Master's Thesis – Master Energy Science

A meta-analysis of the visions of the Dutch industrial sector for 2050

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Abstract

To limit the effects of climate change the Dutch government agreed to cooperate in the emission reduction goals of the Paris Climate Agreement. The industry is one of the major contributors of greenhouse gas emissions in the Netherlands. In order to reduce carbon emissions to the atmosphere stakeholders presented their visions towards 2050 including several reduction options to decarbonize the industrial sector. The aim of this research is to analyze the different visions for 2030 and 2050 that have been published by the stakeholders of the Dutch industrial sector and the government. After a literature survey three important topics were chosen to be analyzed in detail: electrification, hydrogen, and carbon capture, utilization, and storage (CCUS). From the different visions the main choices and consequences, which are of importance to advance the energy transition in the Netherlands, were determined. Based on the choices and consequences was determined what long- (10-30 years) and short-term (1-10 years) developments were needed to realize these visions.

There is a clear difference in the level of detail and comprehensiveness of the different reports that were analyzed for this study. The governmental reports often had a relatively clear vision for 2050 for the entire Dutch industrial sector. The reports by the industrial clusters had clear aspirations but lacked detail. The reports by the companies did often lack detailed insight in the visions for 2050. Their reports gave general objectives like CO_2 emission reduction goals but mentioned no technologies or tools they would use to achieve this. The consultancy reports did have well elaborated visions for 2030 and 2050, each report with its own strengths.

There is a broad consensus that the Dutch industrial sector is expected to be electrified to a large extent. This will increase the demand for renewable electricity. To facilitate this development the grid capacity will need to be reinforced. Similarly, consensus consist that the hydrogen production for 2050 will increase as it could be used as a feedstock for chemicals, such as ammonia and methanol, and to balance the electricity grid. This can increase the electricity demand further, because a large part is expected to be produced from water electrolysis, which requires electricity. Towards 2050 it is expected that the overall electricity demand for the industrial sector could increase with 29.2 GW. To achieve the 2030 reduction goals CCS is a vital tool to use. It enables the industrial sector to reduce the CO_2 emissions up to 7 Mt within the coming years, with an expected minimum of 3.4 Mt. In some reports it was expected that CCS will still be necessary until 2050. CCU is a tool that could be used too, but currently has limited potential. It is expected this potential will increase towards 2050.

Contents

1 Introduction

The Dutch government has agreed to cooperate in the goals set by the Paris Climate Agreement of 2015 to reduce the greenhouse gas emissions. For the Netherlands, the goal is a CO_2 emission reduction of 49% in 2030 and 95% in 2050, both in comparison to 1990 (Rijksoverheid, 2019). To achieve this large reduction in the Netherlands, the industrial sector needs to reduce the emission. The goal of the Dutch industrial sector is a 59% reduction of CO_2 emission in 2030, and a near zero emission in 2050. The 2030 target implies a reduction of 19.4 Mt reduction in CO_2 emission. This is a combination of the base pad proposed by PBL in 2017 (PBL, 2017a) which implied a 5.1 Mt emission reduction, and an additional 14.3 Mt of emission reduction (Rijksoverheid, 2019).

1.1 Research Background

Several studies were performed to identify the emission reduction possibilities and ambitions of the Dutch industrial sector. Studies for sectoral breakdowns and possible pathways were performed by Dutch governmental organizations like Centraal Bureau voor de Statistiek (CBS, 2016; 2018) and Planbureau voor de Leefomgeving (PBL, 2011; 2019a; 2019b). These studies provide the first steps to possible visions for 2050. The climate agreement and energy agenda by the Rijksoverheid (2019; 2016) give structure and guidelines for the emission reduction goals. More recently the Minister of Economic Affairs and Climate send a letter to the Chairman of the House of Representatives, highlighting the importance of a sustainable and climate neutral primary industry, and posed some possibilities to achieve this (Wiebes, 2020).

Next to these governmental reports, similar researches by other organizations have been performed. For instance, Roelofsen et al. (2017) conducted a report on behalf of McKinsey to identify the possibilities and options for a necessary transition. Stork et al. (2018) described the possibilities for the Dutch chemical industry. Van Soest et al. (2016) described the possibilities to transition towards a lower CO_2 emitting industry in a short report. Kerkhoven et al. (2017) wrote about the future of the Dutch energy-intensive industry, with a view towards both 2030 and 2050.

Furthermore, each of the industrial companies have their own strategy and vision in how to achieve emission reduction. They publish sustainability reports or publications with their own goals and visions for 2030 and/or 2050. In the Netherlands there are several industrial clusters. These are groups of companies that are located in proximity to each other and can thereby create advantages by working together. The exchange of gasses and lower transportation cost are examples of this. For the rest of the research these clusters are known as industrial areas. These industrial areas have their own unique properties and qualities, so all will have different views of the best way to achieve the set emission reduction goals. They to publish visions for 2030 and/or 2050.

Some of the previous mentioned reports describe the development of the emission reduction of the companies and areas. These reports illustrated that the Dutch industrial sector already reduced its greenhouse gas emissions by 32% from 1990 to 2014, but this was mainly a reduction of other gasses than CO_2 such as CH_4 and N_2O (Roelofsen et al., 2017). This reduction shows the willingness and ability of this sector to change when feasible and economically favorable. Important to remember is that predictions and estimations of future developments are uncertain and should not be seen as the 'truth' for the future, but more as one possible scenario or range of possible scenarios.

1.2 Research gap

While several research projects and reports were published regarding the Dutch industrial sector, the overall vision of what the industrial sector in 2050 will look like can still be unclear. The large variety of reports present diverse scopes, visions, and final conclusions on how the future energy landscape of the Netherlands will evolve. This research will focus on the differences and similarities in the choices and consequences made underlying the different visions. It will combine reports by the Dutch government, industrial companies, industrial areas, and scientific articles to better understand the aligned visions towards a low carbon future.

1.3 Research questions

What are the choices of the Dutch industrial sector for 2050 and what are the consequences of these choices?

<u>Sub questions:</u>

1. What does the industrial landscape look like in the Netherlands in 2020?
2. What are the visions of the stakeholders in industry for 2050?
3. What are the consequences of the visions by the stakeholders?
4. What are the necessary developments needed to realize these visions?
5. What short-term action is required to make these visions possible?

To understand what the future of the Dutch industry will look like, it was first necessary to identify what it looks like right now. For a lot of older research, the year 2020 is the first moment of reflection in becoming more sustainable. Therefore, it was useful to see which of the goals were already reached and which were not. This information could be used as the first guide in assessing whether the goals set for the future are realistic. This created the first sub question: 'What does the industrial landscape look like in the Netherlands in 2020?'

After the industrial landscape was clearly defined and their respective emissions and energy use was identified, the next step was analyzing the visions of 2050. The reports by the largest and most impactful stakeholders in industry were analyzed in this research. The focus of the outcome of this part was on the choices made by these stakeholders.

The proposed choices presented certain consequences, both within their own area/company or outside of it. For instance, if a large demand for biomass was proposed, this could reduce the available biomass for other sectors like the energy sector. Or if a large demand for sustainable hydrogen production were proposed, there would be a large need for renewable electricity. The choices could have a large impact on the entire Dutch economy. Therefore, the next step of the research was to identify and analyze the consequences of the proposed choices.

These presented visions have certain choices and consequences in the pathways to achieve certain goals. To achieve these goals some long-term developments are required to both technologies and the socio-economic environment of the industrial sector. For example, reduced prices of the latest innovations because of a higher cumulative installed capacity.

Finally, to achieve the CO_2 emission reduction goals of the companies and areas, action is required. Short-term goals that can prove the viability of technologies, can identify potential scaling problems, and can identify necessary regulation changes by the government. Instead of postponing investments and anticipating lower prices in the future, action is required to take the first steps.

2 Methodology

To analyze the Dutch industrial sector a meta-analysis of previous research was constructed. It was both a quantitative and qualitative analysis. This research existed of both articles by academics, as reports published by companies and areas in industry themselves, and the government.

2.1 Dutch industry in 2020

To answer the research question the Dutch industrial sector first needed to be defined. Who the different stakeholders are and what their economic, social, and environmental impact is right now. For this research, the five most polluting industrial areas were analyzed, since they contribute to a large share of the total emission of the entire Dutch industry. Furthermore, there are many industrial companies in the Netherlands but there are twelve companies that contribute to the largest share of the total emissions of the Dutch industrial sector. These twelve companies were analyzed and introduced in this part of the research. The main activities, current emissions, employment availability and locational properties were described.

2.2 Stakeholder visions for 2050

After the Dutch industrial sector was analyzed, the next step was analyzing several reports to identify the structure and focus of the research. For this first analysis eight reports were used, three by the Dutch government and five by the Dutch industrial areas. The reports were: Rijksoverheid, 2016; 2019; Wiebes, 2020; NZKG, 2014; Chemelot, 2020; CE Delft, 2016; König, C et al., 2018b; Kroes, C et al., 2018. In this part of the research three categories were analyzed as summarized for all the reports. These three categories were the economic value and portfolio of the future industry, the future energy supply and the greenhouse gas emissions and other environmental impacts of the stakeholders in 2050.

<u>Economic value and product portfolio of future industry</u>

In 2050 it is to be expected that the world will be different than it is nowadays. We consume different products, eat differently, use energy differently and use other means of transportation. With this change it is uncertain what the industrial sector will look like in 2050. Therefore, the first step towards the visions for 2050 was to analyze what the economic value of the Dutch industry as a whole. This economic value can illustrate how much impact the industrial sector has on the total Dutch economy. It could determine whether the Dutch industrial sector still is the ‘economic powerhouse’ as stated by Roelofsen et al. (2017). It thereby can illustrate the development of the Netherlands throughout the path towards sustainability. The possible changes in industry have different impacts on the various companies and areas. Some sectors might grow, whereas other shrink or shift their business to other more sustainable types of products. It is uncertain if the companies produce the same products and in the same quantities.

<u>Future energy supply</u>

The value created by the industrial sector is, amongst others, created with energy. With a shift in product portfolio and economic, social, environmental, and technological development, the future energy supply can change drastically. Therefore, the next step of the research was to analyze the energy management of the companies and areas. The energy generation types, energy sources and energy demand/supply per company all determine the overall future energy supply of the industrial sector, so these were the main focus points of the research.

<u>Greenhouse gas emissions</u>

The future energy supply emits greenhouse gasses like carbon dioxide (CO_2). This part of the research analyzed these emissions by the companies and areas. This was done by determining the total final emission, but also include the pathways in which this has been done. For example, by determining if there is a need for carbon capture and storage (CCS) or carbon capture and utilization (CCU) to achieve the proposed numbers.

