The Uncertain Future of Oil Refineries:

A Roadmap for Relevance and Integration of Oil Refineries into Future Energy Systems

TUDelft

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The Uncertain Future of Oil Refineries: A Roadmap for Relevancy and Integration of Oil Refineries into Future Energy Systems

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Acknowledgements

I have always been interested in social studies research and the opportunities it provides to open discussion regarding the state of technology, society and humanity. During my bachelor's, even though I was studying civil engineering, I went out my way to pick electives regarding risk management, ethics and sociology. That's why when I graduated, I knew Complex Systems Engineering & Management was the perfect fit for me as the amalgamation of technology, society and the impact of their interactions on our current life and future. As I delve more into the courses and the research on upcoming technological developments in complex systems, I generally felt like there is a lack of attention to the human aspect and this motivated me to involve social studies and qualitative approach in the projects that I had the chance to accomplish. I am constantly inspired by people and their accomplishments so working towards objectives that benefitted the society as a whole made me feel instrumental and satisfied.

Starting my thesis was more struggling than I expected prior. My initial lack of ideas compounded with the effects of COVID-19 pandemic put me on the backfoot from the start. A week-long visit to my family in Turkey turned out to be a 4-month stranded stay with no international flights and the effects of the pandemic was starting to make me question the future of my thesis. That's why I'm very grateful to Aad Correlje and Ivo Bouwmans for the opportunity they provided for me to generate a thesis subject and follow through with it until its completion. Aad, thank you for presenting the idea of the future of oil refineries and your feedbacks even though I sometimes lacked to present things that warranted a feedback. Your expertise and help were crucial in structuring and forming this thesis. Ivo, thank you for extensive guidance and leadership that got me to this point. I remember our exchanges in Spring fondly as I was stressed and pessimistic about the whole thesis process and you have done so much to push me and lead me to this topic with this committee. Lastly, once again thank you both for accommodating this thesis schedule and enabling me to work harder and more focused.

I had high expectations from TU Delft when I arrived 2 years ago because I knew the university was top notch in many fields but all my expectations were exceeded when I came across how TU Delft treats its students with hospitability and enthusiasm and that helped me get through many stages of my master's education. I also want to thank my friends back home and in various parts of the world for keeping me sane, motivated and relaxed. You guys know I will be there for you whenever you need me as well. A special thank you to Damla, for believing in me and supporting me throughout everything I have been going through. Lastly and most importantly, thank you mom and dad for your all your efforts, attention, blood, sweat and tears to help me get to any point in life. I couldn't have done anything without your love and support. I love you both very much and hopefully, there are more wonderful days ahead of us. It has been the roughest summer ever, but the spring day will come.

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Executive Summary

The oil refining industry is facing an uncertain future as technological advancements in the energy industry improve efficiency and performance in operations, environmental legislation being imposed with established carbon emission goals and demand for conventional refined products set to hit a plateau in the near future. Decarbonization and digitalization trends in the energy sector create technological and environmental implications on oil refineries which will need to transform their businesses, feedstock and products in order to adapt to the standards of future energy systems. Current challenges in the oil refining industry, developments and plans that the industry is preparing to correspond to those challenges and the evaluation of the alignment of challenges and developments with respect to technological advancements, environmental legislation and carbon emission goals are issues that are not clarified in the academia and a direction or a vision is required for defining and establishing a role of oil refineries in decarbonized and digitalized energy schemes of the future. Thus, the following research question was generated to tackle these aforementioned uncertainties in this research thesis:

Main Research Question
"How can oil refineries maintain their relevance and establish integration into future energy systems with environmental legislation, carbon emissions and technological advancements?

The qualitative research approach taken in this research is fresh and unique for energy-related studies and it allows for systematic analysis of interactions. Data collection is accomplished through a desk research of various types of literature such as academic articles, government documents and company reports. Technological and environmental challenges and respective developments the oil refining industry is currently hosting are inspected with respect to their implications for integration, which refers to establishing connections and cooperation with other elements of energy systems, and relevancy of oil refineries in future energy systems. Qualitative Content Analysis is utilized for aligning and compiling the resources from the conducted desk research and provide meaningful criteria for further analysis of scenario building. Scenario building inputs the meaningful criteria as a basis while assembling and filtering the scenarios and forecasts that are abundantly found in the literature regarding the future of oil refineries and draw conclusions from the analysis to create a roadmap for oil refineries to be relevant and integrated in decarbonized and digitalized energy systems of the future. The roadmap would consist of viable actions to facilitate the transition of oil refineries to comply with the standards of technological advancements in energy efficiency and operations while enhancing emission mitigation to the fullest and time horizons for each action step will be designated with respect to the technological readiness and environmental legislation planned timelines.

The oil refining industry is currently up against technological and environmental challenges that hinder their integration and participation in the ongoing energy transition. The main product of refining is conventional transportation fuels such as gasoline, diesel and kerosene and the demand for these products are expected to hit their peak in the near future. Most refineries are technically mature with low efficiencies and high emissions and retrofitting those refineries present high capital costs, investments and planning that many refinery owners are uneager to accomplish. In terms of environmental impact, the oil refining industry is one of the highest emitting industrial sectors per facility and refining processes, feedstock, products and waste generated all contribute to carbon emissions greatly. Emissions are the central parameter in the global strive for obtaining climate stability and in order for refineries to be a part of the energy sector that is currently driven by renewables, emission mitigation and technological breakthroughs, transformative developments need to happen to ensure a defined role for oil refineries in decarbonized and digitalized energy systems of the future. For combatting these aforementioned challenges, oil refining industry is preparing technological and environmental developments. Implementation of digital technologies such as the Industrial Internet of Things is expected to provide refineries with improved decision-making, waste and asset management, data collection, analysis and monitoring. As the demand for conventional transportation fuels is set to hit a plateau, petrochemicals emerged as the next driver of demand for refined products and petrochemical integration became a priority for newly developed and constructed refineries especially in Asia and the Middle East. In addition, carbon capture and storage technology has been indicated to be influential in emission mitigation throughout all elements of energy sector and oil refineries are exploring opportunities to implement this technology as well. Cleaner feedstock, products and operations are being developed and introduced through oil refineries and the impact of them are also expected to be increasingly potent as the world progresses into more environmentally conscious business and industry operations.

Qualitative Content Analysis is used to align and compile these challenges up against the developments to generate meaningful criteria for scenario building to analyze. The gathered literature is first decontextualized in order to find meaning units in the resources that is of importance in terms of the research objective. Then, these meaning units are condensed to more digestible forms for clarification and coherence. After that, the condensed meaning units are categorized with respect to the research questions and theme of the research thesis. Finally, compilation and presentation of the analysis are accomplished and two meaningful criteria that were generated with QCA were *demand for refined products* and *carbon emissions of refineries*. Combination and investigation of scenarios for these two criteria would express the realized ambition of emission mitigation of the refining industry while giving a sense of financial stability and survivability that is threatening the refineries as of right now. Scenario building is utilized to assemble and investigate the scenarios regarding the future of oil refineries with respect to the criteria generated by QCA in order to find a viable pathway to the integration and relevancy of oil refineries in decarbonized and digitalized energy systems. For both of the criteria, a fundamental driver is singled out, the effects of the driver are examined, the relevant time horizon for the analysis is determined, scenarios and forecasts are assembled and configured if needed for assumptions and bifurcations and finally conclusions were drawn. After the compilation and reflection on the findings of scenario building, a three-step roadmap for integration of oil refineries in future energy systems was generated. The roadmap calls for the subsequent actions for improved CO_2 efficiency of refinery operations, relentless progression of emission mitigation and integration of oil refineries into industrial clusters.

This thesis has a unique place in the academic periphery with the utilization of quantitative approach and social studies methods in energy-related research. The data analysis procedures include a creative and recommended combination of Quantitative Content Analysis with scenario building, reinforcing the systematic approach that qualitative studies strive to express. With the final deliverable of a viable roadmap, this thesis aims to contribute to securing the position and integration of oil refineries by providing insights on effective usage of their resources, facilities and products. Future studies in this research area have the potential to further investigate the possible discrepancies between local and global scale refinery emissions. Also, the huge stakes put on petrochemicals could have unexpected environmental impacts in terms of pollution and harm to wildlife, so it is important to consider the scale and cleanness of petrochemical integration.

Contents

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List of Acronyms

bbl	barrel of oil
BP	British Petroleum Company
CCS	carbon capture and storage
CIEP	Clingendael International Energy Programme
Concawe	Conservation of Clear Air and Water in Europe
CoSEM	Complex Systems Engineering and Management
DTI	Digital Transformation Initiative
ESG	environmental, social and governance
EU	European Union
EUROPIA	European Petroleum Industry Association
IEA	International Energy Agency
IIoT	Industrial Internet of Things
IMO	International Maritime Organisation
IoT	Internet of Things
IPIECA	International Petroleum Industry Environmental Conservation Association
LNG	liquid natural gas
LPG	liquefied petroleum gas
MARPOL	International Convention for the Prevention of Pollution from Ships
mmbd	million barrels per day
NGO	non-governmental organization
QCA	Qualitative Content Analysis
R&D	research & development
UKPIA	United Kingdom Petroleum Industry Association
US	United States

1. Introduction

This chapter provides the introduction and background information for the research conducted on the master thesis. Section 1.1 contains an overview of the oil refining industry, its most glaring issues, recent trends and developments. Section 1.2 presents the problem statement related to this master thesis which is the questionable relevancy of oil refineries in future energy systems. Section 1.3 explains the research objective of this thesis. Section 1.4 includes the research scope. Section 1.5 defines the main research question and sub-questions of this master thesis and gives the aligned answers for those questions. Section 1.6 explains the analytical foundation that is utilized in this thesis. Section 1.7 details the societal and academic relevance of this oil refineries research and thesis. Section 1.8 concludes the first chapter with an outline of the thesis.

1.1 Background Information

For almost a century, demand for oil increased throughout the World for many uses such as generation, transportation and production. However, a radical transformation is knocking at the door as environmental legislation and global conjuncture on energy is shifting towards renewables and more sustainable means. Technical breakthroughs and an increased number of operating renewable plants will continue to reduce the levelized cost of electricity for solar and wind energy while developments in energy storage and electric vehicle technologies combined with aggressive CO2 sanctions are on course to slowly phase oil out of the new energy order (Concawe, 2018).

Refineries are an essential part of the oil industry and they are one of the parts that are highly affected by the energy transition. Security of supply concerns, technological transformations in urban mobility and environmental legislations put the oil industry under such pressure that even refineries operated by oil giants are facing the threat of closure. A recent poll among European refining executives corroborates this view: Four-fifths think that only a few will survive by 2030 (Bain & Company, 2019). Decreasing profit margins of refined fuel products also push companies to integrate petrochemical plants with their refineries to diversify and optimize their production. Petrochemicals are experiencing robust demand from developing markets like China, India and Saudi Arabia and these products can be a way of refineries staying relevant and open to business. Recently, Saudi Aramco announced that they will invest more than $100 billion in petrochemicals over the next decade in an effort to make its downstream business as prominent as its upstream operations and they project chemicals would represent about one-third of world oil demand growth between now and 2030, and nearly half by 2050 (Deloitte, 2019).

