large industrial consumers has been discontinued. The grid fees consists of a fixed part, and a part which depends on your peak usage per month. This means that if you have a large peak in consumption the grid fees will be very high. We therefore take our peak consumption into consideration when planning the shut-downs of units, or even by asking a unit to temporarily shut down. We have to be careful as this will reduce the amount of our product that we can produce.

The large CAPEX invested in our production infrastructure also needs to be taken into account, which means the electricity price needs to be high enough to make load shedding worthwhile. The decision also depends on the margin on our product at that particular time. If the margin is small it is more attractive to adapt to the electricity market. Shutting units down is a complex procedure so the financial benefits also needs to be high enough to make load shedding worthwhile.

We are also offering balancing services to the grid operator, as that also has a positive business case. This process is run by a third party balancing service provider. We do not participate with the program where they can control the process from a distance, that would be too complicated to implement. We receive a call and we have to respond within a certain number of minutes.

How will the ability to operate flexibly change in the future?

We expect that the electricity market will become more volatile and we therefore expect that there will be more opportunities to make a profit with flexibility. We also think more will be expected from the industry with regards to flexibility. We are taking flexibility into account when designing our new process units.

This will not mean that we will fully shut down for long periods, but during a 'dunkelflaute' (a combination of no sun and no wind) we might operate at a lower capacity because the electricity has become too expensive. In periods of cheap electricity we are limited by the maximum capacity of our production facilities, but we would indeed look into using that to maximum capacity at those moments.

We also expect that other companies will embrace flexibility as well, as far as their process allows it. The financial incentives for large electricity consumers will be the driving factor.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

The transition cannot be made based on normal business cases, so we need the aid of the government to cover the difference. We are negotiating with the government about that. As part of that process we also talk about the future role of our company in the electricity grid.

Is there a topic which was not addressed that you think would be relevant for this thesis?

The international competitive field is very important for us. You see that other countries in Europe have already made commitments to support their industry. The Netherlands has been more hesitant in this regard up to now. We also see that other countries compensate their industry for high grid fees, which does not happen in the Netherlands. This hurts our competitive advantage compared to other countries. If we are not careful in a few decades we will have all the necessary infrastructure in the Netherlands, such as the electrical grid and the hydrogen pipeline, but all the industry will have left the country.

F Summary Company F

Company F

Category: Commodity Chemicals

Role interviewee: Energy Manager

Summary Interview

What is the core business of your company?

We produce basic chemicals using an electrochemical process. This is done using raw materials that we extract ourselves. We have multiple production locations in the Netherlands.

Does your company have greenhouse gas emission reduction targets?

Yes we do.

Can you estimate which part of the production process emits the most greenhouse gases?

Steam is used in the production process to extract the necessary feedstock from the raw materials. Steam is used for this which is generated using a co-generation plant running on natural gas. Some of the natural gas is also produced by neighboring plants burning biological feedstock or waste. A limited fraction of this extraction process is run using MVR, a type of heat pump, which require electricity. The electrochemical process also consumes a lot of electricity.

What measures is your company considering to reduce emissions originating from utilities?

This is a big focus because a lot of energy is used in the production process. To reduce energy all raw material extraction needs to be converted to run on the basis of MVR. We are in talks with the government to speed up this process. We have already signed a joint letter of intent with the government on this topic.

Does your decarbonization include a change in process technology, such as electrification (electricity based processed such as electrolysis)?

To switch to heat pumps for the extraction process an entirely new facility would need to be built, be the technology itself is already available and mature. Initially the plan was to fully transition to this technology by 2040. With the support of the government, this could be accelerated to 2030. Some of the required support would need to be in the form of assurances about permits to reduce the risk of the investment.

An additional consideration with an accelerated implementation is that equipment would need to be written off which has not been fully paid off, so the business case would need to make sense. However, for the government it is also important that there is not an overcompensation.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

This is an important factor. In some of the areas where production locations are located we are encountering grid congestion. As this is a critical factor in the feasibility of our energy transition plans, we need assurances from the government as part of the negotiations that the grid capacity will be available. The grid congestion is therefore definitely a critical factor in the planning of the transition roadmap.

Would you consider running your process in a flexible way?

Some of our processes are already running flexibly. We have our own electricity plant. Some of the processes can also already be shut down as part of demand response. This is done through a balancing service provider. Through them we deliver demand response services to Tennet.

An important factor in the decision whether to engage in demand response is the production demands. Flexibility is only considered when the production schedule and safety allow it. The financial incentives offered by flexibility are also an important factor. Certain strike prices can be agreed upon with the balancing service provider, at which point it becomes financially worthwhile for us to engage in demand response.

Integrating the ability to offer demand response into the production processes is a fairly complex task, so this is done step by step throughout the production chain.

One area of concern is that it is not yet clear what the long-term impact of flexibility will be on the production equipment. It is expected that the wear and tear will be larger than with a steady state operation.

Once the extraction process has been electrified that will have some flexibility potential as well.

Would your company consider flexibility if it meant quicker access to more grid capacity?

Possibly, but that would depend on the exact conditions. It is something we would consider.

How is your relationship with the Grid Managers?

The grid fees in the Netherlands are relatively high compared to surrounding countries, and they they have risen a lot the last few years. The government plays an important role in deciding the exact cost of those fees. The Netherlands is not as protective of its industry as other countries in Europe.

An example of this is Nyrstar, which is mothballing their operations partially due to the high grid fees in the Netherlands, while their locations in Belgium and France are able to continue operating.

It is important that in the end the government is realistic about what industry can do. We understand that the new infrastructure needs to be paid for, and we do not want to dodge that responsibility, but the investment climate needs to remain competitive with those of neighboring countries.

The government should focus on making sure the grid fees encourage the desired behavior, for example by stimulating flexibility. This would give more room for business cases that can provide that flexibility.

What role (if any) does flexibility play in your company's roadmap to GHG emission-free production?