The results of the analysis can be found in Appendix 10.1: First Analysis. This analysis of the first eight reports resulted in three of topics: electrification, hydrogen and carbon capture, storage, and utilization. For each of the different stakeholders a number of reports was used to analyze the visions for 2050 on these three topics. For the governments point of view regarding these three topics, fourteen reports were fully analyzed and can be found in Table 1. For the five industrial areas, a total of fourteen reports were used which can be found in Table 2. For the twelve companies in total nineteen reports were used, which can be found in Table 3. Important to note is that for Zeeland Refinery no report could be found, so the majority owner of Zeeland Refinery and previous owner of the refinery itself was used instead, namely Total. For some companies, the international vision of the company was used if no Dutch vision was published or found. Finally, there were reports performed by consultancy firms that describe either the entire Dutch industry or a part of this. These researches were also analyzed, and their visions described. Here three reports were used which can be found in Table 4. The choices that each of the stakeholders made to create the visions are described in this part of the research.

Table 1: The reports by the government and governmental organizations used to analyze the visions for the industrial sector for 2050.

Governmental organizations	Reports
Rijksoverheid	Rijksoverheid, 2016; 2019; Wiebes, 2020
PBL	PBL, 2011; 2017a; 2017b; 2019a; 2019b
CBS	CBS, 2016; CBS, 2018; CBS, 2020
Meerjarige Missiegedreven Innovatieprogramma’s	TKI Energy en Industrie, 2019a; 2019b; 2019c; 2019d

Table 2: The reports used to analyze the visions for the five areas for 2050.

Areas	Reports
Rotterdam-Moerdijk	Kroes et all, 2018; Porthos, 2019a
Zeeland	Provincie Zeeland, 2009; CE Delft, 2016; 2020
Noordzeekanaal	NZKG, 2014; 2018; 2020; Athos, 2019
Chemelot	Chemelot, 2016; 2018; 2020
Noord-Nederland	Konig et al., 2018a; 2018b

Table 3: The reports used to analyze the visions for the twelve companies for 2050.

Companies	Reports
Tata Steel	Tata Steel, 2019; 2020b
Shell	Shell, 2020c
ExxonMobil	ExxonMobil, 2019; 2020a
BP	BP, 2020b
Dow Chemical	Dow, 2018; Dow, 2019
Yara Sluiskil	Yara, 2019
SABIC	SABIC, 2018; 2019
Zeeland Refinery	Total, 2019
Air Liquide	Air Liquide, 2020a; 2020b
Air Products	Air Products, 2020
OCI Nitrogen	OCI, 2019; 2020
Nouryon	Nouryon, 2018b; 2020

Table 4: The reports used to analyze the visions for the three consultancy firms for 2050.

Consultancy	Reports
McKinsey	Roelofsen et al.,2017
Quintel	Quintel, 2017
VNCI	Stork et al., 2018

2.3 Consequences

Within the visions of the stakeholders certain choices were identified. These choices have consequences for either the company or area itself or on a larger part of the Dutch economy and society. These consequences were analyzed and described in this part of the research. Combining the choices and consequences of different stakeholders provided some insight to what extent the industrial sector could have an impact on the entirety of the Dutch economy.

2.4 Developments needed

For many of the choices and consequences the different stakeholders proposed in the reports, there are some challenges that exist right now. Some long-term developments are needed to make the visions possible. The necessary developments were analyzed for the three topics. Combined with the choices and consequences, this analysis could determine what actions needs to be undertaken within the next thirty years to achieve the necessary reduction goals for 2030 and 2050.

In order to determine the sustainable electricity demand in the electrification part of the research, data from the areas was used (See Table 2). This data was used to calculate an expected offshore wind power demand of the five largest areas of the industrial sector. To determine the expected future capacity factor of offshore wind power farms IEA (2019a) data was used. An energy demand could thereby be converted to a power demand with the following formulas:

$$Energy = Power * Time * Capacity\ Factor$$

$$Power = \frac{Energy}{Time * Capacity\ Factor}$$

The wind power calculated could be compared to the estimated offshore wind power production to analyze the magnitude of the electricity demand for the industrial sector.

Furthermore, to determine the price development for three different types of electrolyzers, the learning curves were used which were published by Schmidt et al. (2017). The price development of the next ten years could be determined. Estimations and expectations by stakeholders such as the government and academic research could further determine the future price development for 2050.

Further analysis were based on comparing data by the reports with scientific data to analyze the effect of the consequences and the expected outcome for 2030 and/or 2050.

2.5 Short-term action

Besides the long-term developments it was important to determine short-term goals. The risk of analyzing long-term developments is the unwillingness of short-term action. However, to finally achieve the long-term goals, short term- action is required. What the companies or government should do right now to ensure a transition towards a lower emitting Dutch industry. What are problems that hinder progress already or pose to be problems in the next ten years. These problems and possible solutions where identified and analyzed in this final part of the research. It could therefore be seen as an advice for different stakeholders of what to do within the next ten years to achieve their proposed visions.

3 The Dutch industry in 2020

In order to analyze the visions of the different stakeholders for 2050, first the Dutch industry needs to be defined. In the Dutch industrial sector, a number of clusters are formed where companies can more easily work together, the industrial areas, with several advantages like lower transportation time and cost. Especially with newer implementations like heat-, steam- and CO_2-grids, cost reduction could be obtained by locating the production sites at the same location. While there are a large number of industrial clusters, this research focuses on the five most polluting areas. Furthermore, this research focuses on the twelve most polluting companies. Both the five most polluting areas as the twelve most polluting companies are introduced in this chapter. In total the Dutch industrial sector emitted 56.3 Mt of CO_2-eq in 2019 (CBS, 2020).

3.1 Areas

First of all, the five clusters are described, some locational details as well as the energy use and CO_2-eq emission. To clarify, the clusters will from now on be known as areas. In Figure 1 these areas are indicated. Number 1 is the Rotterdam-Moerdijk area, number 2 is the Zeeland area, number 3 is the Noordzeekanaal area, number 4 is the Chemelot area, and number 5 is the Noord-Nederland area. They are ranked by their direct CO_2 emissions.

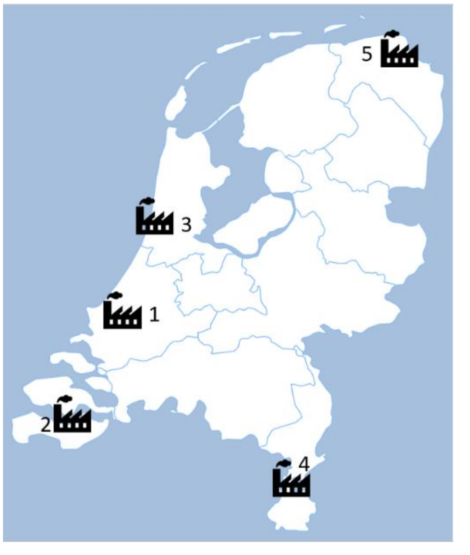

Figure 1: The five most polluting industrial areas in the Netherlands, ranked by their direct CO_2 emissions.

3.1.1 Rotterdam-Moerdijk

Along the West coast of the Netherlands in the province of South Holland, the industrial area Rotterdam-Moerdijk is located. This area is first and foremost known for the Port of Rotterdam. The port is the largest seaport and industrial complex in Europe. The area is mainly known for the petrochemical sector. Companies like Shell, BP and ExxonMobil, Air Liquide, Air Products and Nouryon have large facilities in the area. The area used 260 PJ of energy for the production processes and emitted 18.6 Mt of CO_2 in this 2016. The area had an added value of €13 B for the Netherlands and offers jobs to 75,000 employees (Kroes et all, 2018).

3.1.2 Zeeland

Along the South-West coast of the Netherlands is the industrial area of Zeeland located. For the low populated province, the industrial sector is the largest contributor of pollution of the entire province. The industrial area of Zeeland emitted 10.9 Mt of CO_2 in 2018, and it offered employment for 22,500 people (TNO, 2019). The industrial area is mainly dominated by Yara Sluiskil, Dow Chemical Terneuzen and Zeeland Refinery.

3.1.3 Noordzeekanaal

Along the West coast in the Netherlands in the province of Noord-Holland, the industrial area Noordzeekanaal is located. The industrial area is mostly known for the steel producing company Tata Steel, which is the largest emitting company in the Netherlands. The direct emissions of the area were 8.6 Mt of CO_2 in 2018 (NZKG, 2020), and offered employment for 70,000 people (TNO, 2019).

3.1.4 Chemelot

In the South of the province of Limburg the industrial area Chemelot is located. The area is mostly known for the chemical products by SABIC and the nitrogen products of OCI Nitrogen. In 2017 the area had a total CO_2 emission of 4.75 Mt (Chemelot, 2018) of which OCI Nitrogen and SABIC were mainly responsible. The added value of Chemelot was €4 B in 2019 (Chemelot, 2020), and offers employment to 16,000 people (TNO, 2019).

3.1.5 Noord-Nederland

Along the North coast of the Netherlands in the province of Groningen, the industrial area Noord-Nederland is located. This area is mostly known due to the gas production in the area and the industry surrounding this area. It is located around the Port of Eemshaven and the Port of Delfzijl. In the Noord-Nederland area companies like Nouryon and Dow have large facilities. The area emitted 1.6 Mt CO_2 in 2017. The area offered jobs to 25,000 employees (Konig et al., 2018a; Konig et al., 2018b).

3.2 Companies

While there are a large number of industrial companies in the Netherlands, only the twelve most polluting companies are further analyzed. These twelve companies are introduced here.

3.2.1 Tata Steel Nederland

Tata Steel Nederland is part of Tata Steel Europe, which in turn is part of Tata Steel Group. It is one of the largest steel manufacturers in the world. In the Netherlands Tata Steel has around 11,000 employees, 9,000 of these work in the facilities in Ijmuiden. In the port of the city of Ijmuiden is the largest facility of Tata Steel Europe. Tata Steel Europe produced 10.6 Mt of crude steel and recycled 1.8 Mt (Tata Steel, 2020a). At the location of Ijmuiden Tata Steel emitted 7.0 Mt of CO_2 in 2017 (NEA, 2019). This is the largest part of the total Dutch metal industry, which is 7.8 Mt of CO_2 in 2017 (CE Delft).

3.2.2 Shell

Shell is a Dutch-British multinational and one of the largest oil and gas companies worldwide. The Shell headquarter is located in the Netherlands. In the Netherlands the main production activities can be divided in two parts: the refineries in Pernis and the chemicals in Moerdijk (both near Rotterdam). The Shell Pernis refineries are among the largest in the world, which process 20 Mt of oil per year (Shell, 2020a). Shell Moerdijk is one of the largest chemical complexes of the Netherlands, and produces 4.5 Mt of products per year (Shell, 2020b). In the Netherlands in 2018 9,800 employees worked at Shell (Shell, 2019). The Shell Pernis refineries emitted 3.8 Mt of CO_2 and Shell Moerdijk emitted 2.7 Mt of CO_2, both in 2017 (NEA, 2019).

3.2.3 ExxonMobil

ExxonMobil is an American multinational and one of the largest oil and gas companies worldwide. The ExxonMobil headquarter is located in Texas. In the Netherlands the main activities are located around the Port of Rotterdam. In that area ExxonMobil has one refinery that is also known as the Esso refinery (Esso Nederland B.V.), four chemical factories and lubricating oil factory (ExxonMobil Chemical Holland B.V.). At Esso Nederland B.V. around 570 employees work for ExxonMobil (ExxonMobil, 2020b), and the refinery emitted 2.1 Mt of CO_2 in 2017 (NEA, 2019). At ExxonMobil Chemical Holland B.V. around 380 employees work for ExxonMobil (ExxonMobil, 2020b), and the chemical factories emitted 0.6 Mt of CO_2 in 2017 (NEA, 2019).