Another recent trend oil companies face is investor and shareholder pressure on sustainability and environmental governance. According to a 2018 global survey by FTSE Russell, more than half of global asset owners are currently implementing or evaluating environmental, social and governance (ESG) considerations in their investment strategy. One of the most successful activist groups has been Climate Action 100+, a global network of institutional investors that targets the world's 100 largest corporate greenhouse gas emitters. In March, the group, working with others, forced the oil giant Shell to make a legally binding commitment to use a broader definition of greenhouse gas emissions in its carbon-reduction targets. In another example, at BP's annual general meeting in Aberdeen in May, Climate 100+ secured overwhelming approval for a motion that called on the oil giant to document its efforts to meet Paris Agreement goals in quarterly reports (Deslandes, 2019). Even though some companies such as Exxon and Chevron still fight against environmental accountability by not disclosing and documenting the actions taken to comply with the Paris Agreement, oil companies and refinery owners are obligated to alter their operations to satisfy environmental standards and technological developments of the current age of energy with the means of digitalization and data science.

With losses, unemployment and closures on the horizon, oil refineries need to adjust their position in the upcoming new energy order to stay integrated and relevant. Incentivized by profit margins, shareholder pressure and environmental requirements, acting upon prevalent issues some of which are mentioned above can be done by the refining sector which is dominated by private entities. Adapting to the new energy order could mean altering refineries' production, governance and infrastructure but their survival depends on this adaptation as illustrated by the pessimism of officials in the refining sector. In order to not just live off in the energy landscape but also to contribute to the energy transition, oil refineries should undergo a similar transition that addresses technical, economic and institutional challenges that await the sector in the short, medium and long term.

1.2 Problem Statement

Due to global environmental and energy legislation, a disruptive energy transition period is underway. With the EU's sights on 2050 for substantial change for emission-free energy production and transportation, refineries are in a purgatory-like position where their products and services are being demanded less and less. However, the refining industry is still going strong with over 100 mb/d of refining capacity in operation or under construction today, 40% of which is in North America and Europe and another 40% in developing countries in Asia and in the Middle East (McGlade, 2020). Even against strict environmental regulations, the refining industry strives for greater profit margins. With the ongoing developments of electrification of transportation, producing newer products such as biofuels and LNG became an important solution for refineries (Meijnknecht et al., 2012). Although biorefineries may look like a solid alternative for traditional refineries, they require feedstock, harvesting sites, processing routes and suitable markets alongside many other sustainability criteria that can be impossible to satisfy (Santibañez-Aguilar et al., 2014). These new developments of environmental constraints and decreasing demand concerns may push the refineries into obscurity in terms of the new energy order that is supposed to sustain an emission-free energy and electricity production system. That's why there is an urgent need for planning for the oil refineries' short-term future.

For oil refineries to undergo a significant change, they would need to physically change some of the parts and systems that they have been using for the traditional refining processes. Big data analysis, increased automation, machine learning and neural networks are some technological developments that can help the efficiency of refineries. These digitalization measures also help negate the human reliability element of oil refineries as still most accidents in the petrochemical industries are caused by human error (Abílio Ramos et al., 2020). However, in order to implement these developments, research and development (R&D) investment are required and R&D investment only accounts for a small portion of 1-3% of total sales in the oil refining sector (Lim and Lee, 2020). Integration with petrochemical plants is also one of the most repeated examples in the sense of increasing the profit margins of oil refineries so that they can stay operating but this integration also requires high costs and technical upkeep that may keep the refinery closed for a while. In the current economic circumstances of the crash of crude oil prices, political implications and a global pandemic, refinery owners would not be keen to close their plant for a while for this integration.

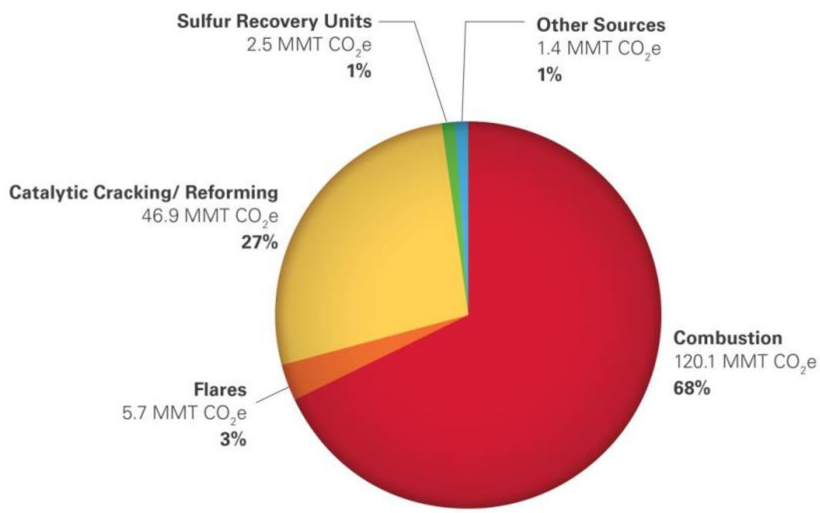

Figure 1.1: Petroleum refinery emissions by source (EPA, 2013)

An important recent development that had a huge impact on the oil refining industry was the International Maritime Organization (IMO) MARPOL Annex VI regulations on marine fuel sulfur content. This regulation required 2 million barrels of oil per day to be switched to distillate fuels and the capacity of conversion processes to be increased in order to match the sulfur cap of 2020 (Chu Van et al., 2019). Also, it was noted that “fuel oil non-availability” can lead to operational limitations for the refineries and medium-run LNG could be inevitable for maritime industries as LNG’s use as a bunker fuel is expected to increase significantly (Ruble, 2019).

Hindered by environmental legislation and technological developments, oil refineries must find a way to be relevant and efficient in the upcoming energy transition and in the future energy system of zero emissions. Investment and R&D are essentially needed for this transition for new parts, new conversion technologies and new integrated plants. Even though refinery owners and companies intend to go forward with overhauling their refineries, refineries tend to invest less when plants that nearby have already invested in their plants in the previous year (Chesnes, 2015). Even though this may signal individualism in the industry, there are organizations such as FuelsEurope (formerly known as EUROPIA) that present a shared vision for refineries for 2050 and they reiterated their aim of enabling the low-carbon transition of this industry in line with the EU ambition of a climate-neutral economy by 2050 but also noted that a facilitated economic recovery is required for the sector to keep going. This situation again illustrates the desperate situation of refineries where things that are needed to be done are apparent but no investment, action or policy is being implemented to oversee a change in the industry. That's why this thesis hopes to initiate a discussion for the future of oil refineries and their relevance in the upcoming energy transition.

1.3 Research Objective

This research aims to investigate what kind of steps oil refineries should take in order to stay relevant in future energy systems with low carbon emissions and technologically developed infrastructure. With international legislation on environmental issues such as Paris Agreement and profit margins for traditional refining products becoming smaller, oil refineries face technical, financial and environmental challenges that force them to take action to adapt to the standards of day and age. In order to stay relevant in future energy systems, oil refineries have to undertake a role that aligns with decarbonization and digitalization trends of energy in the near future. The approach taken upon this research is to clarify critical technical and environmental challenges that refineries ought to face, compile the recent developments in refining industry that serves the aim of decarbonization and digitalization and analyze critical forecasts, scenarios and projection regarding oil and oil productions demand. The analysis to be conducted in this research will utilize Qualitative Content Analysis and scenario analysis to find global consensus lessons learned regarding the near future of oil refineries and their prospective role. The expected outcome is a filtered roadmap for relevancy and integration of oil refineries in future energy systems that are decarbonized and digitalized.

1.4 Research Scope

The scope of this research includes mostly technological and environmental challenges that oil refineries are facing on global and local scales. Social and financial issues related to the current and near-future situations of oil refineries are also considered but not taken into account as thoroughly as technological and environmental issues since these issues are highly constrained by the international legislation and technological necessities of the current day and age. The challenges and their corresponding developments in the oil refining industry are chosen and utilized in Qualitative Content Analysis for alignment and coherent argumentation purposes. The scenarios and projections included in the analysis are chosen with respect to emission goals and environmental laws that are set in stone by countries and organizations with the objective of aligning timelines and more robust comparisons.

1.5 Research Questions

The aim of this master thesis is to uphold the relevancy and integration of oil refineries in the new energy order that will be sustained by environmental constraints and sustainability pressure while obtaining an operational profit margin and satisfying the demand of existing oil and refined products. With the conducted literature review for this research, it is observed that refineries are facing a tumultuous near future with disruptive changes and overhauls incoming. For as long as oil reigned supreme as the most valuable asset in the world, refined products demand increased continuously throughout this period but the environmental legislation, technological advancements in transportation and transportation fuels blurs the role of oil refineries in a decarbonized energy system. Thus, our main research question and sub-questions are generated as follows:

Main Research Question
"How can oil refineries maintain their relevance and establish integration into future energy systems with environmental legislation, carbon emissions and technological advancements?

1) What are the current challenges that oil refineries face in the context of international environmental legislation, emission goals and technological advancements?

This question establishes the base of the line of argumentation for this thesis by defining the challenges that should be taken action against and showcases the alignment of challenges and developments to be investigated further down the thesis. Literature review shows a shared understanding in the academia and media for the issues that oil refineries are facing and will continue to face in the future but it also creates the problem of losing the scope with a variety of different issues that may not contribute to the goal of this thesis. Thus, focusing on technological and environmental challenges provides the healthiest path to relevancy and integration of oil refineries as there are goals and laws set in stone throughout the globe to drive the approach this thesis hopes to accomplish. Desk research will be utilized for answering this sub research question alongside forecasts and projections from company reports, government documents and other organizations' resources.

2) What are the developments that oil refining industry is currently undertaking and planning to undertake in the near future to combat the challenges of international environmental legislation, emission goals and technological advancements?

This question enables the alignment of the thesis by providing corresponding developments in the areas that are determined to create challenges for the oil refining industry in the short and mid-term future. In the context of this thesis, developments symbolize the collective actions, plans and strategies that the oil refining industry has currently underway or has the plans in place for future implementation. Literature review shows that the oil refining industry has already taken a few steps towards adapting and overhauling their assets for the upcoming energy transition period and more comprehensive changes are already confirmed to be on the way. Through desk research on academic articles, energy-related news articles, company reports and government documents, certain upcoming developments and concrete plans can be investigated and commented upon with respect to constraints of environmental legislation, timelines of environmental and technological goals.

3) How does the developments in the oil refining industry respond to the current challenges with respect to scenarios, forecasts and trends for the future energy systems?

This question illustrates the current problem-solution dynamics that oil refineries are facing and evaluates the robustness of the upcoming planned developments to be addressed to combat against technological and environmental challenges. Literature review and desk research showcases that for oil refineries are due to a massive overhaul in order to adapt to the decarbonized and digitalized future energy systems. Thus, evaluating the robustness of developments and plans to take place in the refining industry in the face of technological and environmental challenges in the context of carbon emission goals and advancements in transportation is vital for understanding the current position and estimating the future role of oil refineries. In order to effectively utilize the abundant resources of scenarios, forecasts and projections, scenario analysis will be conducted. In order to systematically evaluate the alignment of how serviceable planned developments correspond to current challenges that oil refining industry is facing, Qualitative Content Analysis (QCA) will be used.

4) What steps should the oil refining industry take in the short and mid-term to have a sustainable role in the decarbonized and digitalized future energy systems?