Yes flexibility certainly plays a role.

G Summary Company G

Company G

Category: Commodity Chemicals

Role interviewee: Plant Manager

Summary Interview

What is the core business of your company?

We are in the commodity chemicals business, making inorganic compounds used for pigments.

Does your company have greenhouse gas emission reduction targets?

Yes, a total reduction of 50% in emissions by 2030.

Can you estimate which part of the production process emits the most greenhouse gases?

Our main source of emissions is process heat. In one part of the process a fossil fuel based feedstock is used, and in the other part the process requires process heat. This process heat in the second part of the process is delivered using steam.

What measures is your company considering to reduce emissions originating from utilities?

We are focusing on improving the efficiency from our current process, such as integrating the heat more efficiently. We are not thinking of changing the fundamental process.

We are investigating how we could redesign our process to reduce our emissions further. We had a consultancy come look at how to redesign the process. There are some electrification options, but it would be challenging to decarbonize. On the short-term it is more effective to focus on using the coke more efficiently.

There are two main challenges to increase heat-integration to use process heat more efficiently. The first is that our production units are spread out throughout the plant, meaning it would be difficult to make the necessary connections between units. The second challenge is that the heat we can recover has relatively low caloric heat, making it difficult to reuse.

Some of our waste stream is mixed with natural gas to produce steam. The rest of our steam is produced by our neighbor, which generates it using biological feedstock. The steam is therefore considered sustainable.

We do not use a lot of electricity. We have some compressors and other appliances which required quite some electricity from our perspective, but which are small compared to large consumers. The consumption is stable throughout the day. We do not think that our consumption will change in the next five years. Should we choose to electrify a part of our process then our consumption would increase significantly.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

With our existing technologies we do not anticipate the grid connection being a bottleneck. If the decision is made to electrify bigger components, then grid connection will be an issue. The grid congestion would be a critical bottleneck for any such plans.

However, we expect that our industrial cluster would help prevent this becoming a bottleneck for companies. Especially for the relatively small scale of our consumption we do not expect that it would be an issue. We are not worried about it at the moment as our electrification plans are still in a very early stage.

It will be challenging to arrange funding for any electrification plans, as the margins are very small in our business. This makes it hard to make a good business case for such an investment.

Does your company have a detailed roadmap to achieve your emission targets?

Not as such. A 5-year plan would be of limited utility in this business, we would probably need to rewrite it after a few months.

In the future once the infrastructure is there, the government will probably force us to electrify or become sustainable in another way. Or we might be forced by circumstance once most systems have transitioned away from natural gas and it will no longer be available. But we are not sure if that day will come.

There is a pressure from our customers to reduce the carbon footprint of our products. There is a chance that at some point they will cut us off and switch to a more sustainable supplier. Customers are also increasingly asking if we have certain sustainability certificates (ISO certificates). We are working on obtaining those certificates.

Our company decides a global level what each site needs to produce. Energy use is considered to some extent at that level but it is mainly considered at the local level. Our production site runs more efficiently compared to other production sites of our company in other parts of the world energy is less expensive than here. The European Union has the most demanding sustainability requirements so the priority for these kind of projects will be on the sites in Europe.

There is a global fund within our company for sustainability which is distributed equally across all sites. Although this can fund some exploratory studies, it is not enough to fund the investments into new infrastructure by itself.

Would you consider running your process in a flexible way?

This is not a viable option for us. This may be an option in the future if we improve our process control. It might be possible to ramp down our process somewhat during the night. Ramping the process up and down is quite complex and our current process control would currently not be able to handle it.

An additional challenge with flexible operation would be to meet our production quotas when operating flexibly. Under current circumstances it is sometimes already difficult to achieve those.

Finally, we would still need to pay our labor costs even if we scale down the production. We would therefore only consider industrial flexibility if our capacity was not fully sold out.

Would your company consider flexibility if it meant quicker access to more grid capacity?

That would not be feasible for us.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

The unpredictability of policies laid out by the government makes it more difficult to find funding for sustainability projects.

H Summary Company H

Company H

Category: Specialty Chemicals

Role interviewee: Plant Manager

Summary Interview

What is the core business of your company?

We produce basic chemicals and polymers, mainly for the packaging industry. Outside of the Netherlands we are also involved in other products. We have one production site in the Netherlands but more than a hundred locations globally.

Does your company have greenhouse gas emission reduction targets?

Our goal is to reduce our emissions by 25% by 2030. We do not yet have a specific goal for 2050. The current economic climate is not conductive to making the necessary investments to reach those goals. We are actively looking for possibilities to reduce our dependence on natural gas.

Follow up: Are these global or local goals?

These are the global targets, but each local site has its own targets as well. The larger sites such as ours are expected to have a leading role in this transition as compared to the smaller sites.

Can you estimate which part of the production process emits the most greenhouse gases?

Our production process requires a lot of energy, mainly in the form of natural gas. This energy is used to produce process heat, with only a small fraction being electrical energy. Energy makes up less than 10% of the production costs. The feedstock costs are the biggest part of the production cost.

What measures is your company considering to reduce emissions originating from utilities?

Our production process is exothermic, which means that it produces more heat than the process requires if we were able to recover it. Currently most of the heat from the process is is lost but our focus at the moment is to recover this heat into low pressure steam and then repressurize it using large industrial heat pumps (MVR) to high pressure steam. The plan to do this is ready but we need to wait until the funds are available for the investment. The economic factors are the limiting factor. If this plan is successful it would reduce the natural gas usage by 80%.

If we implement this plan, we would also decommission our co-generation plant, which currently allows us to offer some balancing services. Moreover, our electricity consumption would double in this scenario.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

To make our plan to recover the heat from our production process possible our grid connection would need to be expanded by at least 30%. This is currently an important obstacle to the plan to recover more heat from the process. An alternative plan has been developed which could be implemented within the limits of our current grid connection, but this would require a long term reduction of the production capacity of this site.