3.2.4 BP

BP is a British multinational and one of the larges oil and gas companies in the world. The BP headquarter is located in the United Kingdom. In the Rotterdam BP has a has one of the largest operating refineries of Western-Europe, which processes 19 Mt of oil per year. In total 2,000 employees work for BP in the Netherlands, with 730 at the refinery in Rotterdam (BP, 2020a). In 2017 the BP refinery in Rotterdam emitted 2.1 Mt of CO_2.

3.2.5 Zeeland Refinery N.V.

In the province of Zeeland, the company Zeeland refinery is located. Zeeland refinery used to be Total Vlissingen and is currently owned by Total (55%) and LUKoil (45%). Zeeland Refinery had around 400 employees in 2011 (Zeeland Refinery, 2011). Zeeland Refinery N.V. emitted 1.6 Mt of CO_2 in 2017 (NEA, 2019).

3.2.6 SABIC Geleen

In the south of Limburg in Geleen at the Chemelot industrial park is a large complex of SABIC Europe located. SABIC is the largest petrochemical enterprise of the Middle East. At SABIC in Geleen 948 employees worked to produce and transport 2.666 Mt of products (SABIC, 2018). In Geleen the emissions from SABIC were 2.7 Mt of CO_2 in 2017 (CE Delft 2018).

3.2.7 Dow Chemical

In the province of Zeeland at the city of Terneuzen a large complex of Dow is located. Dow Chemical in Terneuzen is the second largest production facility of Dow worldwide, with seventeen factories. In 2017 3,200 employees work at Dow in Terneuzen. The main products of the location are plastics. The location produced 5,374 mln kt of products in 2017 with a total value of €2.0 B. Dow Terneuzen emitted 2.5 Mt of CO_2 in 2017 (Dow, 2018).

3.2.8 Yara Sluiskil

In the province of Zeeland in Sluiskil one of the largest producers of fertilizer and nitrogenous products in Europe is located. In 2019 the Yara Sluiskil produced around 5 Mt of products. During the production 3.8 Mt of CO_2 was produced, and 2.2 Mt was emitted. In 2019 Yara Sluiskil had 631 employees (Yara, 2019).

3.2.9 OCI Nitrogen

OCI Nitrogen is the Dutch subsidiary of the parent enterprise OCI. OCI Nitrogen produces ammonia, fertilizer and melamine. It mainly is located at the industrial complex Chemelot in Geleen. In 2018 OCI Nitrogen in Geleen had 450 employees (De Gees, 2017). In 2017 OCI Nitrogen emitted 1.9 Mt of CO_2 (CE Delft 2018).

3.2.10 Air Products and Chemicals

Air Products and Chemicals is an American corporation and a supplier of industrial gasses and chemicals. In the Netherlands Air products had around 200 employees in 2017 (Air Products, 2019) and emitted 0.9 Mt of CO_2 (NEA, 2019).

3.2.11 Air Liquide

Air liquide is French multinational and supplier of industrial gasses. In the Netherlands Air Liquide has six locations, with a total of 400 employees. The main production facilities are located at Rotterdam and Bergen op Zoom (Air Liquide, 2020c). In the Netherlands Air Liquide emitted 0.7 Mt of CO_2 in 2017 (NEA, 2019).

3.2.12 Nouryon

In 2018 AkzoNobel Specialty Chemicals was split from the company and named Nouryon. Nouryon produces industrial chemicals, and in the Netherlands Nouryon has 2,500 employees (Nouryon, 2018a). In 2017 Nouryon emitted 0.4 Mt of CO_2 (NEA, 2019).

4 Electrification

Electrification is stated as one of the largest possible contributors to CO_2 emission reduction. Electrification can be seen as changing from one technology that is not powered by electricity to the electric counterpart.

4.1 Stakeholder visions for 2050

4.1.1 Government

Since the Energieagenda (2016) published in response to the Paris Climate Agreement in 2015, the government identified electrification of heat as an important option to reduce CO_2 emissions. They stated that electrification of heat requires innovation to develop technologies towards 2050. In 2016 heating technologies with electricity as energy source were not developed enough to be competitive, and innovation was crucial to achieve electrification on a large scale according to the report (Rijksoverheid, 2016). However, in the letter by the Dutch minister of Economic Affairs and Climate (Wiebes, 2020) the timeline was slightly changed. Electrification could have a large impact on the reduction potential as soon as 2030. Heat pumps, electric boilers, and other electric technologies combined with subsidies could already have an impact on the short term.

This focus on electrification is in line with the MMIP8 (Multi-Year Mission Driven Innovation programs eight) of 'mission industry' which was created in response to the climate agreement (2019). The focus of MMIP8 is on radical new processes to aim for maximum electrification. Renewable energy will mainly be available in the form of electricity, so electrification is crucial in every reduction scenario. Power-to-heat (heat from electricity), power-to-molecules and power-to fuels (hydrogen or other chemicals from electricity) will be key in the industrial processes (TKI Energie en Industrie, 2019d).

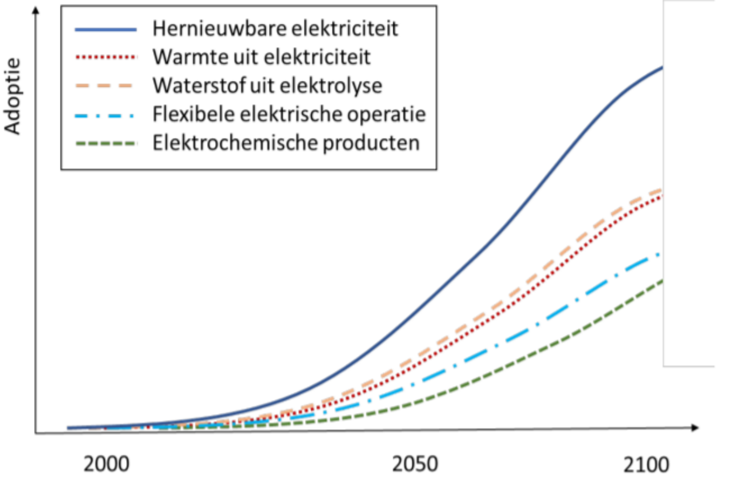

Figure 2: A schematic display of the growth in use of sustainable energy. From top to bottom: renewable electricity, heat from electricity, hydrogen from electrolysis, flexible electrical operations and electrochemical products (TKI Energie en Industrie, 2019d).

Figure 2 illustrates how the power can be used in the future industrial sector. The large expected rise of solar and wind power should facilitate this increase in demand for electricity. The total emission reduction potential by 2050 of electrification and other radical process innovation is estimated at 20 Mt of CO_2 (TKI Energie en Industrie, 2019d).

4.1.2 Areas

To facilitate the future energy demand by the Rotterdam-Moerdijk area, a large focus will be placed on electrification. The area aims at using electricity to produce heat, hot water, and steam at different temperatures. To produce high pressure and temperature steam electricity might be less suitable, due to the large demand for electricity. For 2030 the potential emission reduction for electrification might be 2.5 Mt for this area but will require 3 GW of offshore wind power and a reinforcement of the electricity grid. For 2050 the expected supply of electricity from offshore wind power is estimated at 180 PJ and from other sustainable sources additional 10 PJ. This is a total sustainable energy demand of 190 PJ (Kroes et al, 2018).

Electrification for the Zeeland area will be used for power-to-heat and electrolysis to produce hydrogen in near future. This will result in an expected increase of electricity demand of 3.5 PJ in 2020 to 8-16 PJ by 2030. For 2050 this is expected to increase even further. Towards 2030 every year roughly 1 GW of offshore wind power will be installed, which will be a large source for power for the area. Investments for grid reinforcement are required to accommodate this increase in power demand (CE Delft, 2020).

The Noordzeekanaal area expects an increase of 6 GW of offshore wind power near the area by 2030. This will be necessary, since the demand for electricity is expected to grow with 55 PJ/y from 2016 to 2030 (NZKG, 2018). Towards 2050 the demand is expected to be 120 PJ of electricity. The supply of solar and wind power by 2050 is expected to be 5.5-18 GW (NZKG, 2020). This enormous growth is to facilitate the heat generation, hydrogen production and other industrial processes.

The Chemelot area will electrify a large part of the production processes. Heat production processes will all be electrified, and the supplied electricity will all be produced from sustainable energy sources. The expected electricity demand for 2050 will be 29 PJ per year. (Chemelot, 2020)

The Noord-Nederland area right now is largely dependent on natural gas for its energy supply. This will be electrified for a large part by 2050. Furthermore, for the large increase in green hydrogen production and datacenters build. There is an expected growth of 7 GW of electricity demand for 2050. The hydropower plants in Norway could supply this, as well as offshore wind power near the Noord-Nederland area. It will strongly depend on the price of electricity to decrease, to make it affordable for companies (Konig et al., 2018a).

4.1.3 Companies

The electrification strategy of Tata Steel Europe, OCI, Air Liquide and Yara Sluiskil, is only aims at enabling the sustainable electricity for the production of green hydrogen (Tata Steel, 2020b; OCI, 2020; Air Liquide, 2020b; Yara 2019). ExxonMobil purchases large amounts of sustainable electricity, but no clear electrification goal could be found (ExxonMobil, 2019). As an international focus, Shell and SABIC continue investing in sustainable electricity generation, but no clear 2050 electrification goals could be found (Shell, 2020c; SABIC, 2019). For BP, no electrification goals are found for 2050 (BP, 2020b). As an international strategy DOW purchases an increasing amount of renewable electricity, but a clear 2050 electrification goals were not found (DOW, 2018; 2019). For Zeeland Refinery no reports could be found regarding visions, so the vision of the owner of Zeeland Refinery and previous owner of the refinery itself was analyzed, Total S.A. Total states the low-carbon electricity could be 15-20% of the energy mix by 2040. Furthermore, Total started investing in small-scale electrification options, but has not stated a 2050 goal for electrification (Total, 2019). Air Products continues investing in green electricity, but no clear 2050 visions for electrification was stated (Air Products, 2020). For Nouryon no electrification goals for 2050 or earlier are found (Nouryon, 2020).

4.1.4 Consultancy firms

The report by McKinsey (Roelofsen et al., 2017) identifies an emission reduction potential of 11 Mt by 2040 and 17 Mt by 2050 with the electrification of medium to high temperature generation. However, the electrification together with other emission reduction scenarios that require electricity could create an increase in electricity demand by the Dutch industrial sector of 215 PJ, to a total of 340 PJ.

The report by Quintel (2017) expects electrification on a large scale. Solar and wind power are seen as complementary, meaning usually one will increase if the other decreases. Mainly wind power should enable the electrification. The expected Dutch offshore wind power capacity to grow to 25 GW by 2025 and even to 75 GW by 2050.