This question aims to formulate a roadmap for the oil refining industry to correspond to the challenges it is facing and utilize the developments that the industry and the energy sector as a whole are going through in an effective way to become relevant and integrated into future energy systems. Through literature review and desk research, it is observed that there are certain ideas and plans to make the operations of oil refineries greener and more sustainable without sacrificing their profits but in order to accomplish those ideas and plans, there are necessary steps to be taken that are affirming of the decarbonization and digitalization philosophies that future energy environments will be based on. Scenario-building will be utilized to create a roadmap for relevancy and integration of the oil refining industry for the future energy systems in the context of international environmental and technological goals with the aid of trends, projections, forecasts and scenarios.

1.6 Analytical Foundation

This research contains elements from Qualitative Content Analysis, scenario analysis and scenario building methods, thus creating a variety of analytical approaches. Qualitative approach to an energy systems problem creates the dynamic of both deductive and inductive approaches. Using established research and data to formulate a hypothesis is part of this research as a deductive approach whereas potential themes and questions emerging from investigating the acquired data show the inductive approach to be taken in this thesis. Utilizing the data and resources that are found abundantly in the form of scenarios and forecasts enables the research to use scenario building for creating an effective road map that is technically and academically valid. Qualitative Content Analysis ensures the alignment of challenges and developments in the oil refining industry and creates a coherent line of argumentation for the outcomes of the thesis and the answers to the generated research questions. Qualitative research approach is fundamentally potent gaining insight on how policies impact environmentally consequential patterns of human engagement and since this thesis aims to investigate the prospective integrated role of the refining industry in future energy systems where human – energy interaction is prominent, qualitative research suits the gist of this research (Shelly, 2016).

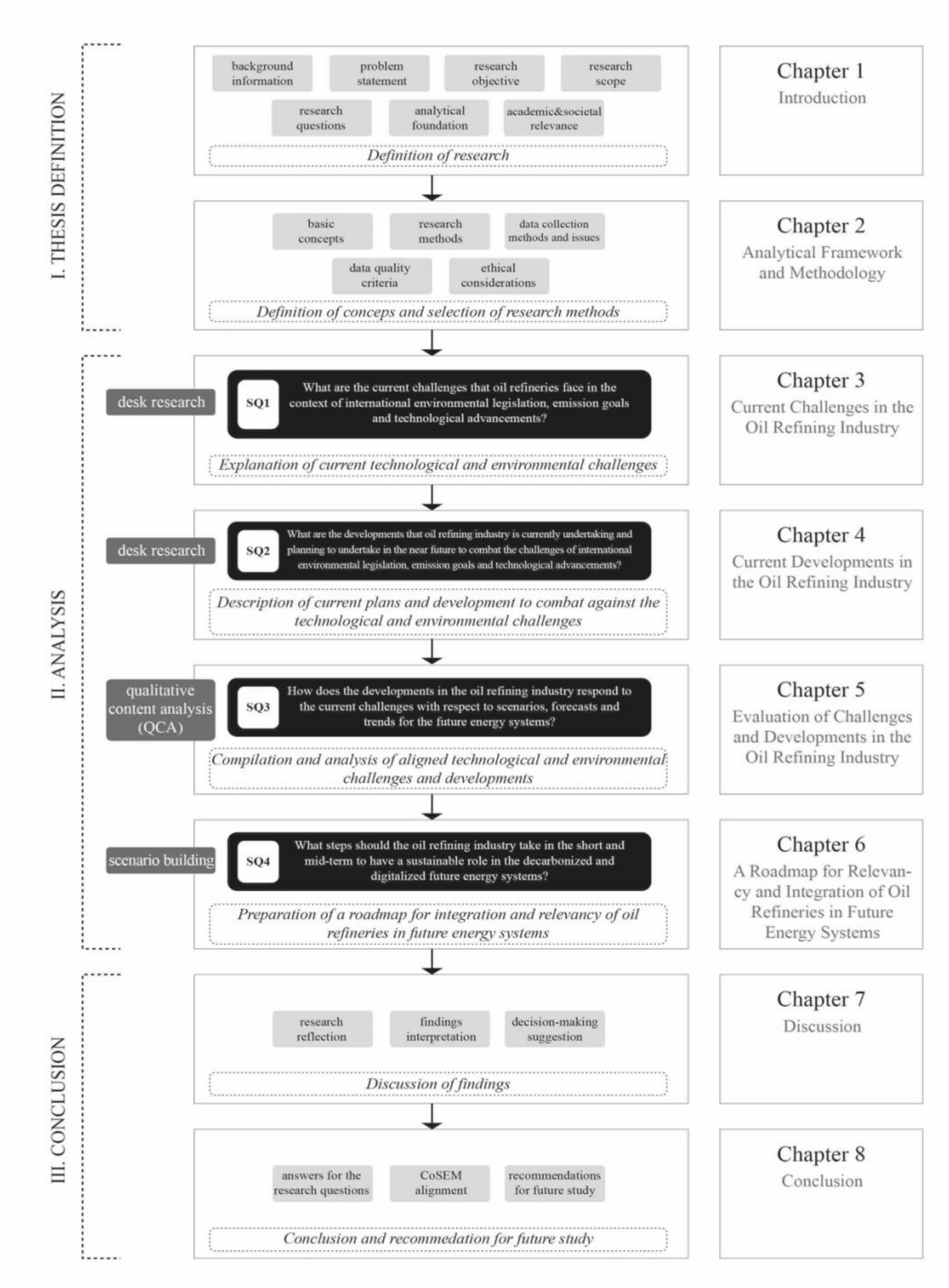

Figure 1.2: Research flow diagram

1.7 Academic and Societal Relevance

Scientific and societal relevance of this thesis would be a more precise placement of the role and position of oil refineries in the design of future energy systems research. Ideally, oil would be phased out completely and replaced with all renewable means of energy and electricity production but that would be unrealistic considering the pace that even the most developed countries are progressing towards emission goals and environmental requirements. Oil and oil refineries still have a role to accomplish in the comprehensive energy order and more clear definition and distribution of roles would be helpful to policymakers and academics in designing micro and macro energy systems. In addition, oil refineries are a source of greenhouse emissions and environmental harm (Purvin & Gertz, 2008). The strategies and actions this thesis aim to acknowledge and present contribute to reducing emissions and mitigating the environmental implications of the oil refining industry, thus contributing towards a positive societal impact.

In the academic literature, there are articles mostly regarding the performance of oil refineries or optimizing and digitalizing oil refineries using data sciences but the institutional and economic placement of oil refineries is lacking. Developments about the refineries are usually retrieved from news sites, oil companies, NGOs and energy ministries. Thus, this thesis would have a unique place in the academic periphery. Compiling and filtering of a plethora of academic resources, forecasts and scenarios could assist in future research in this area with the analysis of scenarios and scenario building that this thesis utilizes. In addition, qualitative research on energy studies and the oil industry is less prominent than quantitative research on technical parts of these areas. Therefore, this thesis illustrates a commonly neglected part of energy systems with oil refineries using qualitative research, which is also commonly neglected in this area of research, creating a dynamic that satisfies the knowledge gap that this thesis hopes to acknowledge.

1.8 Thesis Structure

This thesis consists of three parts and eight chapters. The first part is defined as thesis definition and in this part, the framework and the foundation of the thesis are explained with Chapter 1 of Introduction and Chapter 2 of Analytical Framework and Methodology. In the Introduction chapter, the problem is introduced and in the Analytical Framework and Methodology chapter, the background information regarding the research subject, the descriptions of data collection and analysis methods and the analytical framework of the thesis are showcased. The second part of this thesis report is called the analysis and this part consists of Chapters 3,4,5 and 6 of this thesis. In Chapter 3, current technological and environmental challenges that the oil refining industry is facing are described. Chapter 4 illustrates the current developments the oil refining industry is preparing in the face of technological and environmental challenges. In Chapter 5, current challenges and developments are analyzed with Qualitative Content Analysis for alignment and compilation means. Chapter 6 utilizes scenario building to assemble scenarios and forecasts regarding the future of oil refineries in order to generate a roadmap. Chapter 7 expresses the reflection on the study process and results. Finally, Chapter 8 concludes this thesis with the answers to the research questions, alignment with CoSEM and recommendations for future study.

2. Analytical Framework and Methodology

This chapter lays the analytical and methodological foundation for the academic research conducted in this thesis. Section 2.1 provides the analytical framework by defining the concepts in the oil refining industry and explaining the current trends that are prominent in the refining industry. Section 2.1 concludes with the illustration of the analytical framework that shows how this thesis combines the concepts and trends related oil refining industry to guide the methodology in a systematic way. Section 2.2 discusses the methodology of this thesis with an explanation of the selection of methods which are Qualitative Content Analysis and scenario building with respect to the scenarios and forecasts made on the oil refining industry. Section 2.2 also contains data collection methods, data collection issues, validity and reliability of the data and ethical considerations.

2.1 Analytical Framework

Analytical framework consists of a brief explanation of the basic concepts in the oil refining industry and showcasing the current trends that are influential on the challenges and developments that arise in the oil refining industry. The basic concepts of refining include general components of refining such as feedstock, products, operations and facilities. These concepts aid this research on the refining industry as the refining process includes a few elements that are vital on a global scale so illustrating the simplicity but also the influence of oil refining on energy systems would be important. In addition, the relationship between the oil refining industry and the transportation sector is quite intrinsic and this relationship causes a mutual dynamic that results in shifts or developments happening in one affecting the other quite powerfully. Presenting the current trends surrounding the oil refining industry also shows where the industry is heading towards in terms of challenges and developments and paves the way for future chapters as this thesis indulges more into what steps should be taken for relevancy and integration of oil refining industry in future energy systems.

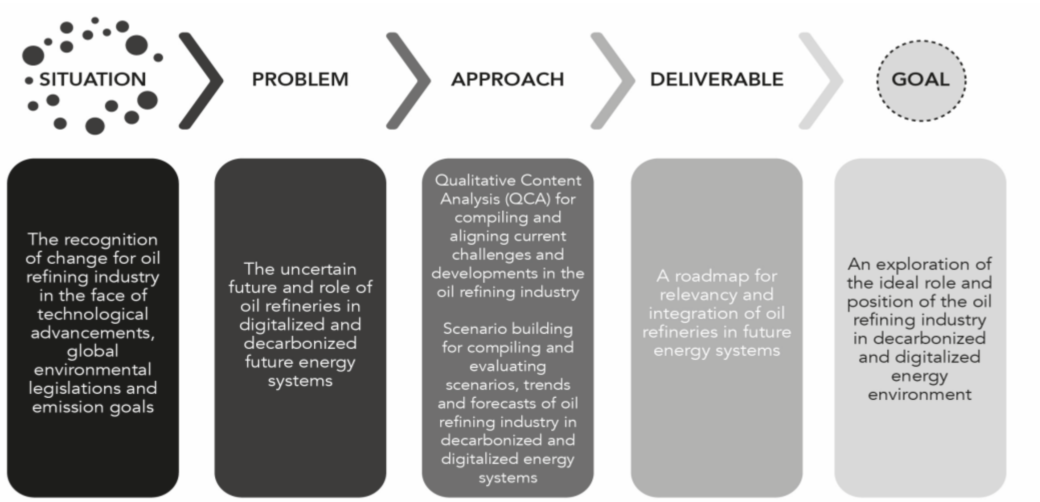

Figure 2.1: Analytical framework with respect to the research objective

2.1.1 Definition of concepts and trends in the oil refining industry

The oil refining industry is an integral element of the global energy system and is considered essential to downstream oil activities. Through the operations facilitated at oil refineries, crude oil is transformed into a plethora of products and services such as fuel for transportation, heating, electricity and road building. Because this variety of vital systems are interlinked with the oil refining industry, global refining capacity has been steadily increasing in order to satisfy demand from users of all kinds. Global refining capacity is 106.1 million barrels of oil per day (mmbd) as of 2019 and it is expected to rise to 125.2 mmbd by 2024 (IEA, 2020). Economic and population growth throughout different parts of the world also resulted in an immense increase in oil demand, with 100 million barrels per day in 2019 and is expected to gain 1 million barrels per day per year of additional demand growth (IEA, 2020). This immense capacity and the forecasts that project even more demand growth is attributed to increased access to automotive and aviation transportation in developing countries, which are expected to account for 97 percent of the population growth until 2030, and the expansion and the development of chemical products industry. This trajectory apparently encourages investors and suitors to channel their money into the refining sector with 154 global refineries are planned to be built by 2024 with 40 percent of those being in Asia and 20 percent being in Middle East (GlobalData Energy, 2020). Sustained with the population growth of developing regions and technological advancements that enhance the manufacturing of chemical and oil refining products, oil refining is slated to be an important part of the global energy systems for the next 10 years.