Our site has a relatively large grid connection compared to what the production process currently uses. We have investigated whether we could give back part of the connection to reduce grid fees. However, if we were to need more grid capacity later, such as for the energy recovery plan discussed earlier, we would have to start at the back of the waiting list again. The reduced grid fees are therefore not worth the opportunity cost of giving up that capacity. The current situation of limited grid capacity incentivizes companies to hold on to unused capacity, which leads to the grid not be used optimally.

The government and grid managers have been too slow in building new grid connections, we are ten years behind where we should be as a country.

Follow up: How is your relationship with your grid operators?

There is some frustration in the relationship with our grid operator. Grid operators complain publicly about the grid congestion, but companies such as ours are overlooked by them. The grid operators work very formally and communication takes a long time. We recently signed up to to offer balancing services, but they will only get back to us after ten weeks. It is now eight weeks later and we still have not heard anything. It is frustrating when they complain publicly about grid congestion but do not respond quickly to companies who show interest in offering balancing services. We have heard similar sentiments from some of our neighbors in our industrial cluster.

Another example where grid operators could be more proactive is with regards to the unused capacity that some companies, such as ours, have. We have not been approached about the discrepancy between our usage and our grid connection capacity.

An interesting solution to this problem would be if grid connection capacity could be sold between companies. However, the grid operators have indicated that this is not allowed under current legislation, as they have a duty to ensure a connection for everyone.

We are investigating whether we can offer more balancing services under our current production set-up, but the grid operators want to be able to automatically start the equipment from a distance in response. There is some organizational resistance against this. Our aggregator said it could be done based on a phone call, but the grid operator blocked the implementation because they want be able to control the balancing service directly from a distance. We will most likely end up implementing it such that it can be controlled from a distance by the grid operator.

Would you consider running your process in a flexible way?

Our production process itself runs 24/7 and cannot easily be scaled up or down, so constant supply of electricity would be necessary. However, we can engage in energy flexibility with our steam production facilities. This is because we can generate steam from natural gas-based boilers, as well as a co-generation plant which generates both electricity and heat. Based on the relative prices of natural gas and electricity this allows us to switch between different energy sources. This also allows us to participate in flexibility programs such as emergency capacity and frequency stabilization programs of the main grid operator. The switching between energy sources for steam generation occurs based on the day ahead market.

However, once we implement our emission reduction plan and decommission the co-generation plant our ability to engage in energy flexibility will disappear.

Follow up: Would you consider running the production process itself flexibly?

No, the energy makes up a relatively small portion of the production cost (<10%), so economically it does not make sense. Moreover, you cannot easily shut down the production process without damaging the equipment.

We consider it unlikely that the chemical industry will become flexible in the future in response to changing availability of electricity. The only way to earn back the investment on a production facility, is if it runs 24/7, 365 days a year. Bulk chemical production has low margins and profit is made by producing large volumes. To make flexible processes possible new processes would be needed, and new types of plants are always expensive. It is unlikely that this investment could be earned back if it operates flexibly.

Is your company considering alternative feedstocks to replace fossil carbon feedstocks?

Yes, we are looking into this. One of the possibilities would be feedstocks from biological sources, but the biggest contender is to use recycled feedstock. Our customers have a legal obligation to have at least 25% recycled plastic in their packaging starting in 2025. That is the most important driver for the use of more recycled feedstock. We could chemically recycle the waste plastic by using it as a feedstock. This makes sustainable products more competitive, as without regulations the price would still be the deciding factor.

I Summary Company I

Company I

Category: Specialty Chemicals

Role interviewee: Plant Manager

Summary Interview

What is the core business of your company?

We produce monomers, as well as the resulting polymers. The production process is continuous.

Does your company have greenhouse gas emission reduction targets?

Yes, we have emission reduction goals. The impact of our production process on the environment is also an important factor. We have to reduce the release of harmful compounds to the environment as the regulations for this are becoming stricter. This is an important factor because if these regulations are exceeded, it is possible to lose our license to operate.

Can you estimate which part of the production process emits the most greenhouse gases?

Only 30% of the emission footprint of the production process is in direct energy usage. 70% of the carbon footprint is in the feedstocks we use in our process. There is a larger focus on the transitioning to green feedstocks than on reducing direct energy usage.

More than the half of our price is dependent on the price of various feedstocks. The direct energy costs are a very small part of the production process (<10%).

What measures is your company considering to reduce emissions originating from utilities?

We are considering electrification of process heat. The technical obstacles are solvable, despite the lack of necessary infrastructure. One challenge is that some of our processes need temperatures which are not easily reached using electrical alternatives to natural gas.

Does your company have a roadmap to achieve your emission targets?

Yes, but there are multiple important factors. First is the safety and quality of the product, with the level of sustainability of a technology being a secondary factor. New technologies need to be as safe as the current production processes.

What problems does your company foresee that could arise from electrifying your processes?

If you switch to electrification you are fully dependent on one source of energy. The ideal situation is to use both natural gas boilers as well as e-boilers, as this means we can still operate if one of the options becomes inaccessible.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

Yes, the grid connection is a limiting factor in our energy-transition plans. However, the technical challenges to electrify some of our processes are a more important limiting factor.

Is your company considering alternative feedstocks to replace fossil carbon feedstocks?

Most of our feedstocks are currently on the basis of fossil fuel feedstocks. It is expected that soon some sustainable alternatives will enter the market. Once they enter the market we will evaluate them.

We do not want to manufacture the sustainable alternatives ourselves, but we are supporting some of the suppliers who are developing the sustainable feedstocks which could be used in our process

Follow up: Do get pressure from customers to produce more sustainable products?

Yes, we get pressure from our customers to use more sustainable feedstocks. A lot of our customers are in the car industry, and the regulations to reduce the carbon footprint in that industry have an impact in our industry through pressure of our customers. Being able to produce more sustainable products is a distinguishing feature for the EU and US markets.