The report by Stork et al. (2018) state that with full electrification efforts a demand of 980 PJ of electricity could be required for the chemical industry by 2050. This is mainly due to the large amount of hydrogen production from electrolysis. If solely supplied by offshore wind power this would require around 62 GW of offshore wind power. The reduction potential of this strategy would reduce the CO2 emissions of the chemical industry with 1.9 Mt in 2030 and 39.2 Mt by 2050. Further emission reduction by electrification could be achieved by power-to-heat, with a 3.7 Mt CO2 emission reduction.

4.2 Consequences

Since the reports by the areas focus on the electrification, the demand for electricity will increase dramatically. While it would be a good solution to replace the current fossil-based production installations with electric counterparts, other challenges occur. Several challenges are discussed in this part of the research.

In the reports for the visions for 2050, there was a clear difference in outcome between the stakeholders. In the reports by the government and the areas there often was a plan for 2030, a short-term plan, and 2050, the long-term plan. The companies often did not have these clear visions. When electrification was one of the goals for 2050, some consequences were described.

- Electrification of the industrial sector will create a large demand for electricity. The current production processes that will be electrified, as well as the production of hydrogen through electrolyzers will create this large demand for electricity.
- The increase on electricity demand requires an increase in grid capacity for the areas surrounding the industrial facilities, as well as long distance grid reinforcement for availability for an area such as Chemelot. With a large part of the electricity production coming from offshore wind power, the Chemelot area has a larger challenge than the four other areas that are located near the coast.
- The increase in electrification, and this electricity being produced from renewable energy sources would result in a decrease of the fossil fuel demand. Especially the natural gas use could be reduces significantly.
- Another consequence of the goal to electrify a large share of the Dutch industrial sector is the large demand in investment for production processes powered by electricity. One of the reasons the companies do not yet fully report the strategy of electrification is the higher cost for production facilities on electricity compared to the current facilities in which is already invested. These will need to be phased out earlier than anticipated and could create a higher cost due to this earlier shutdown. To remain competitive subsidies are required for electrification, to stimulate industrial companies to invest in new technologies without losing to much money. The report by Konig et al. (2018a) states the current cost for production with electricity to be roughly twice as expensive as the current fossil-based energy.

4.3 Developments needed

4.3.1 Define goals

Area like the Rotterdam-Moerdijk (Kroes et al, 2018) and Noord-Nederland (Konig et al., 2018a) expect a large increase in electricity demand due to electrification. The report by Kroes et al. (2018) states how electrification of heat from a technical perspective could be managed in an uncomplex way. The MMIP8 of mission industry (TKI Energie en Industrie, 2019d) by the government mentions how power-to-heat, power-to-molecules, and power-to-fuels could radically transform the industrial sector and greatly reduce the GHG emissions of industry. However, in the reports found for the companies, often little to no clear electrification goals for 2050 are stated. The goals that are stated mainly mention the use of electricity for hydrogen production (Tata Steel, 2020b, Yara 2019, Air Liquide, 2020b, OCI, 2020) or the investments made in sustainable electricity (Shell, 2020c, ExxonMobil, 2019, Air Products, 2020). A clear 2050 vision for electrification for the companies often could not be found.

4.3.2 Sustainable electricity demand

One of the consequences of the visions by the stakeholders is the large amount of sustainable electricity that is needed. Since the companies often have an international strategy and not always a vision focused on the Netherlands, this analysis will be based on the visions by the areas. With the visions of the five largest areas and the largest emitters in these areas, a large portion of the total emission by industry is covered by this analysis.

The area of Rotterdam-Moerdijk describes they expect an electricity demand by 2050 of 190 PJ or 52.8 TWh, to be supplied mainly by offshore wind power (Kroes et al, 2018). The Noord-Nederland area expects an increase of sustainable electricity power demand of 7 GW by 2050, again mainly by offshore wind power

(Konig et al., 2018a). The Noordzeekanaal area expects a 120 PJ or 33.3 TWh demand for sustainable electricity by 2050, and again mainly on offshore wind power (NZKG, 2020). The Chemelot area is not located at sea, so will either need longer transmission lines to the area for offshore wind power, or other sustainable energy sources. The area expects a demand for sustainable electricity of 8 TWh by 2050 (Chemelot, 2020). For the Zeeland area no vision regarding the electricity demand by 2050 could be found, so here the highest value of the 8-16 PJ range for 2030 will be used, so 16 PJ (CE Delft, 2020). The true value is expected to be higher, but this is unknown so cannot be determined. The area also states wind power is the main contributor for sustainable electricity.

To perform calculations on the total electricity generation capacity that is required to fulfill the demand of the five largest emitting industrial areas, the entire production will be assumed through wind power. Though this is not entirely correct, the true distribution is uncertain and can therefore not be calculated. It is assumed that all sustainable electricity is generated by offshore wind power. New offshore wind projects have an expected average capacity factor of 40-50% (IEA, 2019a). For the calculations, an average capacity factor of 45% is used. The calculations can be found in Appendix 10.2: Wind power calculations.

For the Rotterdam-Moerdijk area a wind power capacity of 13.4 GW is required. For the Noord-Nederland area a capacity of 4.3 GW of wind power, as stated by the area (Konig et al., 2018a). The Noordzeekanaal area 8.4 GW of wind power is required and for the Chemelot area 2.0 GW. With the assumption made for the Zeeland area, only 1.1 GW of wind power is required. This in total is a 29.2 GW of wind power to facilitate the five largest polluting areas with sustainable electricity. For 2050 the total offshore wind power generation for the Dutch economy is aimed at 35 to 75 GW according to the MMIP1 of mission 'a CO_2 free energy system' (TKI Energie en Industrie, 2019a).

These calculations imply that for all other sectors, like the build environment, transportation, and agriculture, only 5.8 to 45.8 GW of wind power generation would be available if the proposed wind power generation is achieved. If in fact these visions by the industrial sector are achieved, the Dutch society faces an enormous challenge in which the sustainable electricity demand is high. The lower bound of the range for sustainable wind power capacity will not be enough to cover all sector with sustainable electricity.

4.3.3 Reinforcing of electricity grid

The Zeeland area expects the electricity demand to increase from 3.5 PJ in 2020 to 8 – 16 PJ by 2030. The current 150 kV-cable does not have the capacity to supply the Zeeland area when this electricity demand increases this much. Furthermore, the wind power parks near this area are expected to be finished in the near future, thereby increasing the demand for electricity grid capacity. In response to this the Zeeland area has planned to install a 380 kV-cable grid connection together with TenneT before 2030 (CE Delft, 2020).

Similar challenges will occur in all industrial areas if electrification increases. Therefore, it is important to take similar action. Four out of the five large industrial areas, Rotterdam-Moerdijk, Noord-Nederland, Noordzeekanaal, and Zeeland area are located at or near the coast. They have nearly direct access to the large capacity of offshore wind power that will be constructed. For the Chemelot area this creates an additional problem. Grid capacity problems could increase for this area since it is not located near the coast and electricity would need to be transported there over a longer distance. The entire grid towards and surrounding this area will need to be analyzed in order to determine to what extent reinforcement is required.

4.4 Short-term action

In order to start with electrification as a sustainable alternative for fossil fuels, the production of sustainable electricity should increase fast in the upcoming decade. The growth in offshore wind power the next few years is a good start, but needs to speed up in order to facilitate the growth in demand for sustainable electricity.

In the short-term it is important to plan grid reinforcement as soon as possible. The Zeeland reinforcement is an example of anticipating in future growth, since the reinforcement projects could take ten years to be completed (CE Delft, 2020).

5 Hydrogen

According to Dincer (2012) green hydrogen is hydrogen that emits no GHG or other pollutants in the atmosphere during the process or extracting the hydrogen from the energy source. There can be four categories of energy extraction methods classified, which are electrical, thermal, biochemical and photonic. Currently most of the hydrogen is produced from fossil fuels, close to 50% from natural gas, about 30% from oil/naphtha and 18% from coal (Dincer, 2012). Production from fossil fuels with GHG emission is called gray hydrogen. Next to green and gray hydrogen, blue hydrogen is another option. This is the production of hydrogen from fossil fuels in which CCS is used to limit the emitted CO_2 emission (Berenschot, 2019).

5.1 Stakeholder visions for 2050

5.1.1 Government

Since the Energieagenda (2016) published in response to the Paris Climate agreement in 2015, the government identified green hydrogen as an important option to reduce CO_2 emissions. It could be used for seasonal storage both in the form of hydrogen or ammonia or be a feedstock for the chemical sector. More recently (Wiebes, 2020) the green hydrogen production is seen as an even more important element for reducing the CO_2 emission of the Dutch industry. The Netherlands could use the international connectivity already in place and expand this like the pipelines and ports along the Dutch coasts. Especially the area near the North Sea could have great potential, with the large amount of wind power installed in the next decades. Hydrogen production and storage could have a large impact on balancing the electricity grid. The next few years will be used to accelerate the scaling potential of this technology with subsidies from the government.

In the MMIP8 of mission industry (TKI Energie en Industrie, 2019) one of the key focus points for 2050 was power-to-molecule, of which a large part is the production of hydrogen with electrolysis. A part of the aim of this program was reduce the investment cost to €350/kW by 2030 to achieve a hydrogen price of €2/kg and a price of €1/kg by 2050. Right now, it is not yet price competitive, so large investments are required to reduce the cost. The next decades will also be used to determine at what scale electrolyzers should be used. Should each company or factory have its own electrolyzers or should it be scaled up to cluster scale or even more clusters combined. The total long-term reduction potential by 2050 due to green hydrogen and other renewable feedstocks is estimated at 10-20 Mt of CO_2 emissions. However, for the short-term blue hydrogen seems to be more the focus. The current production of hydrogen could be maintained and combined with CCS to reduce the CO_2 emission by 60% to 95% (TKI Energie en Industrie, 2019).

5.1.2 Areas

To produce high temperature steam and heat, the Rotterdam-Moerdijk area identifies hydrogen as the ideal solution. To produce products like ammonia or other hydrogen containing products hydrogen could also be used. However, green hydrogen is not expected to be price competitive by 2030. The aim therefore in this period is blue hydrogen, conventional hydrogen production with fossil fuels and capturing the CO_2 with CCUS. Developments in technology and prices can make electrolysis with sustainable energy price competitive. In 2050 the area will use green hydrogen on a large scale, which could increase the sustainable electricity demand with 50 TWh (Kroes et al., 2018).

The Zeeland area currently uses large amounts of gray hydrogen which is produced from natural gas. The area has an opportunity to shift the production first towards blue hydrogen, where natural gas is combined with CCS, and later to green hydrogen from sustainable sources. The large demand that already exists will create a perfect opportunity for the shift towards sustainable production. For green hydrogen different options exist: hydrogen could be produced on land or at sea, thereby either transporting electricity or hydrogen over large distances with different transportation losses (CE Delft, 2020).

The Noordzeekanaal area identifies hydrogen potential for mobility, the production of a clean fuel for aviation and shipping, circular chemistry, and as seasonal storage for energy. To facilitate this a hydrogen infrastructure is required. From 2020 to 2025 the first steps are proposed, with the largest green hydrogen production facility of the Netherlands of 100 MW in Ijmuiden. Furthermore, 10-50 MW of green hydrogen production facilities are proposed in the area (NZKG, 2020). The electricity will be provided from nearby offshore wind power. In 2030 this could be expanded to 1 GW of hydrogen production and in 2050 even 5 GW (NZKG, 2018).