Oil refineries are generally huge industrial complexes, containing piping, storage and processing facilities. A prospective oil refinery requires planning the construction and capabilities of the refinery, designing integral parts of the refining system including piping and storage, acquiring the necessary permits and finally constructing the oil refining plant which can take 5 to 7 years to build and costs approximately 7 to 10 billion dollars. This initial cost is even extended with the purchase of the land that the refinery is to be built, personnel, maintenance and operational costs. However, entry costs being quite high does not discourage investors from entering the oil refining market as annual global oil investments in new refining capacities rose from 34.9 billion dollars in 2015 to 54.4 billion dollars in 2019 (GlobalData Energy, 2020).

In order for oil refineries to compensate for the huge sunk costs and investments they made, they need to produce a wide range of products to profit off. For the production of these products, they need their feedstock which is crude oil. Crude oil is the feedstock of oil refineries' operations and having an integral component that is globally contested in your product chain presents risk and volatility for the feedstock. Crude oil is an asset that has logistical, political and financial implications for the whole global landscape of energy business. The price of oil and oil-related products are impacted by a plethora of parameters such as political tension, technological trends, economic stagnation and the recent supply of feedstock. Even though, refineries have a wide portfolio of products, it is inevitable not to be impacted from the changes in crude oil supply and price scot-free. A recent example of price volatility causing disruption in the oil and oil-related products market is the crash of crude oil prices in March 2020 due to oil price war between Saudi Arabia and Russia. With the price war, quarterly oil prices fell by 65 percent and crude oil prices fell by 26 percent (Hall, 2020). During this period, International Energy Agency (IEA)'s director Fatih Birol announced that this price war put 50 million jobs in oil refining and retail at risk. Whiting Petroleum Corporation and Diamond Offshore Drilling, two US companies announced their bankruptcies (Financial Times, 2020). Europe's leading oil exporter, Norway, also faced a historic drop in their currency, Krone, against the Euro and Norwegian Central Bank is preparing to intervene with its currency for the first time in two decades (Financial Times, 2020).

The added-value gained from oil refineries is the products that are processed from crude oil. These products are utilized in a variety of ways and industries. First and maybe the most recognizable of them all is fuel. With the refining process, crude oil can be converted into gasoline, jet fuel, diesel fuel or liquefied petroleum gas (LPG) which are all forms of fuels for different modes of transportation such as automotive, aviation and maritime. Throughout this last century, those modes of transportation have become more accessible and available for the public and this trajectory is also accompanying the increase of oil, therefore fuel demand across the globe. This phenomenon can be explained by demographics as countries with large populations such as China, India, Brazil and Indonesia have propelled their economies to match the size of developed G7 countries and nearly 3 billion people are expected to graduate into the middle class by 2050, a shift that United Nations describes as historic and not seen for 150 years (Yueh, 2013). With more citizens in the middle class, owning multiple cars in single households and using airplanes to travel become increasingly common alongside the usage of other refinery products such as pharmaceuticals, synthetic fibers and packaging. With respect to the trends and trajectories mentioned above, it is safe to say fuel products will be demanded for the foreseeable short term.

The second product that is going to be highlighted is plastic goods. Plastics are made from natural resources such as crude oil or natural gas through a polymerization or polycondensation process. In our current day and age, it is impossible to avoid plastics whether at home, work or school. Even if only plastic water bottles are taken into consideration, 1 million plastic bottles of water are being sold every minute. Oil refineries are an important part of plastics manufacturing as about 8 to 10 percent of US total oil spent on producing plastics. Even though Europe has showcased periods of stagnation and even decrease in plastic consumption, worldwide plastic consumption is increasing at a rapid rate, especially in Asia with the reasons behind the rise can also be explained with large population regions having a surge in middle-class. Alongside fuel and plastics, there are other various types of products of oil refineries that are utilized very commonly in our current daily life. Asphalt which is used to pave roads and making building materials, paraffin wax, aromatics and sulfur are other products that oil refineries can produce to widen their spectrum of products and provide oil refineries other means of maintaining their business alongside supplying various kinds of fuel.

For most of the time period that spanned this last century, oil was one of the most important assets in the world and oil companies were able to strengthen their position towards organizations, governments and the public through lobbying, negotiating and other expansionist strategies (McCarthy, 2019). Oil and gas lobbies have spent millions of dollars for election campaigns in the United States and they have been exposed in several scandals during the Bush administration such as arranging projects like distributing Iraqi oilfield contracts two years before the Iraqi war and Exxon being consulted by the US government prior to negotiations regarding the Kyoto Protocol. This type of corruption is not exclusive to the United States though. BP, Shell, Exxon, Total and Chevron, the five biggest oil companies, are stated to have spent at least 251 million euros for lobbying the European Union over policies related to the environmental impact of their operations between 2010 and 2019 (Laville, 2019). The reluctance showed by oil companies might be a deterrent in terms of the transformation that oil refineries will eventually have to go through in order to confirm with the environmental standards and emission goals.

With the turn of the millennium, protest activities and awareness for environmental issues have become prominent. Globalization, skepticism of the young generation towards big corporations and governments fueled by a new age of media spearheaded by social media successfully created the understanding of climate change and the environmental impact of many economic and industrial activities regularly done around the globe. Greta Thunberg became an inspirational figure for climate change activism in 2019 when she sailed to New York to attend 2019 United Nations Climate Action Summit in order to gain traction for a movement called Flygskam. Flygskam translates to flight shame or flight conscience and it supports the refusal to fly due to carbon emissions that are generated by the airline industry. Public awareness of wrongdoings of oil companies against the environment are expressed much widely nowadays and public perception of companies or events can influence the sales and consumption of a companies' products when they are exposed to the public of their environmental hazard. NGOs are a very important part of campaigning for more regulation and indictment on oil companies for emissions and environmental impact. Shareholder pressure has been very influential in terms of forcing oil companies to take action against their carbon emissions and environmental impact because unlike other protests and criticisms, that shareholders have authorization and direct information upon companies' activities. There is a transition in the energy market where climate change and sustainability largely dictate agendas and conversations between companies and stakeholders. With shareholder activism's impact on transparency, companies can no longer go unregulated and are ought to take responsibility for their actions such as environmental hazards and illegal write-downs.

The oil refining industry is unfortunately among many businesses that are impacted by COVID-19 negatively and this pandemic showcases one of the biggest challenges that the industry has ever faced according to 2020 Oil Market Report. Although COVID-19 does not simply create new and unforeseen problems, it reinforced refiners' problems and created more headaches for refineries in the short term. Even though this pandemic can be singled out as an example of a force majeure incident, it also presented the risks that the refining industry undertakes with their huge scale operations in the face of an unlikely scenario such as COVID-19 or natural disasters. International Energy Agency (IEA) projects the global utilization rate of refineries to fall to 72 percent, its lowest mark in 37 years and states that the demand landscape of refined products has been deeply deformed by the COVID-19 pandemic. As explored in this thesis several times, transportation fuel products correspond to a large portion for the profits that oil refineries make and the effect of COVID-19 on domestic and international travel has been a massive blow to the demand of oil refining products. Summertime is especially a period of time where the demand for refined products reach their highest level through the year due to the increased road, air and sea transportation for holidays and travels. In this pandemic period where even leaving the house is discouraged for health and safety reasons, oil refiners are struggling to sell their products since the demand for transportation fuel is maimed by COVID-19. Commuting to work or to neighborhoods is still inevitable in this period, so fuels that are for cars such as gasoline and diesel still see some kind of demand in the market. On the other hand, jet fuel is the product that was impacted the most as refineries in the Netherlands and Spain are at risk of being forced to cut off their jet fuel output as there is not enough demand (Kachkova & Ramsay, 2020). With business and profits hampered during the pandemic while also having the challenges of decarbonization and economic volatility, many refiners started to face shutdown risks due to the cumulation of the issues (Argus, 2020).

2.2 Methodology

2.2.1 Selection of Methods

Methodology of this thesis consists of Qualitative Content Analysis and scenario building. In the research area of oil refineries, there are some advantages and drawbacks in terms of resources and the possible utilization of those resources for analytical purposes. Through literature review and desk research, it is observed that there is a lack of qualitative approach to the oil refining industry compared to quantitative studies done on the efficiency and sustainability of refining processes. On the other hand, there are an abundant amount of comprehensive scenario simulations and forecasting models that shed a light on what to expect in the refining industry and related systems in the future. In order to achieve the goal of this thesis, which is illustrating a roadmap for relevancy and integration of oil refineries in future energy systems, maximizing the effectiveness of resources in hand is necessary. The method that provides the thesis with filtered and aligned challenges and developments in the oil industry is Qualitative Content Analysis. Qualitative Content Analysis is a method used in a mixed methods approach where a procedural rule is established to establish alignment and importance of factors with criteria that are determined to be important by the researcher (Mayring, 2014). With the use of QCA, the work of leaders in the research of the oil refining industry will be integrated and extended to establish parameters for evaluating the robustness of possible future developments in the refining industry in the face of critical challenges that hamper the progress of relevance of oil refineries in energy systems.

After consolidating the challenges and developments that have a sizeable impact on the future integration of oil refineries into energy systems, a method for envisioning a roadmap with respect to various scenarios and timelines presented in this research area is necessary. Scenario building and analysis is determined to be suitable in this specific area of research where there are an abundant number of simulated scenarios and forecasts that contain similar and same constraints of timelines, parameters and resources. Gathering, compiling and filtering of conducted scenarios and forecasts aids the analysis in the path of reaching an approximate consensus while including most of the prominent perspectives on this specific issue. The research boundaries that are defined and clarified by Qualitative Content Analysis helps scenario building and analysis outcomes to be more robust and the results of scenario building with respect to scenarios and forecasts conducted for the refining industry within these research boundaries make the deliverables sound and coherent in the context described above (Hsieh & Shannon, 2005).