Would you consider running your process in a flexible way?

There is virtually no possibility to run our process flexibly, nor is there any buffer in the utility usage of our production process. Our production equipment is running 24/7.

Would your company consider flexibility if it meant quicker access to more grid capacity?

That would not work for us, our process cannot be run flexibly. The grid operators have enquired whether we could implement demand response but we have indicated that this would not be possible. We have a neutral and professional relationship with the grid operator, without any specific issues.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

There is a strong regulatory pressure from the government, but it is important to realize that it is very difficult and expensive for the chemical industry to transition away from fossil fuel based energy and feedstocks.

Our competitors are often in areas with less strict regulations. If our production became more expensive, or intermittent (if we were to implement flexibility), this would have an impact on our competitiveness. Our product is essentially equivalent to that of our competitors, so the price is the most important factor.

As a company you are always looking at whether it makes sense to keep your production in the Netherlands, or even Europe. The government should take this into account when writing policies.

Is there a topic which was not addressed that you think would be relevant for this thesis?

As a company we need to be careful not to get complacent in our current patterns, we need to think outside the box. Mindset is an important factor in this energy transition. Often too few factors are considered when making an investment decision. The whole system needs to be considered.

J Summary Company J

Company J

Category: Specialty Chemicals

Role interviewee: Engineering Manager

Summary Interview

What is the core business of your company?

We are a specialty chemicals company. We produce surfactants and intermediate products used in the production of personal care products. Part of our feedstock is biological, with the rest being synthetic.

We are operating a batch process and we can tailor our product to a large number of different variations. The factory operates 24/7, with every batch starting immediately after the previous one.

Does your company have greenhouse gas emission reduction targets?

Yes, compared to 2019 we will have 30% reduction in emissions in 2030. Around a 10% reduction in electricity use, a 10% reduction in water usage, and a 10% reduction in waste water.

Does your company have a roadmap to achieve your emission targets?

We have a roadmap, as well as a chief sustainability officer, who is responsible for the implementation of the roadmap. At each site there are also working groups which are working out the details of the sustainability plans.

Can you estimate which part of the production process emits the most greenhouse gases?

We have an exothermic process. Some of that energy is already recovered to heat other parts of the process through heat integration. This heat cannot be used for all of the units so for some units steam needs to be used. This steam is generated using natural gas. We are currently working on plans to further expand the heat recovery from the process to reduce the need for external process heat.

Only a relatively small (<10%) of the production costs are energy costs. There would therefore only a relatively small benefit in running our process flexibly.

We actually have to expend energy to get rid of some of the low level heat produced in our production process. We are investigating whether we can use a heat pump to upgrade this heat to a useful level. However, this technology is not yet fully mature so it would be risky to implement.

Are you considering the decarbonization of process heat?

We have a developed plan to incorporate e-boilers into our process. However, this plan cannot be implemented as we are currently limited by grid congestion. Without this obstacle we would already have reached zero carbon emissions.

What problems does your company foresee that could arise from electrifying your processes?

One of the benefits of using e-boilers is that theoretically no significant redesigns should be necessary to implement it into our production process.

Would you consider running your process in a flexible way?

Potentially. One option that we are considering is installing the e-boilers next to the natural gas powered steam boilers. The downside is that you would not be allowed to label yourself net-zero.

A second option that is being investigated would be to place a battery between the grid and the production process. That would also allow us to offer balancing services.

Our process itself would not be feasible to run in a flexible way. As it is a batch process the energy consumption is not constant. The consumption has relatively strong peaks. These peaks occur throughout the day. We don't want be beholden to electricity usage requirements when running our process. Although it would be technically possible to predict those peaks, we would lose operational flexibility. Moreover, operating the production process flexibly might result in us achieving the deadlines set by the contracts with our customers.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

Yes, it is currently the only obstacle blocking our electrification plans.

We will need to wait around 2030 before the grid is expanded in our area, at which point we might have to wait even longer as first the companies ahead of us in the queue will get a connection. We applied as quickly as possible for significantly more grid capacity than we would need, to allow us flexibility in planning. This means however that grid operators most likely have an unrealistic view of how much capacity is required.

Currently part of our grid connection capacity goes unused, so we would be willing to temporarily exchange capacity. However, this is not possible under current legislation. Most companies want to protect the capacity that they have.

Would your company consider flexibility if it meant quicker access to more grid capacity?

Yes. If we implement a battery into our process this would already result in a sensible business case to make use of flexible energy prices.

Is your company considering alternative feedstocks to replace fossil carbon feedstocks?

Yes we are looking for sustainable synthetic feedstocks. With regards to scope 1 and 2 emissions our emissions will be net zero around 2030. Scope 3, which includes the impact of feedstocks, is being mapped.

We are not planning to produce the alternative sustainable feedstocks ourselves, but we are looking for suppliers who are working on producing sustainable versions of the necessary feedstocks. Some suppliers already offer this at a premium, which we results in the sustainable variants of our products being more expensive. The demand for these products is increasing, however the price difference is still too great to fully switch to sustainable feedstocks.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

The government does listen. A member of parliament came to hear about the obstacles we encountered. It is a topic of concern on the political level. However there is no true plan, grid operators are left to solve the issues themselves.

Grid congestion is an important factor in the decision of companies whether to invest in the Netherlands. The lack of necessary infrastructure leads to uncertainty for investment decisions. It makes other countries more attractive for investments as there the infrastructure will at least not be a limiting factor. The government should step in to ensure the business climate in the Netherlands remains competitive.

An additional impact that the government has is through taxes and tariffs. The tax on natural gas increased which suddenly made sustainable business cases more feasible. However, this needs to be balanced against the need not to worsen the investment climate too much.

K Summary Company K

Company K

Category: Specialty Chemicals

Role interviewee: Process Engineer

Summary Interview

What is the core business of your company?

We are a specialty chemicals company and our products are produced in relatively small volumes. We also have a big R&D component.