The Chemelot area identifies green hydrogen as a good alternative for the hydrogen now produced with natural gas from the area. The hydrogen produced is used in the production of ammonia, fertilizer, and melamine. This green hydrogen could be produced both from electrolysis as using domestic waste (Chemelot, 2020)

The Noord-Nederland area aims to become the number one hydrogen-hub in Europe. When using intermittent renewable energy sources like solar and wind power, electrolysis could be a perfect solution to use this energy. The hydrogen than can be stored at the area and used or transported to the rest of the Netherlands to use. (Konig et al., 2018b)

5.1.3 Companies

Tata Steel together with Nouryon and the Port of Amsterdam join together to create a large green hydrogen cluster in Amsterdam (Nouryon, 2018b; Tata Steel, 2020b). The first step is to build a 100 MW water electrolysis facility which should produce 15.000 tons of hydrogen per year. This is part of the long-term strategy by Tata Steel Europe to use hydrogen, but Tata Steel Europe expects not a large enough scale of hydrogen available at least until 2040 to replace coal. Nouryon also partners together with BP and the Port of Rotterdam for another green hydrogen project. The project aims to create a 250 MW water electrolysis facility to produce 45.000 tons of green hydrogen (Port of Rotterdam, 2019). Apart from these short-term projects, BP and Nouryon did not propose a long-term vision regarding green hydrogen yet (Nouryon, 2020; BP, 2020b).

Royal Dutch Shell and Total S.A., the company owning the largest share of Zeeland Refinery N.V., identify hydrogen mainly as a possible solution for industrial applications and transportation (Shell, 2020c; Total, 2019). Air Liquide agrees with this possible strategy and has published the plan to enable 1.000 hydrogen-powered trucks to connect The Netherlands with Belgium and western Germany, in collaboration with the Port of Rotterdam (Air Liquide, 2020a). As an international focus, Air Liquide aims at creating low-carbon hydrogen for applications in industry and transport, but no clear numbers or goals for 2050 are defined (Air Liquide, 2020b). ExxonMobil (ExxonMobil, 2019;2020a) and SABIC (SABIC, 2018;2019) have no national or international vision for green hydrogen in 2050 that could be found within the available information.

During the production of ethylene at Dow Chemical Terneuzen hydrogen is formed as a byproduct. The surplus that is not used is transported to and used by Yara Sluiskil. Dow Chemical has no further national or international 2050 vision for green hydrogen (DOW, 2018; 2019). Yara Sluiskil aims at large scale green hydrogen use to produce green ammonia. On a small scale it is already possible, but two to four times more expensive as gray ammonia. Furthermore, it would require a large of green electricity. To make it affordable subsidies are required (Yara, 2019).

Air Products, the world’s largest supplier of hydrogen aims to assist in the energy transition by reducing the emissions created by the current hydrogen production and increasing the volume of blue and green hydrogen produced (Air products, 2020).

At the Dutch OCI Nitrogen locations of OCI, are the driving forces in reducing the impact on climate change. In the Netherlands, the first green ammonia has been produced in 2019, and with large-scale green hydrogen OCI aims at more green ammonia (OCI, 2020).

5.1.4 Consultancy firms

To produce high temperature heat and the change in feedstock for chemical production processes, Roelofsen et al (2017) propose hydrogen could be the perfect solution. This will however have a large impact on the electricity demand like stated earlier when electrolysis is used as the production process. When hydrogen production prices decrease further, it could even be used for seasonal storage and balancing the grid, increasing the demand further.

The surplus of electricity generation could be used to create green hydrogen through electrolysis according to the report by Quintel (2017). This hydrogen could then be used for seasonal storage, or as a feedstock to produce ammonia. For a short period of time hydrogen production could be done by using natural gas and CCS. If CO_2 could be utilized, hydrogen could be produced from natural gas and the CO_2 used.

In the report by Stork et al. (2018) two main production types for large scale hydrogen production are mentioned for future hydrogen production: the combination of offshore wind power with electrolyzers, or the combination of steam methane reforming with CCS. Hydrogen could be used as a feedstock for many products such as ammonia and methanol. When using the hydrogen production through electrolyzers and offshore wind power, a potential reduction in fossil fuel demand of 530 PJ could be achieved. Together with other electrification options the electricity use could increase with 890 PJ.

5.2 Consequences

Most of the choices by stakeholders are to use large-scale green hydrogen from electrolysis by 2050. This is 'Water decomposition into O2 and H2 by passing a direct current which drives electrochemical reactions' (Dincer, 2019). For this process electricity is necessary, and with large amounts of green hydrogen demand, large amounts of electricity are required.

- Similar to the increase in energy demand for electrification, the energy demand for green hydrogen is often larger than for grey hydrogen. For example, conversion losses from electricity to hydrogen by electrolysis has an average loss of 35% for alkaline (ALK) electrolyzers and 43% for proton exchange membrane (PEM) electrolyzers (IRENA, 2018).
- In the electrification part of the research the large sustainable electricity demand for the industrial sector was calculated. For a large part this is due to the large demand of sustainable electricity for green hydrogen production by electrolysis.
- Several of the reports stated a step-based transition towards green hydrogen. First the blue hydrogen could be used to replace the current gray hydrogen and then green hydrogen could be produced and used.
- In 2015 around 95% of the hydrogen was produced from fossil fuels (Hosseini & Wahid, 2016). A switch towards renewable hydrogen with the use of electrolyzers or other non-fossil fuels based production processes could reduce the demand for fossil fuels. VNCI estimate a potential 530 PJ reduction of fossil fuel demand (Stork et al., 2018).
- Large investments in new production processes (e.g., electrolyzers) are required.

5.3 Developments needed

5.3.1 Price development

The study Bartels, Pate and Olson (2010) shows the price of green hydrogen from electrolyzers with solar or wind power ranged from 5.37 to 24.50 €/kg H_2. The price of conventional hydrogen production from natural gas was 2.19 €/kg. The study by Hosseini and Wahid (2016) shows the price of wind electrolysis is 5.58 €/kg H_2, whereas hydrogen from natural gas reforming was 0.87 €/kg H_2 and natural gas with CCS was 1.02 €/kg H_2. A study by the IEA (2019b) shows hydrogen cost using natural gas without CCS in Europe to be 1.43 €/kg H_2 and natural gas with CCS in Europe to be 1.93 €/kg H_2. A recent study by BloombergNEF (2020) showed that renewable hydrogen cost is 2.10 - 3.86 €/kg H_2 and hydrogen from natural gas with CCS cost are 1.18 - 2.44 €/kg H_2. Furthermore, Yara Sluiskill claims the current green hydrogen production is two to four times more expensive than conventional production with natural gas (Yara, 2019).

This large price difference makes green hydrogen not a price competitive alternative for conventional hydrogen production right now. A large decrease in cost for green hydrogen is required to make this a viable option. In MMIP8 by mission industry (TKI Energie en Industrie, 2019) the goal was stated to achieve a renewable hydrogen price of 2 €/kg H_2 by 2030 and 1 €/kg H_2 by 2050. The forecast by BloombergNEF (2020) states a renewable hydrogen price of 1.01 - 2.27 €/kg H_2 by 2030 and 0.59 - 1.34 €/kg H_2 by 2050.

The IEA (2019b) study identifies that for hydrogen production from renewable electricity the fuel cost are 62% of the total cost with a 25.2 €/MWh renewable electricity price, 34% are capital expenditures, and 3%

are operational expenditures. Both electricity prices as the capital expenditures have a large impact on the cost and will need to decrease in order to make the technology more price competitive.

Schmidt et al. (2017) describe the expected capital expenditures for three different types of electrolyzers, the Alkaline Electrolysis Cells (AEC), Proton Exchange Membrane Electrolysis Cells (PEMEC) and Solid Oxide Electrolysis Cells (SOEC). For these three technologies the expected decrease in capital expenditures are described for two scenarios, the first with current levels of R&D funding and no further scale-up, and the second with higher levels of R&D spending and production scale-up. For these three technologies the expected decrease in capital expenditure for the first scenario is 42% ± 10% for the AEC, 52% ± 13% for the PEMEC, and 52% ± 20% for the SOEC. With increased R&D and production scale-up these numbers rise to 50% ± 12% for the AEC, 62% ± 10% of the PEMEC, and 86% ± 19% for the SOEC. This illustrates the importance of investing in the technology to decrease the prices of the technologies (Schmidt et al., 2017).

The areas expect largest amount of sustainable electricity to be supplied by offshore wind power (Kroes et all, 2018; Konig et al., 2018a). In the IEA (2019a) research the LCOEs for new wind projects in Europe are expected to decrease from 84 – 134 €/MWh in 2018 to 42 – 67 €/MWh in 2040. This is a decrease in LCOE of 50% in 22 years, thereby having the potential to decrease the green hydrogen price. The hydrogen price from sustainable electricity has the potential to decrease with a large amount, but until this decrease occurs the price will be high. It will be up to subsidies and/or CO_2 prices to make the technology price competitive before 2040-2050.

5.3.2 Electricity demand

The Dutch industrial sector used 828 kt of hydrogen in 2017. With this production of hydrogen an estimated 12.5 Mt of CO_2 is emitted (Berenschot, 2017). The report by… (091209) describe the theoretical minimal required electricity input is 39.4 kWh/kg H_2. However, the best available technology in 201212 uses 53 kWh/kg H_2. In better conditions with lower densities if would be possible to a specific power consumption of 47 kWh/kg H_2. With the 53 kWh/kg H_2 as an input, the production of the currently used hydrogen by the industrial sector with electrolyzers would require 43.9 TWh of electricity. If the 47 kWh/kg H_2 could be achieved, 38.9 TWh of electricity would be necessary for the production of hydrogen through electrolyzers. With an expected increase in hydrogen production due to the use of hydrogen as a feedstock, even more electricity would be required.

5.4 Short-term action

In order to prove the viability of the technology and identify problems, short-term action is required. The first steps are taken with the two projects mentioned earlier: the 100 MW water electrolyzer by Tata Steel, Nouryon, and Port of Amsterdam and the 250 MW water electrolyzer by Nouryon also partners together with BP and the Port of Rotterdam are good first steps.

6 Carbon Capture, Utilization, and Storage (CCUS)

The third and final focus point of this research is Carbon Capture, Utilization, and Storage (CCUS). Emitted pure CO_2 by industry could be captured and then either utilized or stored, often in empty gas fields. The distinction could be made between carbon capture and storage (CCS) and carbon capture and utilization (CCU). These technologies could be used individually or combined.

6.1 Stakeholder visions for 2050

For the third part of the focus points of the research the visions of the stakeholders will again be analyzed. The visions towards carbon capture, utilization, and storage for the four stakeholders is the next part of this research.