2.2.2 Qualitative Content Analysis

Content analysis is defined as “a research method that provides a systematic and objective means to make valid inferences from verbal, visual or written data in order to describe and quantify specific phenomena” (Bengtsson, 2016). Content analysis provides researchers a flexible and pragmatic method for developing and extending human knowledge in a broad range of studies (Hsieh & Shannon, 2005). In this thesis, qualitative approach is taken as the basis of the research. With the conducted desk research, it is observed that the research area of oil refineries is saturated with quantitative approach towards increasing the efficiency and sustainability of the refining processes occurring in oil refineries. However, the goal of this thesis is to project a road map for the integration of oil refineries in future energy systems which include financial, environmental and social factors rather than solely technical. Thus, content analysis becomes a clear choice for this kind of qualitative research approach considering the abundance of challenges and developments that need to be investigated and scenarios and forecasts need to be analyzed. Content analysis has its root in both media and social research and this familiarity makes the method very suitable for this thesis.

In the research area of oil refining industry, a plethora of challenges the industry is facing and the developments to combat against these challenges can be encountered. However, it is important to align and filter these challenges and developments in order to have a more focused approach and in this case, the focus is to compile the challenges and developments that are driving or have the potential to drive the industry in preparation for integration into future energy systems. QCA is method is described as the systematic reduction of content, analyzed with special attention to the context in which it was created, to identify themes and extract meaningful interpretations of the data (Roller & Lavrakas, 2015). The notion of context may seem vague at first but QCA embraces all appropriate data sources such as text, video, audio, graphics and symbols. For a research approach that is going to delve into text, graphics and forecasts, QCA method satisfies the requirements of the approach taken in this thesis given the type of resources need to be analyzed to reach the research objective. With the aid of QCA, patterns and themes that are important to social reality are subjectively understood (Roller, 2019). In the case of this research, QCA will guide this thesis in reaching a consensus on the aligned challenges and developments and their impact on the uncertain role of the oil refining industry in future energy systems. The adoption of social studies and qualitative methods on energy research has been slow and one of the first major contributions to the field came by in 2018 as part of the journal “Special Issue on the Problems of Method in Climate and Energy Research” but the advantages that qualitative energy studies create in terms of decision-making and planning is apparent in the academic and industry peripheries (Müller-Hansen et al., 2020).

The goal of utilizing QCA in this thesis is to cleanse the research process in order to have refined input for the final analysis to be conducted. In the area of oil refining, there is a wide range of issues related to challenges, developments and future positioning of the industry and to reach the aim of preparing a roadmap for specifically relevancy and integration, QCA is going to be exercised to clarify the research space to achieve findings that can be inserted into the scenario analysis. With the application of QCA in Chapter 5 of this thesis, the prospective answer to the third research question of "*How does the developments in the oil refining industry respond to the current challenges with respect to scenarios, forecasts and trends for the future energy systems?*" will be given.

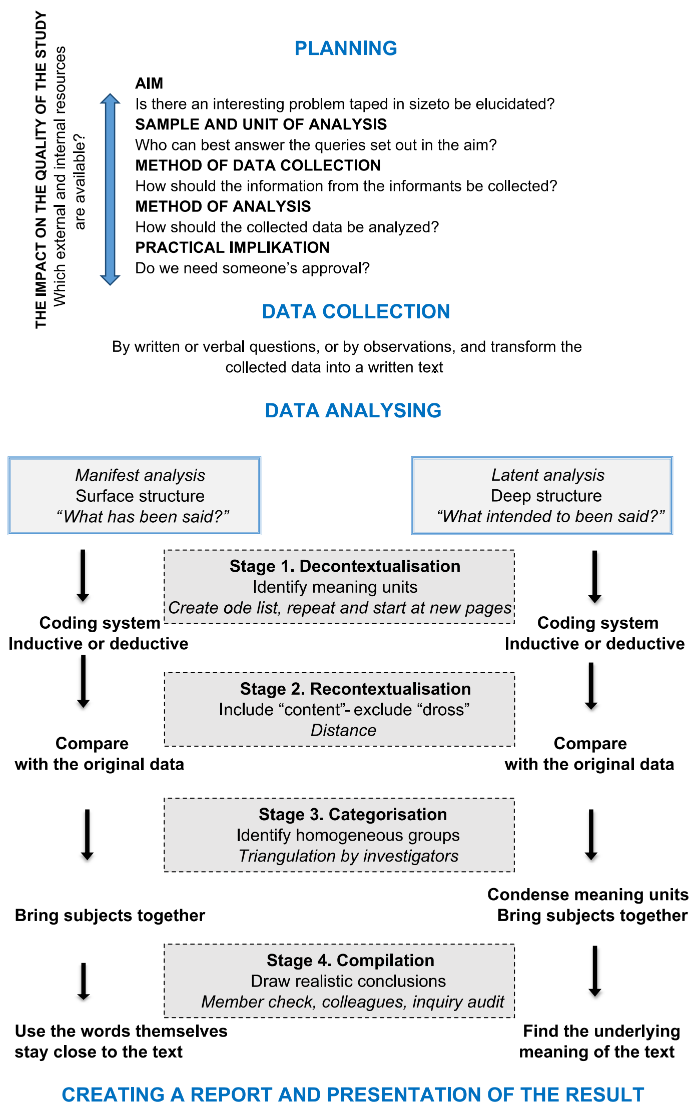

Figure 2.2: Qualitative Content Analysis procedure described by Bengtsson (2016)

Application of QCA is adopted from Bengtsson's (2016) approach and it consists of three stages: planning, data collection and data analysis. Data collection stage of QCA will be accomplished through desk research where there are an abundance of industry scenarios, forecasts, surveys and reports that contain valuable information and in synergy with the collected data to filter through meaningful insights. The planning stage of QCA is where the research objective, research design, data collection methods, research scope, sample size and quality criteria of results are discussed in the context of integration of oil refineries in future energy systems and is applied to this research as follows:

Step 1: *Concrete research question (relevance to praxis, eventually hypotheses, formulation and explication of preconceptions)*

Unlike quantitative studies, it is stated that formulation of a hypothesis is nearly impossible and it is formed eventually during the process of qualitative research. In this step of QCA, an eventual hypothesis will be generated with the investigation of desk research results and examination of scenarios. This hypothesis will guide the research done from gathering the necessary information regarding the challenges and developments of the oil refining industry into which of those challenges and their aligned developments more critically contribute to relevancy and integration of oil refineries in future energy systems.

Step 2: *Linking research question to theory (state of the art, theoretical approach, preconceptions for interpretations)*

In this research, QCA forms the link between desk research and scenario building by directing the critical information regarding the future of oil refineries into our criteria for evaluation in scenario analysis. This step may seem superficial for conducting research, especially in quantitative studies. However, the need for validation and verification is crucial in quantitative studies and to have a coherent line of argumentation not just during the analysis part, but also the research itself.

Step 3: *Definition of the research design (explorative, descriptive, correlational, causal, mixed)*

In this thesis, research design approach is designated as explorative as this research helps to formulate new categories out of existing material because the goal is to establish a roadmap for oil refineries out of obtained resources such as academic articles, news articles, company reports, scenarios and government initiatives. In qualitatively oriented design, the principle of providing a coherent and explicit chain of reasoning is key and setting the research design in principle extends on this principle of having a coherent research resulting in coherent analysis and sound outcomes.

Step 4: *Defining of the (even small) sample or material and the sampling strategy*

Research sample for this thesis will consist of environmental and technological challenges and developments in the oil refining industry. The reasoning for this sample size is that international environmental legislation, emission goals and technological advancements can set the benchmark criteria and become consistent boundaries for the analysis to be conducted in this thesis. In addition, technological and environmental aspects of the future of oil refineries are prevalent in literature and scenarios that have been conducted, thus enabling this research to comprehensively investigate these two factors. Digitalization and decarbonization being two trends that are dominating the energy systems agenda also solidify the case of selection of this sample size. Interventions and force majeure events (such as COVID-19) always carry risks for big-scale operations such as the refining industry but for the coherence and consistency of scenario analyses, the sample size of current challenges and developments are specified to include environmental and technological aspects of oil refineries.

Step 5: *Methods of data collection and analysis*

Data collection in this thesis is handled by literature review and desk research on various types of documents including academic articles, newspaper articles, scenarios, forecasts, company reports and government reports. The synergy of all these aforementioned documents from different perspectives allows the research and subsequent analysis to be comprehensive. Using the QCA, the collected data will be refined and compiled in a systematic way to be inputted into the scenario building analysis, which is the data analysis method that will generate the final deliverable of this thesis, a roadmap for integration and relevancy for oil refineries in future energy systems.

Step 6*: Processing of the study, presentation of results in respect to the research question*

The presentation of the outcomes of the analysis conducted in this research with respect to the research question is set to be in the form of a roadmap aligned with the criteria developed by QCA and admitted into scenario building analysis. In the context of the research question adopted by this thesis, the outcomes will be recommendations for sequential actions in a timeline that allows technological readiness and market trends. In this thesis, this final deliverable is defined as a roadmap for integration and relevancy of oil refineries in future energy systems.

Step 7: *Discussion in respect to quality criteria*

A critical discussion of the generated research results is crucial for all kinds of research but even more so for the qualitative research approach. The rule guided procedures of QCA strengthens its validity and therefore strengthens the inputs that are going to be analyzed with the scenario building method. At the evaluation chapter of content regarding current challenges and developments in the oil refining industry with respect to integration and relevance in future energy systems, a discussion about the results of QCA that is to become inputs in scenario building will be composed and argued for to strengthen the chain of reasoning of this research process.

Data analysis stage of Qualitative Content Analysis consists of four stages: decontextualization, recontextualization, categorization and compilation. Decontextualization refers to the researcher becoming familiarized with the text and obtaining the whole sense of the research area. Meaning units, which are constellations of sentences or paragraphs containing the aspects and insights related to answering the main research question, are generated. For this step in the

QCA, computer analysis can be an alternative way for speeding up decontextualization process but it is also noted that computers are soulless software and human creativity is of importance in these kind of social studies research approaches (Bengtsson, 2016). Second step in QCA is recontextualization, which corresponds to the cross-check that researcher needs to do to ensure all aspects of the content have been covered with respect to the research objective. It is very important for the research process that the researcher distance themselves from unimportant part of the text that does not contribute to the aim of the research and does not fall into the illusion of everything seeming important. This step of QCA is the distilling part of the content where the wide array of resources involved with the future of oil refineries are reduced to their essence and information regarding the integration of oil refining industry in future energy systems is prioritized. Before the categorization step begins, extended meaning units should be condensed into categorizable forms without losing their content. The division of categorization can be handled on the basis of the questions asked during data collection or on theoretical assumptions from the literature. In our research case, the former method of categorization on the basis of research questions is ideal as the research conducted also synergizes with this approach with separate chapters for each research question. The last step of data analysis process of QCA is the compilation stage where the categories are established and the writing up process begins to find the essence of the studied phenomena. With the finalization of the data analysis, realistic conclusions are drawn and for the purpose of this specific thesis, meaningful criteria will be derived from the challenges and developments in the oil refining industry to investigate the role, relevancy and integration of the industry in future energy systems. Those criteria will be inputted into scenario building analysis in Chapter 6 to evaluate the uncertain future of oil refineries with respect to scenarios, trends and forecasts.