Our process is semi-continuous. This means that some of our production process is continuous, while other parts are produced in batches.

Can you estimate which part of the production process emits the most greenhouse gases?

Most of the energy we use is used for process heat. Some of our processes are exothermic, but the temperature is not high enough for heat integration with other units. The rest of the energy is in the form of electricity which is needed to operate the plant, such as pumps and other appliances.

What measures is your company considering to reduce emissions originating from utilities?

We are looking into electrification. One option is to use a heat pump to heat air. However, a heat pump is limited to a specific range. A heat pump also generates a cold stream and as we do not have a 'cold consumer' at our production site so this hinders the feasibility.

A second electrification option is to use e-boilers. However, currently this option is still more expensive than natural gas.

When considering these options the first factor is what the pay-back period of an option is. This is highly dependent on the relative energy price of different energy sources. The second factor is in the decision making is the environmental impact of our process.

As we cannot electrify all units at the same time we first consider the options for the largest energy consumers in our production process, and use a sensitivity analysis to see where new investments would be most effective.

These type of decisions are also highly dependent on the current economic situation of the plant. Our plants are currently not fully booked, which reduces the revenue and affects the profitability. It therefore makes the big investments necessary for electrification more risky.

We also keep track of what other companies in our sector are doing. Currently big electrification plans only occur when they receive support from the government. Funding these types of projects out of internal funds is not financially attractive.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

We are not encountering issues with grid congestion at our location. We have also been able to switch to fully green electricity at our location. The business case and payback period are the main constraints for our decarbonization projects.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility and electrification?

One big influence of the government are the subsidies they provide. However, it can be hard to actually be awarded a subsidy. Although there are official criteria, having influence at the government is very important factor in whether you get a subsidy or not. The most attractive applications are from the biggest energy consumers. Dutch companies generally also have better connections in the political establishment to lobby for certain subsidies.

As a medium or small consumer it is not attractive for the government to allocate money to you. To be attractive for the government you need to be a big company or backed by Dutch investors.

The companies who receive subsidies also still need to invest a lot of capital themselves into the project. The companies who receive it either are a big player, or they can reach 100% sustainability. There are few examples of these kind of companies in the chemical industry.

Follow up: What is the impact of regulations?

The regulations for subsidies are very rigid. In general these are well-written regulations but sometimes they do not make sense from an industrial perspective. As a company we might have projects which could reduce our carbon footprint, but due to a technicality we are not eligible for a subsidy that can help us achieve that.

As a medium sized company you have to lobby through the VNCI (the Dutch Association for the Chemical Industry), or a similar association, otherwise the government does not have time to listen to you. The government wants to do good, but they are resource limited.

The regulatory pressure is impacting us everywhere. Recently 70 companies gathered together to ask EU government to reduce the regulative pressure. If pressure remains unabated, the EU might lose up to 50% of industry in the next 10 years. And that industry is responsible for a decent chunk of the GDP of the EU.

Would you consider running your process in a flexible way?

No. One of the main obstacles of operating flexibly is the labor cost. We would still need to pay all our employees whether or not you run your own process. These labor costs are a significant part of the operational cost are so scaling down the production process in response to changing electricity prices would not be worth it. From an operational view it is better to have a 24/7 steady schedule.

It can be quite challenging to find operators for a chemical plant. If you pressure them into flexible schedules, to accommodate running your process in response to electricity prices, you will lose those operators.

The production schedule and quotas are also an important factor. To deal with this factor you would need more storage, and to change customer relationships because your production would no longer be steady. It makes sense if electricity makes up a large part of the production cost. But if it is only 10% or less, as it is in our case, and other costs, such as labor, are bigger, it does not make sense.

L Summary Company L

Company L

Category: Specialty Chemicals

Role interviewee: Maintenance Engineer

Summary Interview

What is the core business of your company?

Our core business is specialty chemicals. The products are produced in a batch processes, in batches of no more than a few thousand liters. Over a thousand people are working at the production location, of which around a quarter are involved in the production process.

Does your company have greenhouse gas emission reduction targets?

Yes. The goal is to reduce 50% of the emissions by 2030. This includes all three scopes of emissions.

Does your company have a roadmap to achieve your emission targets?

Yes, although many aspects of that roadmap are still uncertain.

Can you estimate which part of the production process emits the most greenhouse gases?

Relatively little energy is used in the production process. Roughly half the energy used in the production process is through electrical appliances such as mixers and pressurized air. The other half of the energy is used for the heating of the buildings in which the production takes place. The energy costs make up less than 10% of the production cost.

What measures is your company considering to reduce emissions originating from utilities?

Improving the isolation of the buildings would help but would be expensive and would have a relatively small impact on energy consumption. Replacing the HVAC units with modern units would reduce energy required for heating, but this would not save enough cost to make it a worthwhile investment until the current units reach their end of their designed lifespan.

Both of the possibilities are on the roadmap, but these are only expected to be implemented when something reaches its end of life and needs to replaced anyway.

Would you consider running your process in a flexible way?

We don’t see potential for flexibility in our production process. Our energy use is too small. Most energy is in heating, which is not coupled to the production process but to the outside temperature.

Is your company considering alternative feedstocks to replace fossil carbon feedstocks?

There is more interest for products which are more environmentally friendly. We are therefore now also offering products where one of the major components in our product is replaced with a more environmentally friendly alternative.

Will electrical energy consumption change in the future?

Not significantly. Energy consumption will increase slightly due to the higher energy requirements of the products using more environmentally friendly feedstocks. We expect the demand for these products to increase. However, despite these products requiring more energy we don't expect that our total electrical energy consumption will increase significantly.

Electrification of heating will most likely also be considered in the future, but this is not yet being actively considered. Within the next ten years this option will be considered and worked out in detail. Our decision to electrify process-heating is actually not driven by the goal of reducing CO2 emissions but rather by the need to mitigate against the risk of an acute scarcity of natural gas.