6.1.1 Government

In the Energieagenda (2016) published in response to the Paris Climate agreement in 2015, the government identified CCUS as an important option to reduce CO_2 emissions. They even discuss the possibility of combining it with biomass use to create a negative emission. In recent reports CCUS is seen as a very important part of reducing the CO_2 emission by industry. In the letter by the Dutch minister of Economic Affairs and Climate (Wiebes, 2020) he highlights the importance of CCS to reach the 2030 climate goals. CCS projects could use the SDE++ subsidy to cover the losses made during the projects. In later stages CCU could be more promising, and even use the stored CO_2.

According to the MMIP6 of mission industry (TKI Energie en Industrie, 2019b) CCUS has the potential to reduce 12.0 Mt of CO_2 emission per year by 2050. The reduction potential is estimated to be 5 Mt/year for CCU and 7 Mt/year for CCS both by 2050. In the Dutch industry in 2020 1.0 Mt of CO_2 is used (CCU) to produce Urea and 0.6 Mt of CO_2 to the greenhouses. The greenhouses state they could use 2.0 Mt of CO_2 the be climate neutral. In the short-term the potential for CCU is limited because it is expensive and offers limited benefits. With increased CO_2 prices and technologies, the long-term possibilities increase. Captured CO_2 could be used as a feedstock as a replacement for fossil fuels, or to harden or even produce concrete. This could improve the quality of the concrete but will cost extra. CCS could be an option to reduce a lot of emission in a short period of time. It buys time for industry to invest in new processes. For the period towards 2025 the first CCS project of 2-4 Mt/year should be realized and from 2025 and later 7 Mt/year. From 2030 a negative emission should be possible with Bio-Energy CCS and Direct Air Capture CCS.

6.1.2 Areas

The area of Rotterdam-Moerdijk is one of the frontrunners regarding CCUS. The Port of Rotterdam, Gasunie and EBN have started a project called Porthos, a CCUS project with storage in the North Sea 20 km of the coast into an empty gas field. The estimation is this project could store 2.5 Mt of CO_2 per year. The construction is set to start in 2022 and should be operational in 2024 (Porthos, 2019a). This illustrates the vision of the Rotterdam-Moerdijk area for CCUS.

The Zeeland area has a potential short-term supply of 1.2 Mt of CO_2 per year that could be available for CCUS. By 2025 CCS of 0.6 Mt would be possible and 1.2 Mt by 2030. A potential collaboration with the Belgium ArcelorMittal could create a larger potential for CO_2 supply. Currently 1.4 Mt of CO_2 from the facilities of Yara are used instead of being emitted.

The Noordzeekanaal area aims to use CCUS to capture the CO_2 emitted from the Tata Steel and AEB Amsterdam facilities. In the short term the focus will be on CCS, and small scale CCU since the demand for CO_2 is limited. This demand is expected to increase, and the infrastructure will adapt to this (NZKG, 2018). The area started the CCS project Athos with the Gasunie, EBN, Tata Steel and the Port of Amsterdam. The construction is aimed to start in 2023 and have a fully operational CCS infrastructure available in 2027 (Athos). The potential of the project is 4-5 Mt of CO_2 storage per year (Athos, 2019). CCU for the area is estimated to be 3.9 Mt by 2050, while it was 0.4 Mt in 2018 (NZKG, 2020).

The Chemelot area aims at collaborating with the Porthos-project in Rotterdam. For CCU the area aims to start several projects, such as pipelines to greenhouses (Chemelot, 2018).

The Noord-Nederland area identifies CCUS as a large potential reduction in CO_2 emissions for the area. If combined with biomass, the area even states it could create a carbon-negative scenario. The CO_2 could be used as a feedstock for methanol production. It could also be used to produce hydrogen from natural gas, to store the CO_2 that is released in this process (Konig et al., 2018a).

6.1.3 Companies

The Porthos project mentioned earlier is a project were four out of the twelve large emitters are participating a in a Joint Development Agreement (JDA). Shell, ExxonMobil, Air Liquide, and Air Products are joining the CCS project together with EBN, Gasunie and Port of Rotterdam (Porthos, 2019b). Furthermore, Shell states it is participating in seven out of the 51 largest CCS projects and aims at expanding this (Shell, 2020c). ExxonMobil is the leader in CCS with over 30 years of experience and a working interest in over one-fifth of all carbon capture capacity and would like to keep expanding this capacity (ExxonMobil, 2020a). Shell, ExxonMobil, Air Liquide, and Air products mention no specific Dutch vision for CCUS in 2050 (Air Liquide, 2020b; Air Products, 2020).

Tata Steel started developing the CCUS project Athos together with Gasunie, EBN and Port of Amsterdam (Athos, 2019). Furthermore, Tata Steel entered a partnership with Dow Chemical to utilize the CO, a by-product from blast furnaces (Tata Steel, 2019). No long-term vision for CCUS is mentioned Tata Steel of Dow Chemical (Dow, 2018; 2019). Both BP and SABIC also mention no 2050 vision for CCUS (BP, 2020b; SABIC, 2018; 2019). Total already invests in several CCUS projects worldwide and will continue with this the next decades (Total, 2019).

OCI is currently performing a feasibility study of storing CO_2 under the North Sea. There is however no long-term vision published (OCI, 2019). Yara Sluiskil currently captures part of the emitted CO_2 during production and uses this or sells it. This helps reducing the CO_2 emission with 15%. For further CO_2 emission reduction Yara Sluiskil is aiming to store 1.0 Mt of CO_2 through CCS by 2023. Finally, for Nouryon no vision regarding CCUS has been found (Nouryon, 2020).

6.1.4 Consultancy firms

The report by McKinsey describes the potential for CCUS could be 15 Mt of CO_2 emission reduction per year for the entire Dutch industry. Although right now it is not yet widely used due to the high cost, it could actually be one of the cheaper options for reduction potential. For example, the production of hydrogen using natural gas and CCUS would be much cheaper than producing it through electrolysis. Large scale utilization would make it even more affordable, since the CO_2 is used as a feedstock (Roelofsen et al., 2017).

The report by Quintel (2017) describes CCS should not be the long-term goal. For a short period of time it could be useful to use in the chemical sector. Even capturing CO_2 from the air to reduce the total concentration in the atmosphere is posed as a long-term option.

For the chemical sector of the industry there is a large potential for CCS to reduce the CO_2 emissions according to Stork et al. (2018). Large CO_2 grids should help connecting the chemical clusters to underground storage. The production of hydrogen through steam methane reforming in combination with CCS could help maintaining the required hydrogen for the chemical sector but reduce the CO_2 emissions. For large scale use of CCS the report state 11.4 Mt of CO_2 could be stored per year.

6.2 Consequences

The choices made in the visions by the different stakeholders regarding CCUS have several consequences for the Dutch industry and economy.

- The choice to envision an industry with CCUS is an important choice. Some might find investments in CCUS a waste of money, since it takes up sustainability subsidy budgets. These budgets can no longer be used for investments in renewable energy sources.
- The reports often state CCS is an option to start using as soon as possible to achieve the reduction goals for 2030. For 2050 CCU could be combined with CCS, or CCS could be decreased if enough CO_2 emission reduction is achieved by 2050.
- The use of CCUS could create a lock-in effect in which polluters could continue using fossil fuels and creating CO_2 as long as a part of this CO_2 is captured instead of emitted. This could limit the push towards renewable energy production.
- For CCS is a limited storage capacity is available. If a large number of companies would like to use the storage capacity this limit could be reached.

6.3 Developments needed

6.3.1 Storage capacity

The Dutch government expects an amount of 7 Mt of CO_2 to be stored by the Dutch industrial sector from 2025. The Dutch government has set a ceiling on subsidies for CCS at 7.2 Mt by 2030 for the industrial sector, and 3.0 Mt for the electricity sector (TKI Energie en Industrie, 2019b). This is a different strategy than proposed in the 2017 coalition agreement (Rutte, Van Haersma Buma, Pechtold, and Segers, 2017) in which an expected 18.0 Mt of CO_2 should be stored from industry and 2.0 Mt from power production by 2030. In an earlier research by PBL (2017) estimations for CCS by 2050 range between zero and 82.0 Mt, dependable on the amount of renewable energy in 2050. In the MMIP6 of mission industry a 1,600 Mt storage capacity in the North Sea is defined (TKI Energie en Industrie, 2019b). In the 'worst' case scenario of 82.0 Mt of CO_2 storage the 1,600 Mt storage capacity could be depleted within 20 years. Extra storage capacity underneath the ground in the Netherlands is estimated to be 1,000 Mt, but due to public opinion on storage underneath the ground this may be less desirable to use (PBL, 2011).

6.3.2 Developing CCU options

Using CCS would be a great solution to lower excess CO_2 that is created during various stages in industry. By storing the carbon in the ground, it is not emitted in the air and will not contribute to global warming. However, for the long term this is not a sustainable option. At some point the CO_2 will need to be used. While the CCS projects that have started (Porthos and Athos) could be used at large scale in a relative short timeframe, reaching a large scale is harder for CCU. To some extent there are projects working right now. Yara Sluiskil uses captures and uses 1.4 Mt CO_2 for urea production or sells it for example to be used as the CO_2 in soda (Yara, 2019; CE Delft, 2020).

6.4 Short-term action

In 1990 the CO_2 emissions of the Dutch industrial sector were 86.7 Mt of CO_2. The goal for 2030 is a near 59% reduction in emissions. This implies a remaining emission of 35.7 Mt of CO_2 by 2030 for the Dutch industrial sector. With the emission in 2019 at 56.3 Mt, there is still a long way to go. In 11 years a reduction of 20.6 Mt needs to be achieved, while over the past 11 years a reduction of only 4.7 Mt was achieved (Rijksoverheid, 2019). The PBL baseline (PBL, 2017a) should provide the first part of the reduction, up to 14.3 Mt of CO_2 reduction (so the first 6.3 Mt). For the remaining 14.3 Mt of emission reduction the strategy is still unclear.

In the study by PBL (2019a) a technical reduction potential for 2030 is calculated for different reduction options. In this study 16.6 Mt of CO2 emission could be reduced with CCS, 7.0 Mt with electrification and hydrogen, 2.6 Mt with process efficiency and 1.3 Mt with 'other measures'. This adds up to a total of 27.4 Mt, so would be enough for the 14.3 Mt reduction that is required by the climate agreement. With the options electrification and hydrogen, process efficiency and 'other measures' the technical reduction potential would be 10.9 Mt, so with the full use of these potentials 3.4 Mt of CCS is required by 2030. This would be the minimal required CCS capacity to achieve the 2030 goals, and would to some extent not be cost effective.

Some electrification potential could cost up to 400 €/t of CO_2 instead of the 100-150 €/t of CO_2 for many CCS options (PBL, 2017a).

As stated earlier there are two CCS projects currently under development, Porthos and Athos. The expected storage potential of Porthos is 2.5 Mt CO_2/year (Porthos, 2019a) and of the storage potential of Athos is 4-5 Mt CO_2/year (NZKG, 2020). This implies a total storage capacity of 6.5-7.5 Mt CO_2/year. Furthermore, in the visions of the climate agreement (Rijksoverheid, 2019) a maximum subsidized capacity of 7.2 Mt of CCS is proposed. The required reduction of 14.3 Mt minus the 6.5-7.5 Mt by CCS would require 6.8-7.8 Mt of CO_2 emission reduction still necessary by the three other stated reduction options by PBL. To ensure a cost effective reduction vision for the industrial sector by 2030, it is important that the Porthos and Athos are operational by 2030.