QCA is utilized in this qualitative research as the link between desk research and scenario building. With the aid of QCA, research conducted into the current challenges and developments in the oil refining industry is compiled and refined in a way to become the starting point of scenario analysis for preparing a roadmap for relevancy and integration of oil refineries into future energy systems. The step-by-step approach taken in QCA solidifies the chain of reasoning for the research process and subsequently the research outcomes as qualitative research requires impeccable coherency for validity. By utilizing QCA in the research process, this thesis aims to discover the essence of this study and have integral inputs to facilitate further analyses in order to answer the main research question in an academically valid way for a qualitative research approach.

2.2.3 Scenario Building

As the central concept for a prospective analysis, a scenario is considered as a rich and detailed portrait of a plausible future world in which narrative evolution of conditions and variables are underpinned by trends and forecasts (Moniz, 2006). An early warning function or anticipation of outcomes can be important if accompanied with a set of ideas or values that enable the research to define a goal and to conceive of a desirable future (De Jouvenel, 2000). The term “scenario” implies that it is derived from the unfolding of trends, which are already present in the structure and orientations of a system rather than being a blind manifestation of unknown or unforeseeable events (Martelli, 2014). Scenario building as a method is described as a story or narrative based on the analysis and understanding of current trends and forecasts. With this method, the identification of possible pathways towards a vision of the future is realized through the development of a set of narratives. In the research area of oil refining industry and its uncertain future, there is an abundance of scenarios and projections that correspond to timelines that are dictated by international environmental legislation, emission goals and technological progress. In order to utilize the resources at hand at maximum effectiveness and reach the research objective of creating a roadmap for relevancy and integration for oil refineries in future energy systems, scenario building is employed to calibrate the pathway to answering the main research question. Although there are drawbacks to this method such as the improbability of excluding all external factors during the consideration and inevitably subjective approach of combining all elements, scenario building equips this research with raising awareness on possible future situations and improving the strategy development process, both of which greatly contribute to the envisioned final deliverable of this thesis, the roadmap for relevancy and integration of oil refineries in future energy systems.

In order to establish a step-wise sequence to scenario building, the definition of the scenario space and description of key measures are necessary. It is suggested to use a variation of Qualitative Content Analysis due to QCA's competence in laying a key emphasis on the interaction or combination of variables taken into account in the research and this thesis satisfies this recommendation by utilizing QCA and scenario building subsequently to achieve an analytical chain of reasoning. Preserving the synergy and alignment of research is of utmost importance in qualitative approach and the presence of QCA enables symmetric causation in the analysis conducted in this research, thus enhancing the final deliverable of this thesis which is a roadmap for integration and relevancy of oil refineries into future energy systems. It is important to remember that results of scenario building do not and should not dictate what decision-makers should do, scenario building sheds the light on the path to take while combining major trends, challenges and developments surrounding a specific issue (De Jouvenel, 2000). With the rise of social studies interactions with energy studies, scenario building became more prominent in the academic research space and several ways of scenario building methods have been generated to serve the purpose of this approach. Typology of scenario studies is divided into three categories and six sub-categories in total. The distinction between predictive, explorative and normative scenario studies is determined by the questioning for the end results for each respective category. The question of "What will happen?" corresponds to predictive scenario studies, the question of "What can happen?" corresponds to explorative scenario studies and the question of "How can a specific target be reached" corresponds to normative scenario studies, which is the approach taken in this research per the main research question. In this category, the sub categories are defined as preserving and transforming scenario studies. In transforming normative scenarios, the starting level is a highly prioritized target but this target does not seem reachable considering the developments surrounding this level (Börjeson et al., 2006). In this thesis, normative transforming scenario building is utilized to showcase a roadmap to lead to the target of integration of oil refineries in the decarbonized and digitalized future energy systems.

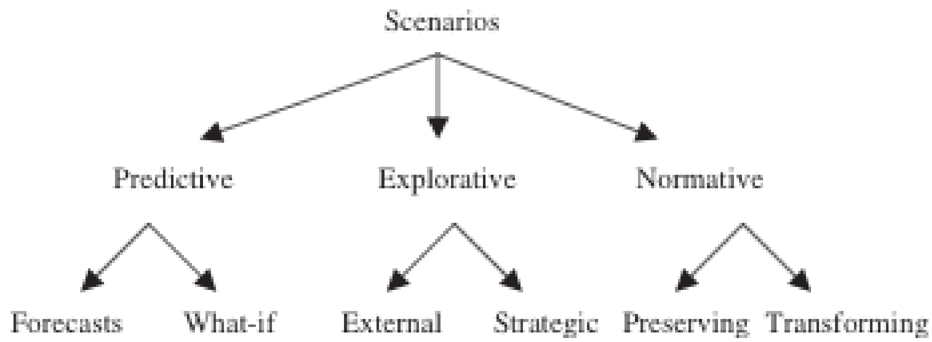

Figure 2.3: Scenario typology from Börjeson et al. (2006)

With the application of scenario building and generating the deliverable of a roadmap for relevancy and integration of oil refineries in future energy systems in Chapter 6 of this thesis, the answer to the fourth research question of "*What steps should the oil refining industry take in the short and mid-term to have a sustainable role in the decarbonized and digitalized future energy systems?"* will be given. Per all qualitative studies, a systematic and step-by-step approach is crucial for the integrity of the research process but it is especially important in a scenario setting of energy. Application of scenario building steps are explained as follows:

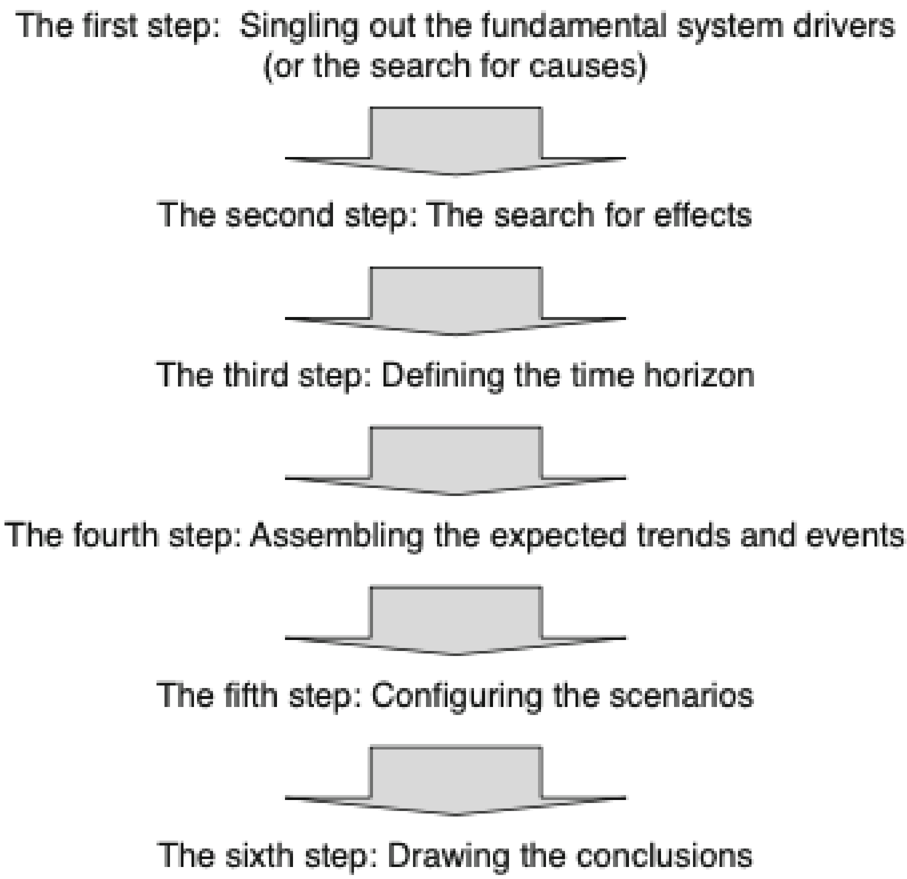

Figure 2.4: Scenario building procedure from Martelli (2014)

The scenario building procedure starts with singling out fundamental system drivers, in other words, causes of current issues and discussions surrounding the research subject. In this research process, Qualitative Content Analysis will provide the fundamental system drivers by refining and compiling the literature so that we can single out causes that are critical in terms of integration and relevancy of oil refineries in future energy systems. The second step of scenario building procedure is the search for effects in which the prospective results of the drivers in the first step is investigated. Then, the time horizon is defined with respect to the timelines of drivers and developments. The research conducted in this thesis confirms this step quite well due to the research boundaries defined by QCA which are declared in consideration of timelines that global actors in the energy and refining industry determined for emissions and environmental legislation. The fourth step of scenario building procedure is assembling the expected trends and events. The abundance of scenarios with respect to the oil refining industry and other interrelated actors in energy systems is previously mentioned in this thesis. This situation alongside the synergy of these scenarios in terms of timeline targets and environmental goals strengthens the alignment of this procedure as timeline and content are the two dimensions that are considered during the assembly process. Configuring the scenarios is at the penultimate step of scenario building procedure and with this step, scenarios are differentiated between each other with labels and assumptions. To conclude the application of scenario building, conclusions are drawn from the material amassed by the aforementioned analysis. With this step, interpretations of all scenarios and resources in this research will be delivered with respect to the scenario building procedure and preceding analyses and drive the conclusion of this thesis in which the answer to the main research question will be evaluated with respect to all the research and analyses conducted prior.

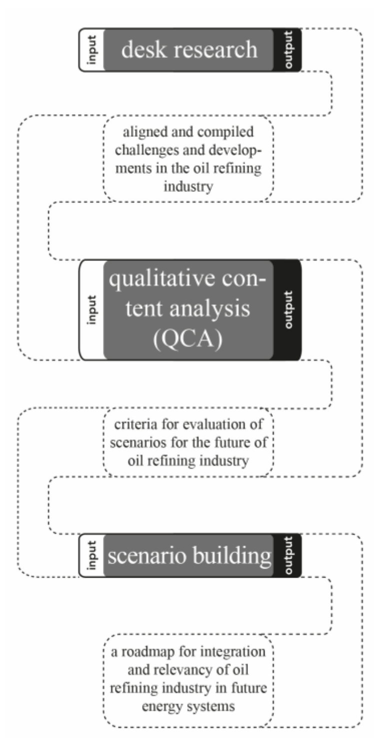

Figure 2.5: Methodological framework

2.2.3 Data Collection Methods and Issues

Data collection method that is mainly utilized throughout this research is desk research upon various types of documents such as academic articles, news articles, company reports, scenarios and other various types of grey literature sourced from governments, NGOs and other organizations. Maximizing the resources that are collected from research is important for tackling the research questions of that research as selection of data collection and analysis methods influence the integrity and validity of the outcomes of research. For the case of the oil refining industry, utilization of desk research creates new opportunities for research and allows the augmentation of social sciences and energy studies to result in a product that addresses an issue in a large-scale complex system. Desk research provides convenient communication and access to data that has been collected and created by researchers. The desk research conducted in this research targeted current environmental and technological challenges in the oil refining industry and their corresponding developments that are underway or being planned by the industry. These challenges and developments are slated to be further analyzed with QCA for alignment and synergy purposes. The research process of desk research has been done mostly on online databases for scientific articles and issues but grey literature from newspapers, third party organizations, governments and NGOs are also taken into considerations to achieve a holistic perspective on the issue of integration of oil refineries in future energy systems. Also collected with the desk research, scenarios and forecasts from agencies and commissions such as International Energy Agency, FuelsEurope and Clingandael Institute.