There is no clear picture yet what the best route is to transition away from natural gas-based heating to a sustainable alternative. A heat pump would currently be too expensive and would not have enough heating capacity. The plan is to wait for a few years, at which point we expect it will be clearer what the best options are.

M Summary Company M

Company M

Category: Hydrogen Producer

Role interviewee: Project Manager

Interview Summary

What is the core business of your company?

Our core business is the production and sale of hydrogen, both for energy and feedstock. The company currently does not have operational production locations yet, but ground on the first factory will be broken soon. We work together with companies who have already signed commitments to purchase hydrogen from us. These customers are mainly companies who already use hydrogen, such as the chemical industry. Companies which are considering potentially changing their feedstock to hydrogen in the future are not making commitments yet.

Do you expect the market for hydrogen to grow due to the energy-transition?

We do not expect the absolute market for hydrogen to grow, but we do expect the relative demand for green hydrogen in that market to grow.

Green hydrogen is still significantly more expensive than grey hydrogen. The exact relative price is dependent on the natural gas price and the cost of CO_2 emissions.

Would you consider running your process in a flexible way?

Yes, the production process will be run in a flexible way. The main reason for this is that hydrogen produced by electrolysis can only be called green when it was produced using sustainable electricity (solar, wind, etc.). This means that our production process is dependent on the availability of sustainable electricity.

The factory will only run if green energy is available at an acceptable price. The first priority is that electricity is green, only secondly do we check whether the price is acceptable. This is also a requirement of some of the subsidies that we receive.

Hydrogen as a battery is not being considered, as this does not work with our production process. That technology is not yet mature enough.

Follow up: Are productions quotas an issue?

Our costumers only use green hydrogen as an addition to grey hydrogen. If not enough green hydrogen is produced by us they can absorb this shortfall with grey hydrogen.

We expect that in the future there will be fewer periods without green electricity. Additionally, Gasunie is developing a large scale storage of hydrogen which will allow us to buffer our production.

Have you encountered issues with the availability of grid capacity, and do you expect this to be a bottleneck in your decarbonization projects?

Although the grid connection are an important factor, it has not been a major obstacle. For a new production site we only need the ground to build on and an available grid connection. We are not bound by existing production infrastructure. We therefore only consider locations where enough grid capacity is available.

One potential issue is that the grid operator can ask us to shut down a certain percentage of the year to mitigate net congestion. Officially this is not required, but in the next phase of grid congestion the grid operator would be allowed to force us to do it. It is therefore in our best interest to be cooperative and proactive in this. It is relatively easy for our factory to shut down, and this intermittent production is accounted for as well in the contracts with our customers. Additionally, it results in significant discounts on our grid fees.

Follow up: Do you have a good relationship with your grid operator?

We have a good relationship with the grid operators, but we only build in locations where there is enough room on the grid so there is not much cause for friction.

Does your company experience the existing regulatory climate as a driver or barrier with regard to flexibility?

The government affects our business in three significant ways:

- They provide subsidies, supporting the construction of the production facilities, as well as covering some of the price difference between grey and green hydrogen.
- The European Union is implementing rules that a certain percentage of hydrogen used by companies should be green.
- The government is supporting the development of a hydrogen network.

These are positive developments for us but it could always be better. The implementation of these policies is taking a long time. One aspect that could be organized better is that subsidies are currently dependent on when you applied for them. If circumstances change this is not taken into account. For example, grid fees have risen by 80% twice in the last few years, without a change in the amount of subsidies which we receive.

Another aspect is that sometimes regulations are clear on an EU level, but not yet at the national level. This delay is often due to lobbying from the chemical industry. Green hydrogen is not yet competitive. If companies are not required to use green hydrogen they will not use it.

To change the industrial sector the carrot of subsidies needs to be combined with the stick of regulations. If we make regulations too strict companies will leave the Netherlands, and we will be essentially exporting our carbon emissions.

Is there a topic which was not addressed that you think would be relevant for this thesis?

Companies need to realize that in the future flexibility will be valuable. The more flexibility your company has, the most future-proof you are.

N Interview Request Message Template

N.1 Dutch Inmail Message

Beste [Name Candidate],

Mijn naam is Henry Verhoeff en ik ben een master student aan de TU Delft. Ik ben op het moment mijn master scriptie aan het schrijven over het gebruik van demand response binnen de chemische industrie. Specifiek ben ik aan het kijken naar de rol die het speelt in de energie transitie plannen van chemische bedrijven. Voor dit onderzoek ben ik mensen aan het interviewen bij verschillende chemische bedrijven in Nederland.

Is [Company Name] bezig met demand response? Ik zou graag u of een van u collega's interviewen over dit onderwerp. Is dit mogelijk?

Het interview zou 30-45 minuten duren en kan zowel online als fysiek plaatsvinden, afhankelijk van wat uw voorkeur heeft. De data zal worden geanonimiseerd en u zult de kans krijgen om de resulterende data in te zien en eventueel dingen te verwijderen of veranderen. Mocht u nog verdere vragen hebben over mijn onderzoek dan beantwoord ik die graag.

Hartelijk dank,

Met vriendelijke groeten,

Henry Verhoeff

N.2 English Inmail Message

Dear [Name],

My name is Henry Verhoeff and I am a master student at Delft University of Technology. I am writing my thesis on the topic of demand response in the chemical industry, and specifically on the role it plays in the energy transition plans of companies in the chemical industry. As part of this research project, I am interviewing people who work at chemical companies in the Netherlands.

Is demand response something which [Company Name] is looking at? Do you have knowledge of this topic or do you know someone else whom I could interview about this topic?

The interview would take around 30-45 minutes and can take place either online or in person. The data from the interview will be anonymised and you would get the opportunity to review the resulting data and request the removal or correction of any part of the data.

Should you have any further questions about my research, please let me know.