7 Discussion

7.1 Data quality and quantity

The aim of this research as described in the introduction was to analyze the large amount of visions for 2050 by the different stakeholders, to compare the choices made and analyze the consequences of these choices. Furthermore, an analysis was made of what long-term developments are needed to facilitate these visions, and finally what short-term action could be taken as first steps. For this research, many reports by the different stakeholders were analyzed. Furthermore, many reports that were analyzed were not seen as useful, due to the lack of information on the focus of the research: electrification, hydrogen and CCUS.

The first analysis of the reports by the stakeholders illustrated a clear picture in the development of reporting. Until the year 2015 most of the reports by the stakeholders focused on growth of the economic activities. If sustainability was mentioned, it was mainly to mention that the growth was within the laws and regulations. From 2015 onwards, after the Paris Climate Agreements a change was visible. Reporting after the agreement and the commitment by the Dutch government created a shift in reporting style. Sustainability reports started to be published by more stakeholders and become more dominant in determining the strategy of the stakeholder.

This was especially visible in reports by for the Noordzeekanaal and Zeeland area. In a report published in 2014 (NZKG, 2014) the focus was on how and why the area could and should grow further within the environmental limits. In the 2018 (NZKG, 2018) and 2020 (NZKG, 2020) reports an entirely different focus. The areas ecological footprint is analyzed and options to reduce the impact on the environment are proposed. A year-to-year plan is constructed to reduce the GHG emissions of the area, while still maintaining the competitive advantage. In 2009 the province of Zeeland (Provincie Zeeland, 2009) publish a report with the vision for 2030. This report focused on how growth of the area could be achieved within the special boundaries. A growth in added value of 2% each year was one of the main focus points. In 2016 CE Delft published a new report in collaboration with the province of Zeeland with the ambition for 2030 for the area (CE Delft, 2016). Shortly after the Paris Climate Agreement, so the first sustainability goals are mentioned together with the aim at economic growth. In 2020 CE Delft published a new report with a very clear sustainability strategy for the Zeeland area for the next decade. The report provides a year-by-year plan for required investments for different projects like the local electricity grid, a hydrogen hub, CCS, and investments to the port.

The limited time has passed since the 2015 Paris Climate Agreements which could be an indicator that long-term plans by the stakeholders are still under development, just like the reports. Often investment strategies could take years to develop and publish. The amount of reports published currently could be limited for this reason. Therefore, it will be important to keep reviewing the new visions by the stakeholders for 2050.

7.2 Result analysis

Apart from the difference in reporting before 2015 and onwards, there is a difference in the quality and usefulness of the reports. With the three chosen topics, electrification, hydrogen, and CCUS, it was important that the report at least mentioned these topics. While many reports focus on GHG emission reduction and the reduction of environmental harm, not all mention these topics. Often the reports by companies lack a clear focus to any of these topics, or many focus on the short-term projects that are completed or under construction. On the other hand, the visions by the reports from the government and governmental organizations as well as the reports by areas and other research have a clear 2050 vision.

Electrification is an example of this, as mentioned in section 4.3.1. The reports by the companies barely mention electrification as a goal for 2050, whereas the reports by the government and governmental organizations as well as the areas and other research do have a clear 2050 vision. This could be seen in de calculations of 4.2.1 or the analysis of 4.4.1, where mainly reports by the areas were used. This trend continued onwards throughout the rest of the research.

For the calculations in section 4.2.1 no data was available for the Zeeland area for 2050. To compensate for this lack of data the highest bound of a range by 2030 was used. This will influence the quality of the results of the calculations. In any of the numbers is a high amount of uncertainty since the data are expectations for 30 years in the future. Any of the made calculations in chapter 4, 5 and 6 which attempt at estimating future occurrences are highly dependent on socio-economic developments, such as the change in demand for certain products by consumers or the growth of the population.

While in the long-term green hydrogen is a great solution to decarbonize the Dutch industrial sector, the current cost are too high to run a large scale project and a limited amount of sustainable energy is available. Therefore, for the next few decades blue hydrogen could be the chosen solution to reduce the CO_2 emissions by hydrogen production. During this time sustainable energy cost could decrease, and investments in R&D for green hydrogen solutions could help reducing the price. Small-scale pilot projects could prove the viability of large-scale projects in the future.

The CCS projects in the Netherlands have always been a subject of discussion. It enables polluters to continue polluting, but the created CO_2 can be stored instead of emitted. It requires large investments and energy to run. The investments and subsidies for this technology cannot be invested in sustainable energy generation like solar or wind power.

As discussed in section 6.4 the total technical potential emission reduction by 2030 is 27.4 Mt. To meet the goals set by the climate agreement (Rijksoverheid, 2019) a 14.3 Mt reduction of CO_2 emissions is required. The 10.9 Mt reduction potential of all non-CCS measures would imply at least 3.4 Mt of CCS, while at most 16.6 Mt of CCS would be technically possible (PBL, 2017a). Large investments are required to achieve this before 2030. The clear reduction goal of 59% compared to 1990 emissions for 2030 is not set for industry by 2050. The overall Dutch emission reduction should be 95% compared to the 1990 emissions, but for industry it is only stated the emissions should be near zero (Rijksoverheid, 2019).

7.3 Future research

This research had a clear focus on electrification, hydrogen and CCUS. In a future research other focus points could be analyzed such as the transformation that is necessary in the heat production. Or to analyze the consequences if certain choices were not made, such as a future scenario without CCS or electrification. Furthermore, the lack of detailed reports by industrial companies could be the reason for a future research. Interviewing companies to truly determine the detailed vision for 2050 for each company to analyze the future industrial sector.

8 Conclusions

In the introduction the research question was introduced: *What are the choices of the Dutch industrial sector for 2050 and what are the consequences of these choices?*

In order to answer the research question several steps were taken. First of all, an analysis of what the current Dutch industrial sector looks like. The five most polluting areas and twelve most polluting companies were introduced. The next step was an analysis to determine the three focus points. For this analysis eight reports were used, and the outcome was a focus on electrification, hydrogen and carbon capture, utilization, and storage. After this a large number of reports with the visions for 2050 by different stakeholders were analyzed, with the choices and consequences as outcome. After this outcome the research continued to determine what developments are necessary to achieve these visions. The distinction was between long-term and short-term action requirements.

The main choice by the government and areas was to focus on electrification towards 2050. This implies a growth in electricity demand, increase in grid capacity demand, and investments necessary to replace the current production processes. The companies were less inclined to give a clear vision for electrification for 2050 or even 2030. Calculations made in the research illustrate the urgency for in investing renewable energy, since the industrial sector is expected to need 29.2 GW out of the estimated 35-75 GW of offshore wind power.

The hydrogen choices and consequences came with different steps. The current production of hydrogen is mainly produced with fossil fuels. In order to relatively quickly reduce the emission of this production, the first step would be to combine the fossil fuel-based hydrogen production with CCUS. The created CO_2 would be captured and used or stored instead of emitted. This would allow time to invest into new green hydrogen development, and makes it price competitive. The 2050 vision for most stakeholders was a large-scale use of green hydrogen, when it would be price competitive by this time. Electrolysis was the main proposed technology for green hydrogen production. This would require an increase in sustainable electricity production, and large investments in electrolyzers.

When analyzing CCUS, there is a certain development over time. To reduce the CO_2 emissions on a large scale for the Dutch industrial sector in the short-term, CCS is the most effective option. The current production processes often need little retrofitting to create almost pure CO_2 to be captured, and several Mt a year could be stored underground. To achieve the 2030 reduction goals CCS will be needed, and many stakeholders include this in the visions. For the long-term CCS could be combined with CCU, to utilize the captured CO_2. If less CO_2 is emitted by 2050, the CCS capacity could be reduced. The choices by many the stakeholders rely on CCS. The consequences could be that a part of the sustainability budget by the government needs to be dedicated to CCS. That would leave fewer budgets available for renewable energy sources.

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10 Appendix

10.1 First Analysis

Government

The first part of this analysis will consist the reports published by the Dutch government and institutions. The reports addressed will form the guidelines by the government for the Dutch industrial sector. There is a great variety of reports, with a lot of different focus points or new lessons throughout the years. Three of these reports are analyzed here.

Energieagenda

In 2016 the Dutch ministry of economic affairs and climate publish the Energieagenda (energy agenda). This in response to the agreements made in the climate agreement (klimaatakkoord, 2016) in 2015 in Paris. The government stated it would not like to take a ‘wait-and-see’ approach but act. The energy transition poses opportunities which could strengthen the Dutch economy. As part of this report, the future of the Dutch industrial sector is highlighted from the governments point of view. Though this is clearly a first outlook at the possibilities, and lacks detailed insights.

Economic value and product portfolio of future industry

The government aims to keep the keep the industrial activities similar as they are nowadays, if it can produce with little CO_2 emissions. The use of ‘waste’ flows like heat and CO_2 requires changes in regulation to be profitable. The government identifies that changes like these are a way for the government to help the energy transition and the emission reduction for the Dutch industry.

Future energy supply

Geothermal energy is identified as a potential heat source to reduce energy use and emission. This in combination with heat grids can greatly reduce the demand for natural gas and other fossil fuels for heat production. Furthermore, the financial benefit for large energy users will reduce and potentially disappear, to encourage the reduction of energy use.

Greenhouse gas emissions

Carbon capture and storage is a great tool to use if no low emission possibilities are available.

Klimaatakkoord 2019

In 2019 the Dutch government presented the climate agreement. This report stated the vision for the Dutch economy for the next decades. It stated that the Netherlands should reduce its GHG emissions with 49% by 2030 and 95% by 2050 compared with 1990. For the industrial sector a further reduction was presented. The emissions by 2030 should be reduced with 59% compared to 1990 and by 2050 the emissions should be near zero.

Economic value and product portfolio of future industry

To ensure the Dutch industrial sector is competitive by 2030 and 2050, it needs to become more sustainable and reduce its emissions. With a large impact on the Dutch prosperity, well-being and employment the Dutch industrial sector is vital to keep intact. It could however transform to some extent to become more competitive and sustainable. Using the five large industrial clusters could help the industrial sector to remain competitive with optimal collaboration between companies.

Future energy supply

Measures like process efficiency, energy savings, CCS, electrification the use of blue and green hydrogen and increasing circularity can enable the transition of the Dutch industrial sector. Furthermore, synergy with the build environment for heat supply could reduce the need for heating by non-sustainable sources.

Greenhouse gas emissions

The greenhouse gas emissions by the Dutch industrial sector should be further reduced with 14.3 Mt by 2030, on top of the previously set reduction goal of 5.1 Mt by PBL (2017a).

Visie verduurzaming basisindustrie 2050

In 2020 the ministry of economic affairs and climate published a letter to the House of Representatives with the vision for making the industry sustainable. This extensive letter was more in-depth than previous reports, and shows the development of the government in this area.