On the other hand, there are some disadvantages of using desk research as a data collection method. Firstly, doing desk research means gathering data collected by other researchers in the field which means there is a question of the reliability of data. This disadvantage is taken care of by using data and resources retrieved from reliable sources. Data collected from verifiable sources such as governments, oil companies, established agencies and organizations equip the research with the validity and reliability needed in terms of data collection. In addition, considering the institutions mentioned and their stances on the issue of the future of oil refineries, it is beneficial to gather a comprehensive perspective during the research. Another drawback of desk research is the effort and time it consumes to gather and utilize enough data for scientific research. However, with a systematic approach and a clear plan to analyze the data, this issue is solved in the thesis as well. Lastly, since the data used in the research is not collected by the researcher itself, it creates the possibility of discrepancy and misalignment as the intended variables might not match with the variables from the data collected (Van Thiel, 2014). This problem is internalized and solved in this thesis with Qualitative Content Analysis linking the desk research to scenario building by filtering the required variables need for the analyses from the desk research. In this thesis, social studies and energy studies are augmented and to ensure academic validity, this systematic approach is taken with respect to the resources that can be collected on the research subject and the required analysis to answer the main research question of the thesis.

2.2.4 Research Design Quality Criteria

The research approach and design applied in this thesis is evaluated with respect to three criteria in order to ensure scientific research integrity and competence. These three criteria are objectivity, reliability and validity (Mayring, 2014). Objectivity describes the independence of research findings from the researcher. This thesis accomplishes these criteria by using resources from all available perspectives in the oil refining research space during Qualitative Content Analysis to feed into scenario building in which the final deliverable of this research will be realized. Reliability refers to the stability and precision of the measurement plus the consistency of the measuring conditions. In order to achieve reliability in this research, research boundaries and focus is determined to align and sync with the resources at hand and methods to be utilized. With the approach of filtering and compiling the findings of desk research through QCA and feed the outcomes of QCA into scenario building analysis as defined inputs, this research ensures consistency of items and variables throughout its process. Validity relates to the question of "whether what is measured is what ought to be measured". In order to satisfy the validity criteria, the findings are inspected in terms of plausibility and appropriateness with respect to the context of the thesis. The sequential research process defined in this thesis ensures all scientific methods to be linked to each other in a systematic approach for the content and variables, thus reinforcing the validity that is vital to ensure in qualitative studies.

2.2.5 Ethical Considerations

There are three ethical considerations that are inherent in the qualitative research approach and they are autonomy, beneficence and justice (Orb et al., 2001). Autonomy refers to the right to be informed about the study, the right to participate and the right the withdraw from the study at will. In qualitative research, this principle is exerted by informed consent. However, considering the methodological approach this research takes with QCA and scenario building, this principle is inapplicable as the only participant in this research is the researcher. Second ethical consideration present in qualitative research approach is beneficence. Beneficence is described as striving to contribute to the existing knowledge in a field without doing harm (Van Thiel, 2014). This research on the future of oil refineries in future energy systems is an outlier in terms of the research subjects and the utilization of social studies methods in this specific research area, thus contributing to the knowledge gap designated in the field. Last ethical consideration is justice, which refers to equal share and fairness. This thesis aims to gather and compile developments and challenges in the oil refining industry from all available perspectives if the resources belonging to that perspective are verifiable. A common practical mistake regarding this ethical consideration happens when the researcher tries to implement the principle of justice to their research. However, this principle is fully realized when the researcher does not intervene with the justice aspect of the research and concentrates on hearing all the voices on that specific issue, which is what this thesis aims to achieve in order to present a valid roadmap for integration of oil refineries in future energy systems.

3. Current Challenges in the Oil Refining Industry

This chapter answers the first research question of "*What are the current challenges that oil refineries face in the context of international environmental legislation, emission goals and technological advancements?"*. Section 3.1 describes the technological challenges the oil refining industry is facing against digitalization and the reconstruction of transportation fuels. Section 3.2 explains the environmental challenges the oil refining industry is facing against decarbonization and global environmental goals. Section 3.3 reflects upon the findings of this chapter and synthesizes these technological and environmental challenges the oil refining industry is up against.

3.1 Technological Challenges

Oil refineries date back to 1853 in the United States, but up until the 1950s, coal reigned supreme as the world's foremost fuel for industry. After the emergence of oil in the transportation and energy sectors, oil is still considered one of the most valuable assets in the world. Oil refineries are large-scale industrial complexes that have been an integral part of energy and transportation. With the increasing rate of emerging technologies and the application of these technologies in all industries and facets of life, modernization of assets past becomes harder but even more so for large-scale complexes and operations such as oil refineries. These complexes are expensive to build and operate with various costs such as maintenance, personnel, purchase of land and utilities attached so, considering the economies of refineries, many refiners do not elect to overhaul their refineries up to the technological standards of the day and age. As the golden era of oil as an asset and ingredient for energy, heating and transportation comes to a close with global agendas of government and companies aligning on a green future with global environmental legislation and emission goals, oil refineries face technological challenges to stay relevant and integrated into future energy systems.

Alongside the oil refining industry, a disruptive transformation is also set to impact the transportation sector. Back in 1900, 38 percent of the cars on the road were electric cars while gasoline cars took up 22 percent and the rest of the cars being run on steam. This all changed with the emergence of Ford Model T, which was a car with a combustion engine and combustion engines that dominated the next century of automotive vehicles (Banach, 2018). With the turn of the millennium, the automotive industry started to feel a shift back to electric vehicles due to the global and collective realization of the damages that fossil fuels and products that use fossil fuels do to the environment. Electric vehicles are seen as the next breakthrough in transportation as environmental legislation and carbon emission concerns throughout the world inadvertently make the automotive industry lean towards this technological advancement. This trend caused automotive makers to alter their business model in order to adapt (Bade, 2019). By the end of 2019, electric passenger cars reached a 2.5% market share with 7.5 million units sold worldwide (IEA, 2020). Volkswagen, one of the biggest car manufacturing companies that also own Porsche, Bugatti and Lamborghini, is preparing to commit 30 billion dollars over the next five years on electric vehicles with the hopes of creating a hybrid version of every vehicle on its lineup. Of course, Volkswagen is not alone in this rush as companies try to invest in battery technologies, acquire smaller companies that focus on electric cars and form partnerships with other car manufacturer giants. The efforts of automotive companies are also reinforced by governments with their environmental goals and legislations. Up to this point, 17 countries have announced their plans to replace combustion engine vehicles with zero-emission vehicles with France even putting this decision into law with the target date of 2040 (BBC, 2017). Considering the emergence of new technologies, with more R&D and practical applications of electric vehicles, more advancements in its technology and lower costs due to adaption and serialization of the technology are also expected.

However, this challenge does not seem to concern oil refineries, at least not at the moment. According to a survey commissioned to inquire international downstream oil professionals on the upcoming effect of electric vehicles on the refining industry, 61.1% of them stated that electric vehicles' impact on the downstream industry is exaggerated in the short term (Sanmugam, 2018). When asked about what kind of impact electric vehicles will have on the refining market in the same survey, 52.8 percent of the respondents stated that they don't anticipate much impact as the demand for refining products in developing countries is strong (Sanmugam, 2018). Downstream industry professionals are more concerned with the International Maritime Organization's (IMO) regulations regarding cutting sulfur oxide in bunker oil that is used in ships. Regulations regarding sulfur oxide levels first came into effect in 2005 and it has been progressively tightening. Then a massive change occurred with the regulations on 1 January 2020 as sulfur oxide levels in bunker oil, which was previously capped at 3.50% mass by mass, is restricted to 0.50% mass by mass (IMO, 2020). Feedstock and fuel-related challenges of oil refineries will be elaborated further in Section 3.2 with environmental challenges as the oil refineries look for ways to make their feedstock and fuel greener in order to adapt to the new energy agenda.

A factor that can determine and secure the position of oil refining industry in future energy systems is digitalization and technological development of physical elements of oil refineries, which are commonly categorized under the umbrella term of Industry 4.0. Billed as the fourth industrial revolution, Industry 4.0 refers to the transformation of operations in the industry such as cloud computing, Internet of Things (IoT), big data, system simulation and many more techniques and methods being utilized in traditional industries such as the oil refining industry (Malins, 2020). Digitalization is defined as the use of digital technologies to transform business operations and provide new value or revenue-producing opportunities. There are three key opportunities that digitalization can create for industries aiming to transform their business operations: 1) automating dangerous, difficult and repetitive tasks, 2) storing, visualizing and analyzing data for smarter decisions, 3) integrating operations with information technologies through connected devices for greater efficiency (Withers, 2020). For the oil refining industry, digitalization can bring various benefits to day-to-day operations and cost reductions (Marval, 2018). The improvements that digitalization provides the oil refining industry in terms of efficiency and productivity is immense. One of those improvements is the Industrial Internet of Things, which is described as system of interrelated computing devices, mechanical and digital machines, objects, or people that are provided with unique identifiers and the ability to transfer data over a network without human-to-human or human-to-computer interaction (Evdokimoff, 2020). Industrial Internet of Things With the machine generated data analysis, oil refineries will have the opportunity to smarter decision-making, insights, design and execution. The emergence of the Industrial Internet of Things (IIoT) alongside the decreasing cost of state-of-the-art sensors vastly improves the data collecting and monitoring operations in oil refineries (DTI, 2017). Another advantage of digitalization in the oil refining industry is the reduction of direct human participation and thus minimizing human error and health and safety risks attained to workers in oil refineries. Mobile devices integrated to oil refinery operations also play an important part in digitalized operations by providing real-time monitoring and communication of data. In order to prevent the threat of becoming obsolete, the oil refining industry will have to adapt to the norms of doing business in the age of Industry 4.0 (DTI, 2017). In 2019, Deloitte conducted a digital maturity index for sectors and oil & gas industry ranked last among all the sectors considered in the research whose results are visible in Figure 3.1.