Thank you very much,

Best regards,

Henry Verhoeff

N.3 Dutch Reminder Message

Beste [name],

[Time since first message] had ik u een bericht gestuurd met verzoek tot een interview over demand response binnen de chemische industrie. Ik stuur dit bericht in het geval u mijn eerste bericht over het hoofd heeft gezien.

Zelfs als [Name Company] niet bezig is met demand response zou het perspectief van uw bedrijf alsnog een waardevolle toevoeging zijn aan mijn onderzoek.

Het interview zou 30-45 minuten duren en kan zowel online als fysiek plaatsvinden, afhankelijk van wat uw voorkeur heeft. De data zal worden geanonimiseerd en u zult de kans krijgen om de resulterende data in te zien en eventueel dingen te verwijderen of veranderen. Mocht u nog verdere vragen hebben over mijn onderzoek dan beantwoord ik die graag.

Hartelijk dank,

Met vriendelijke groeten,

Henry Verhoeff

N.4 English Reminder Message

Dear [Name],

[Time since first message] I sent you a message with a request for an interview about demand response in the chemical industry. This message is a reminder should you have overlooked my initial message.

Even if [Name Company] does not currently use demand response, your perspective would still be a valuable addition to my research.

The interview would take around 30-45 minutes and can take place either online or in person. The data from the interview will be anonymised and you would get the opportunity to review the resulting data and request the removal or correction of any part of the data.

Should you have any further questions about my research, please let me know.

Thank you very much,

Best regards,

Henry Verhoeff

O HREC Application & Informed Consent

O.1 HREC Application

O.1.1 Applicant Information

PROJECT TITLE:	Demand Response in the Chemical Industry
Research period: Over what period of time will this specific part of the research take place	The data collection portion of the research will take place over the course of 8 weeks.
Faculty:	Technology Policy Mangement
Department: Services	Engineering Systems
Type of the research project: (Bachelor's, Master's, DreamTeam, PhD, PostDoc, Senior Researcher, Organisational etc.)	Master's Thesis
Funder of research: (EU, NWO, TUD, other – in which case please elaborate)	N/A
Name of Corresponding Researcher: (If different from the Responsible Researcher)	Henry Verhoeff
Position of Corresponding Researcher: (Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor)	Master Student Management of Technology
Name of Responsible Researcher: Note: all student work must have a named Responsible Researcher to approve, sign and submit this application	Dr.ir. M.D.M. Pérez-Fortes
E-mail of Responsible Researcher: Please ensure that an institutional email address (no Gmail, Yahoo, etc.) is used for all project documentation/ communications including Informed Consent materials	
Position of Responsible Researcher : (PhD, PostDoc, Associate/ Assistant/ Full Professor)	Associate Professor

O.1.2 Research Overview

Please summarise your research very briefly (100-200 words) What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

I will be interviewing 10-20 representatives of stakeholders related to demand response in the chemical industry. They will be asked to assess the impact of implementing electrical demand response for the stakeholder which they represent. This will take the form of semi-structured interviews of around 30-45 minutes. The participants will be recruited through various means. First I will be approaching people through my own network. Besides that, I will also be cold approaching potential stakeholders via LinkedIn or official email addresses.

O.1.3 Risk Mitigation

ISSUE	Yes	No	RISK ASSESSMENT what risks could arise?	MITIGATION PLAN what mitigating steps will you take?
20. Will the study involve disclosing commercially or professionally sensitive, or confidential information? (e.g., relating to decision-making processes or business strategies which might, for example, be of interest to competitors)	X		During the interview the participants may mistakenly talk about things which they would not want to share with their competitors. This could be both harmful for their company as for the employee who might face repercussions due to the mistake.	After the interview I will send the interviewee a summary of what was discussed during the interview. I will ask whether there is anything that they would prefer not be shared. These parts of summaries will be removed and not used in the research process.
28. Will your research involve face-to-face encounters with your participants and if so how will you assess and address Covid considerations?	X		If one of the particpants (interviewer or interviewee) are sick they might spread the infection to the other person.	The official guidelines of the Dutch government will be followed that are in effect at the time of the interview: Additionally if either particpant feels uncomfortable holding the interview in person the interview will be held online.
30. Will the research involve collecting, processing and/or storing any directly identifiable PII (Personally Identifiable Information) including name or email address that will be used for administrative purposes only? (eg: obtaining Informed Consent or disbursing remuneration)	X		If improperly stored this information could be used for other purposes beyond that for which the research subjects gave permission.	The information will be stored in the dedicated storage drive to which only the master student and the first supervisor will have access. All PII will be destroyed within 1 month of the completion of the project.
31. Will the research involve collecting, processing and/or storing any directly or indirectly identifiable PIRD (Personally Identifiable Research Data) including videos, pictures, IP address, gender, age etc and what other Personal Research Data (including personal or professional views) will you be collecting?	X		As the interviews will be recorded video and audio material will be collected. A risk that could arise is that this data is seen by others outside the research team, for which the participants did not give permission in their consent form.	The information will be stored in the dedicated storage drive to which only the master student and the first supervisor will have access. All PIRD will be destroyed within 1 month of the completion of the project.

ISSUE	Yes	No	RISK ASSESSMENT what risks could arise?	MITIGATION PLAN what mitigating steps will you take?
33. Will your research findings be published in one or more forms in the public domain, as e.g., Masters thesis, journal publication, conference presentation or wider public dissemination?	X		The research findings will be published as a Master Thesis and uploaded to a publically accessible repository. There is the potential risk of information being shared which the interviewees did not wish to share publically.	As mentioned in point 20, the summaries of the interviews will be anonymized and the interviewees will have the opportunity to review these summaries and indicate any points which they wish to be removec. Any information will therefore be checked both by the researcher and the participant themselves to make sure the summary was properly anonymized.
34. Will your research data be archived for re-use and/or teaching in an open, private or semi-open archive?	X		The final master thesis will be uploaded in a publically accessible repository. The anonymized summaries of the interviews will be included in the appendices. For the potential risk see points 33.	As mentioned in point 20, the summaries of the interviews will be anonimized and the interviewees will have the opportunity to review these summaries and indicate any points which they wish to be removed. Any information will therefore be checked both by the researcher and the participant themselves to make sure the summary was properly anonymized.