Economic value and product portfolio of future industry

The Dutch industrial sector is positioned excellent with the locational properties, knowledge and infrastructure. By adapting early to the developments necessary for the climate transition, the Dutch industrial sector could even improve its competitiveness.

Future energy supply

Electrification, hydrogen and fundamentally different production processes could radically change the way products are made. New technologies, green electricity and new infrastructure should enable the transition towards 2030 and the longer term. A large part of the Dutch industry is located near the Noordzee, making it the ideal location for offshore wind power.

Greenhouse gas emissions

CCU, CCS, chemical and mechanical recycling should all reduce the carbon emission. The industrial sector should switch toward circularity to achieve the reduction in carbon emissions. CCU in greenhouses could reduce natural gas use, and thus CO_2 emissions.

Conclusion

The government has published a number of reports regarding the future of the Dutch industrial sector. Especially after the Paris Climate Agreement in 2015, these reports all point towards the same goal, reducing the CO_2 emissions with 80-95% by 2050. Some of the reports however often lack a good in-depth analysis of how the Dutch industrial sector should look like in 2050. There have been a number of reduction options presented, but not much more than pointing out possible technologies that could have a positive effect. Expeially the Energieagenda (2016?) lacked any form of detail.

According to the Dutch government, some of the key focus points for the Dutch industrial sector should be electrification, hydrogen and carbon capture and storage -utilization.

Areas

In this part of the research the vision for the Dutch industrial sector for 2050 will be displayed for the different areas. Each of the areas have different characteristics and require different measures to become sustainable in 2050. The areas themselves publish their own visions of their own respective area in the reports below.

Rotterdam-Moerdijk

In drie stappen naar een duurzaam industriecluster

In 2018 a group within the industrial cluster of Rotterdam-Moerdijk published the report ‘in drie stappen naar een duurzaam industriecluster’. The group had identified the current situation of the cluster, and created an outlook to reduce the CO_2 emissions of this cluster towards 2050 in three steps. The cluster will need to adapt due to the energy transition and the changes that occur with this. The team collaborated with representatives from industry, the government, environmental organizations and the scientific community.

Economic value and product portfolio of future industry

The group anticipate an economic value for 2050 that is similar to the current situation, or even growing slightly. In 2017 this was projected to be €13 billion. The cluster supplies possibilities to entrepreneurs unlike anywhere ales, according to the group.The refining sector will reduce in size, but the chemical sector will stay nearly unchanged.

Future energy supply

In 2050 the energy supply is mainly delivered from renewable energy sources. 190 PJ of energy will be generated by wind turbines and solar panels. Electrification of heat and steam production enables the use of the renewable energy sources. During the process of reducing the CO_2 emissions of the area, carbon capture and storage -utilization will be used to achieve the reduction goals. Especially before 2050 it is necessary but no longer in 2050 according to the report.

Greenhouse gas emissions

The CO_2 emissions of the area is expected to decrease from 18.6 MT in 2014, to 4-5 MT in 2050. The article doesn't address the elephant in the room, the 2200 PJ of oil use in 2016, compared to unknown in 2030-2050. It is unclear why CCS is not used in 2050, while 5 MT is stored in 2030.

Zeeland

Ambitie 2030 Duurzaamheid Werkt!

Circular en bio-based: KPI 5A: share bio-based production chemistry 15% in 2030. KPI 5B: share of production based on recycling 5-10% by 2030. Climate change en energy: KPI 6: 40% CO_2-emissionreduction in comparison to 2005 by 2030. The report by the Zeeland area clearly did not state many sustainability visions for 2030 or 2050.

Noordzeekanaalgebied

Visie Noordzeekanaalgebied 2040

The vision of this area is mainly focused on growth. The report describes in a lot of forms how and why it could and should growth. The cluster could even try to use some areas that have not reached the 'environmental limits', and create an even larger burden on the area. The area should become greener the report states, but no details in how this could be achieved are given. No clear 2030 or 2050 goals could be found.

Noord-Nederland

Noord-Nederland geeft gas op de CO_2-reductie

The report by the workgroup 'industrietafel Noord-Nederland' published the strategy for the industrial cluster in Noord-Nederland. Similar like the report 'in drie stappen naar een duurzaam industriecluster' by the Rotterdam group, this report aims at a reduction program in three steps. Phase one is to reduce the CO_2 emissions by 20% from 2018 to 2025, phase 2 aims at a reduction to 56% of CO_2 emissions and phase 3 aims at a reduction of 95% by 2050.

Economic value and product portfolio of future industry

For this area the decision of the Dutch government to phase out the natural gas production from the gas fields in Groningen has a large impact. It changes one of the larger sources of energy for the Netherlands, but also jobs and income in this area.

Future energy supply

The area envisions a large role for hydrogen from renewable energy like wind or solar power, combined with the possibility of storage. This is described as the first pillar to build on. A switch from gas use to renewable energy for local use should be the second pillar for the reduction goals. If solar and wind energy are not enough, biomass and green gasses should be used.

The third pillar is the reduction of fossil based raw material use by using biomass and waste streams. This can greatly reduce the emissions created by converting raw material to usable material.

The final pillar is availability of logistics due to past activities and the knowledge that is a result from these activities. This in combination with some locational properties could help the enabling carbon capture and storage -utilization and energy storage.

Greenhouse gas emissions
The goal for 2050 is a reduction in CO_2 emission of 12.6 Mt, thereby only emitting 0,5 Mt in 2050. This will be done through three steps as explained earlier, with the first step saving 2.7Mt and the second step 7.4 Mt.

Support by the government is required to full the financial gap is installations need to be shut down before the end of the lifetime, and subsidize sustainable options. This could increase the transition towards less emitting installations. Furthermore, the government should adjust laws and regulations that could hinder the possibility of using sustainable energy sources.

Chemelot

Chemelot strategie 2050
The expected size and production of the industrial area will be similar in 2050 as it is right now, but more sustainable. There will be a large focus on circularity and the reduction of raw material use. Furthermore, input solar panels for energy and green hydrogen will reduce the emission. Waste streams and domestic waste will be used as material input.

Chemelot currently needs 2 million MWh of energy for production and estimates this number to grow to roughly 8 million MWh in 2050. This is a direct result of the electrification of processes like heat production with electricity. They expect this to be produced from sustainable sources like solar panels, windmills and biomass.

The area aims to be 'the first circular and climate neutral chemie-site of Europe'. It will use collaboration within the region as a 'Hub for Circularity' (H4C). It even aims to have a net negative GHG emission in 2050. Al fossil fuel based processes will be replaced with circular counterparts.The products will not change a lot, but the production processes and energy sources will.

Conclusion

The five largest areas have some differences in their visions but also a number of similarities. Some differences are site specific, others seem to be based on personal preferences by companies located at the area.

The Rotterdam cluster mainly focuses on the transition to sustainable energy for the energy use at the production facilities within the area. A reduction in refineries is anticipated, but only on a small scale. A larger share of fossil based products will be used in the chemical sector located at the Rotterdam cluster, or exported. Hydrogen production, use of sustainable energy, electrification and the use of CCS/CCU are meant to facilitate the future product portfolio, but this portfolio is largely unknown (Kroes et al., 2018).

The Noord-Nederland cluster anticipates the decline in natural gas extraction. This creates a large decline in employment opportunities and profit for the area. To become a sustainable area and resolve the missing income, the area largely focuses on large scale green hydrogen production, transportation and storage. The energy for this green hydrogen should come from large scale wind power parks in the Northsea. Where the cluster of Rotterdam mainly focuses on creating hydrogen for its own needs, the Noord-Nederland area envisions large scale production as a business opportunity (König et al., 2018a;2018b).

An entirely different point of view is presented in the early reports by the Noordzeekanaal area (NZKG, 2014; NZKG, 2017). The first of those reports was written before the Paris Climate Agreement in 2015 and the second one was the continuation of the first one. The focus of these reports was on growth. There are no reduction goals presented nor a clear goal for renewable energy use. There are some mentions of a growth within the environmental limits, but this hardly seems an emission reduction goal. However, the reports published in 2018 (NZKG) and 2020 (NZKG) are more encouraging. A large shift in focus for the next decades. The vision of the new reports is in line with reduction the goals by the Dutch government. They aim for halving the emissions by 2030 and by 2050 decreasing it much further. They aim at using almost no raw materials in 2050 to reduce emissions, they claim waste is a resource by 2050. The use of offshore wind power parks near the area should decrease the emissions if combined with electrification of the production processes. The first step here is an estimated 6 GW of offshore wind power by 2030. Furthermore the use of waste heat streams and geothermal energy as additional heat sources should reduce the emissions even further. A large scale usage of hydrogen for long distance transportation and seasonal storage is aimed to be used by 2050. In the short term CCS and in the longer term CCU should be used to reduce the CO_2 emissions to a minimum.

The Chemelot area expects the outside look of the area to be relatively similar, but inside all processes are replaced with sustainable processes in 2050. The area is for the largest part circular, using barely any raw material and recycling most material. The electrification of the processes will have a large impact on the demand. They expect the demand to go up from 2 MWh to become 8 MWh of electricity. For a large part this demand will be supplied with large scale solar panel parks. Without a coastal area nearby like the other areas, offshore wind power would require more transportation and more losses (Chemelot, 2020).

Reporting by the Zeeuws-Vlaamse cannel zone is a lot less detailed and only extends to 2030. They expect to use 25% sustainable material instead of raw material due to circularity and biobased materials. Furthermore, they aim at a 40% CO_2-emission reduction compared to 2005. This will be accomplished by switching from fossil fuel based energy to sustainable electricity, energy efficiency gains, transport emission reduction and using sustainable sources (CE Delft, 2016).

Where both the Rotterdam and Noord-Nederland clusters aim at a large reduction of the emissions, the Noord-Nederland cluster seems to be more radical and ambitious. The Rotterdam cluster aims at a reduction of 73-78% reduction by 2050 compared to current emissions, the Noord-Nederland are aiming at a reduction of 95% by 2050. De rest nog toevoegen

10.2 Wind power calculations

$$P = \frac{E}{t * cp}$$

P = Power of wind turbines
E = Energy produced in one year
t = hours per year = 365 * 24 = 8760
cp = capacity factor = 0.45 (IEA, 2019a)

Rotterdam: 52.8 TWh of electricity required by 2050 (Kroes et all, 2018)

$$P = \frac{52.8 * 10^3}{8760 * 0.45} = 13.4\ GW$$

Noord Nederland:

$P = 290 + 675 + 510 + 1825 + 1030 = 4{,}330\ MW = 4.3\ GW$ (Konig et al., 2018a)

Noordzeekanaal: 33.3 TWh of electricity required by 2050 (NZKG, 2020)

$$P = \frac{33.3 * 10^3}{8760 * 0.45} = 8.4\ GW$$

Chemelot 8 TWh of electricity required by 2050 (CHEMELOT, 2020)

$$P = \frac{8 * 10^3}{8760 * 0.45} = 2.0\ GW$$

Zeeland 4.4 TWh of electricity required by 2030 (CE Delft, 2020) since no public data was available for 2050.

$$P = \frac{4.4 * 10^3}{8760 * 0.45} = 1.1\ GW$$