To conserve space only the issue where potential risks were found are shown here. The full HREC checklist can be found on the webpage of the TU Delft HREC: https://www.tudelft.nl/en/about-tu-delft/strategy/integrity-policy/human-research-ethics

O.2 Informed Consent Form

You are being invited to participate in a research study titled Industrial Flexibility in the Chemical Industry. This study is being done by Henry Verhoeff from the TU Delft.

The purpose of this research study is to study the drivers and barriers of the use of industrial flexibility in the Dutch chemical industry and will take you approximately 30-45 minutes to complete. The data will be used for a master thesis research project. We will be asking you to answer questions regarding industrial flexibility at the stakeholder which you work for.

This interview will be recorded. Based on this recording a transcript will be made of the interview. This transcript will be used to make an anonymized summary of the interview. This anonymized summary will be shared with you at which point you will have the opportunity to indicate any points which you do not want to be included in the summary. These points will be removed from the summaries and will not be used in any part of the research project. The anonymized summaries will be included in the appendices of the master thesis, which will be published in a publicly accessible online repository.

As with any activity where data is collected, the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by storing any Personal Identifiable Information (PII) or Personally Identifiable Research Data (PIRD) on a dedicated research project storage drive only accessible by the responsible researcher (Henry Verhoeff) and his supervisor (prof. Pérez-Fortes). All PII and PIRD will be destroyed within 1 month of the completion of the master thesis.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions and you will have the opportunity to review the anonymized summary and request the removal of any part of that summary within 1 month of receiving the summary.

Study contact details for further information:

Henry Verhoeff

H.J.H.Verhoeff@student.tudelft.nl

Explicit Consent

	Yes	No
1. I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.		
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.		
3. I understand that taking part in the study involves: participating in an interview which will be recorded either in video or audio format. These recordings will be transcribed into text after which the recordings will be destroyed.		
4. I understand that the study will end at the end of the master thesis research project, estimated to be in April 2024.		
5. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) such as my name and contact information and associated personally identifiable research data (PIRD) such as recordings of the interview with the potential risk of my identity being revealed with potential risk for my professional reputation.		
6. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach such as: secure data storage with limited access, and anonymization of the data.		
7. I understand that personal information collected about me that can identify me, such as my name and contact information, will not be shared beyond the study team.		
8. I understand that the (identifiable) personal data I provide will be destroyed at the conclusion of the master thesis research project.		
9. I understand that after the research study the de-identified information (an anonymized summary of this interview) I provide will be used for a master thesis.		
10. I agree that my responses, views or other input can be quoted anonymously in research outputs		

Signature

Name of Participant	Signature	Date

P Chemical Companies in the Netherlands

In this appendix a list of chemical companies in the Netherlands is shown. This list was used as a basis for the approach of potential participants, described in Section 3.2.2. Each company has been placed in categories, explained in Section 4.1, based on publicly available information on the internet. The category was based on the production facilities in the Netherlands, without taking the global focus into account. Please note these categories are not exact are only meant as an aid in the analysis of the interview sample.

Company	Category	Company	Category
Air Liquide	Commodity - Gases	Indorama	Commodity - Polymer
Air products	Commodity - Gases	Kraton Polymers	Commodity - Polymer
Albemarle	Specialty	Lanxess	Specialty
Almatis	Commodity	Lubrizol	Specialty
Anquore	Commodity - Inorganic	Lynondellbasell	Commodity - Polymers
Arkema	Specialty	Mitsubishi Speciality Chemicals	Specialty
Arkema	Specialty	Nobian	Commodity - Inorganic
ARLANXEO	Commodity - Polymer	Nouryon	Specialty
Aurorium Netherlands BV	Commodity - Polymers	Nyrstar)	Commodity - Metal
Bakelite Synthetics	Commodity - Polymers	Organik Kimya	Specialty
Basf Nederland	Specialty	Outokumpu	Commodity - Metals
Borealis Plastomers	Commodity - Polymers	Rosier	Commodity - Fertilizer
BP	Commodity - Petrochemical	Royal Shell	Commodity - Petrochemical
Century Aluminium	Commodity - Metal	Sabic	Commodity - Petrochemical
Climax molydenum	Commodity - Metal	Shin Etsu	Commodity - Polymers
Covestro	Commodity - Polymers	Synthomer	Specialty
Croda	Specialty	Tata Steel	Commodity - Metal
Dow chemicals	Commodity - Petrochemicals	Teijin Aramid	Commodity - Polymers
Dr. W. Kolb	Specialty	Trinseo	Commodity - Polymers
DSM	Specialty	Tronox	Commodity - Inorganic
Ducor	Commodity - Petrochemical	VYNOVA GROUP	Commodity - Inorganic
Dutch Glycerin Refinery	Commodity	Westlake	Commodity - Polymers
Exon Chemicals	Commodity - Petrochemical	Wilmar Oleochemicals	Commodity
Fibrant	Commodity - Inorganic	Yara	Commodity - Fertilizer
Huntsman Holland	Specialty	Zeeland Refinery	Commodity - Petrochemicals
icl ip terneuzen	Commodity - Fertilizer		

Tab. 8. A list of chemical companies operating in the Netherlands and the category to which the belong.

Of the 51 companies, 37 companies fell in the commodity category (72%), and 14 in the specialty chemicals sector (28%). Of the 37 commodity companies 13 were in the Polymer sub-category, 7 in the petrochemical sub-category, 5 in the metal sub-category, 3 in the fertilizer sub-category, 5 in the inorganic sub-category, and 4 not fitting into a specific sub-category.