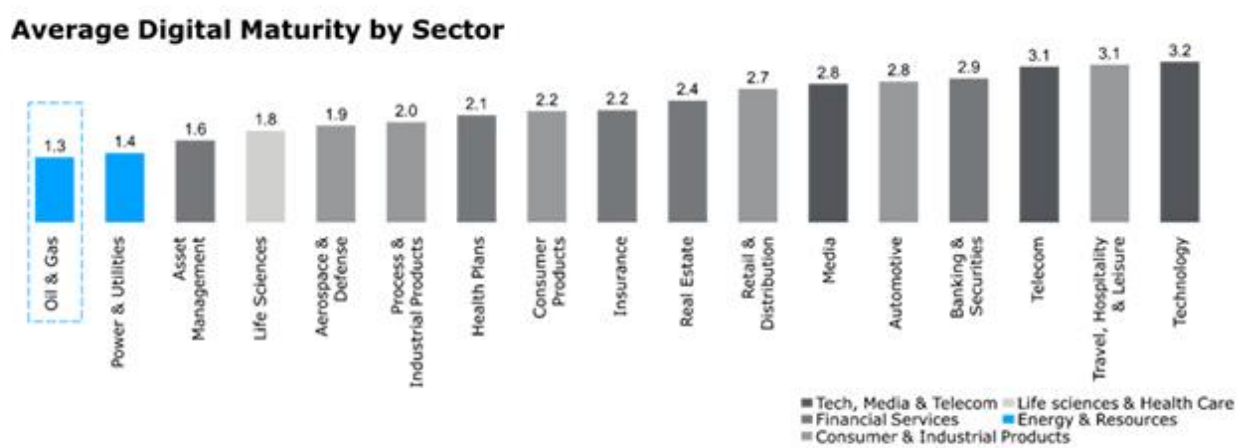

Figure 3.1: Average digital maturity by sector (Deloitte, 2019)

Most of the oil refineries in the US are between 50 and 120 years old, with the average age around 40 years old. Older refineries are prominent all around the world due to high investment, operation and maintenance costs discouraging refiners to take the chance to overhaul their refineries (Eberhart, 2014). These refineries of the past lack the efficiency of newer refineries with hardware and software updates and their operations have a bigger negative impact on the environment compared to their modern successors (Carpenter & Wagner, 2019). The lack of connectivity also put these refineries under contention of closure as revamping the refineries completely to fit the current standards of industry practices is costly. Recently, BP decided to overhaul its facility in Whiting, Indiana for 4 billion dollars which is close to the approximations of building a new refinery at around 5 to 7 billion dollars. The diagnosis for this situation is that the industry probably overbuilt over the last decades, overestimating the golden age of oil, and now these old refineries in the US and Europe can’t compete with their counterparts in developing countries with emerging economies such as China and the Middle East (McKinsey, 2019). According to the Refining Fitness Check made by European Union’s Joint Research Centre, it is observed that operating costs of EU refineries are relatively higher than those in the other regions of the world and experienced a relative decrease in net margins compared to main competitor regions during the time period of 2000-2012. The presence of significantly underperforming refineries in the EU and the stabilization of margin for even adequately performing refineries indicates the lack of upgrades and overhauls in these refineries can’t prevent the losses in this highly expensive sector whereas significant growth and profit is observed in oil refining’s competitor regions.

3.2 Environmental Challenges

The biggest challenge for refineries in our day and age to adapt to the global and public agenda of becoming environmentally conscious, preventing pollution and limiting carbon emissions as much as possible. The oil industry has always been problematic and apathetic towards environmental issues that itself or its various operations created. Gulf War oil spills, Deepwater Horizon and Lakeview Gusher accidents are more prominently known incidents that are commonly known among the public as these events were displayed via the media or academic articles. Hydraulic fracking is also a process related to oil drilling activities that result in a lot of water wasted and chemicals injected into this wastewater to damage the environment. However, oil spills can be considered just the tip of the iceberg when concerned about the environmental impact of the oil industry. The processes of extracting, refining or transporting oil presents several environmental risks as during these processes, substantial amounts of hazardous materials and waste are generated (EUROPIA, 2012). Due to oil-related activities, toxic materials, byproducts and waste get in touch with the surroundings, creating air, soil and water pollution. Alongside pollution, oil industry activities cause acid rains that cause harm to all ecosystems, ocean acidifications that disrupt marine life and most importantly, climate change that impacts rainfall patterns, the retreat of glaciers and average sea levels (Ramanathan, 2009).

The oil refining industry of course is not an outlier case in terms of oil-related activities’ impact on the environment. Oil refineries emit many chemicals and gases that are toxic and hazardous for human and wildlife health. These chemicals and gases vary as oil refineries have a variety of products that differ in terms of process, equipment and materials. Sulfur dioxide, carbon monoxide, hydrogen fluoride, methane and nitrogen oxide are some of the toxic gases and chemicals that are released from oil refinery operations and harmful to human beings and the environment surrounding the facilities. Aside from the oil refining processes, the products that refineries produce such as fuels, sulfur and plastics are also posing an immense threat against the environment and sustainability of our civilization. Transportation is the sector that is responsible for the largest share of carbon emissions with 28 percent in the US and the second largest worldwide with 16.2 percent, only behind energy use in the industry with 24.2 percent (Richie & Roser, 2020). Among the transportation sector, emissions from the burning of fuel from all types of road transport take the bulk of the percent with 11.9 percent (Richie & Roser, 2020). Considering these statistics and the increasing buying power and middle-class population of developing countries where more cars are projected to be bought, it is important to take action against this status quo. As mentioned above, electric vehicles are considered to be a long-term solution for the emissions generated by road transport. However, the process of electric vehicles taking a respectable market share in the roads is not imminent and the effects of climate change and pollution are very much visible in many densely populated cities around the world (Concawe, 2018). The shift from conventional fuels to sustainable means of power generation also creates the uncertainty of profit margins and survivability of oil refineries for financial reasons because of the projected decrease in demand for traditional transportation fuels such as gasoline and diesel (IEA, 2019).

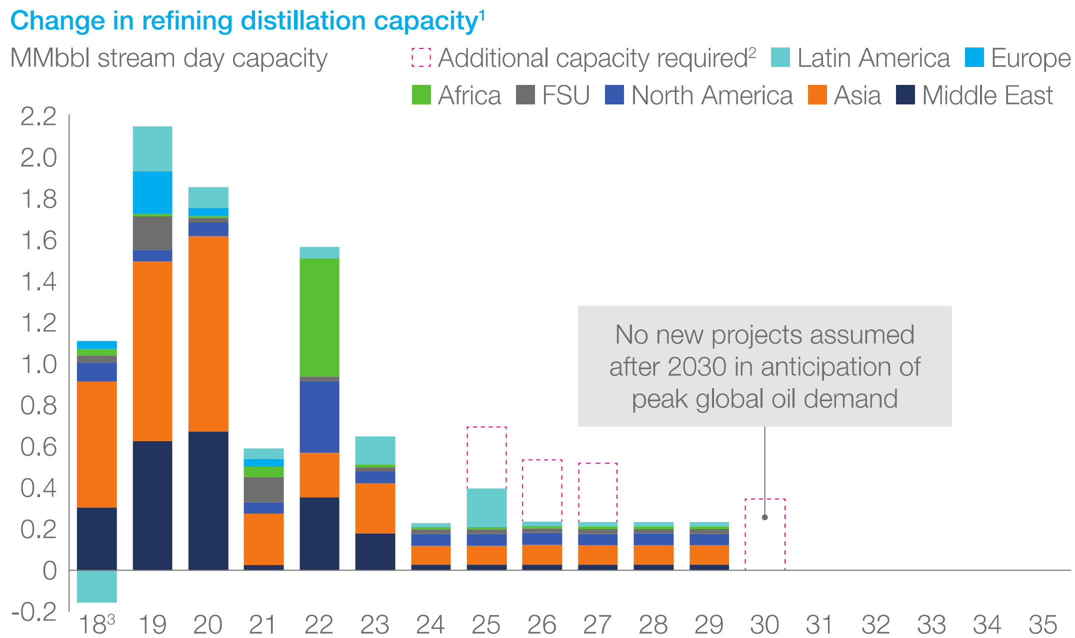

Figure 3.2: Global change in refining distillation capacity (McKinsey,2019)

Plastics are viewed as the next driver of demand in oil refining products since the shift in transportation fuel started to impact the profit margins of refineries (IEA, 2018). With its negative impact on the environment so evident, many authorities have placed limitations and bans on single-use plastics, lightweight plastic bags and plastic packaging. However, plastics are still very cheap to produce and convenient to use in almost every aspect of business and life due to plastics performing very well in durability and functionality compared to their cost of production. Almost 360 million tons of plastics are produced and discarded yearly throughout the globe, 8 million tons of those plastics escape from coastal cities straight into the ocean, causing the world's plastic pollution crisis (Parker, 2020). From birds to fish to endangered animals, nearly 700 species have been impacted by plastics and millions of animals are killed by causes related to plastics like entanglement and starvation (Parker, 2020). Oil refineries that are old or not revamped generally does not have the capabilities or integration with a petrochemical plant to produce plastics but still plastics take up nearly 9 percent of the oil demand (BP, 2020). This slightly optimistic statement doesn't hold much value though as plastics are the largest component of growth of demand in oil products. Already accounting for half the amount of plastic produced globally, Asia will facilitate more than half of the refining capacity that comes on stream from 2019 to 2027 and 70 to 80 percent of this prospective capacity will be plastics-focused (JWN Energy, 2020). This position of oil refining industry where it is heavily prioritizing plastics and other petrochemical products showcases that in reality, the industry's projections for the future show that society will fail to find any solutions to effectively reduce, substitute or recycle plastics.

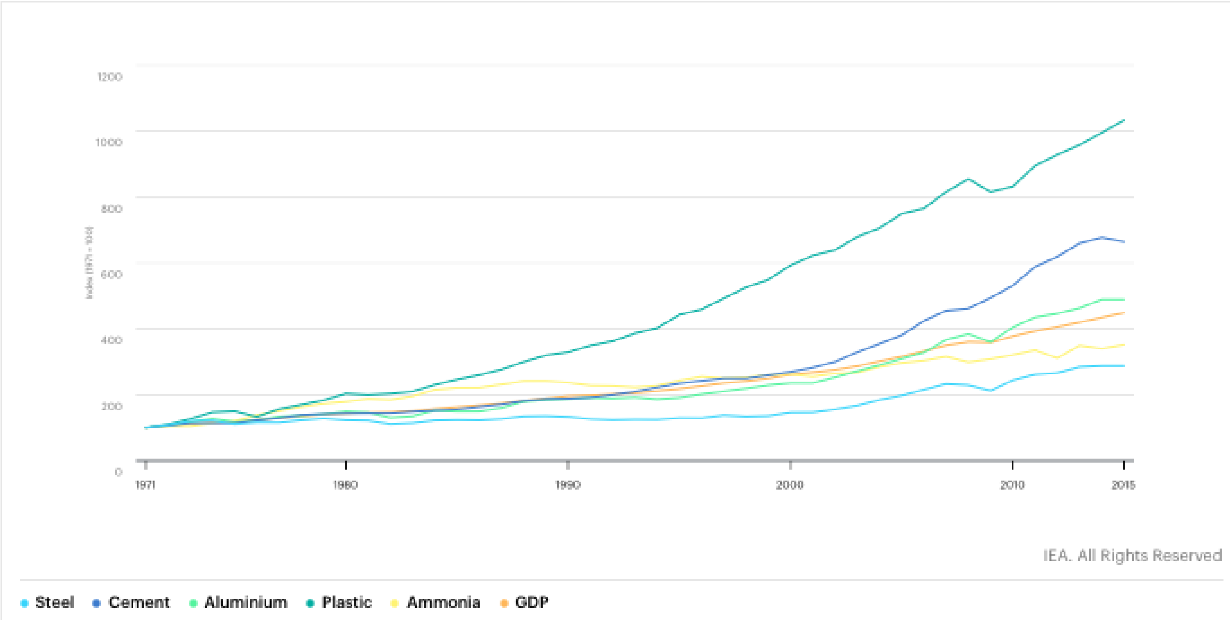

Figure 3.3: Production growth of selected bulk materials and GDP, 1971 – 2015 (IEA, 2018)

A feedstock is any hydrocarbon input to a processing unit and is generally in the form of crude oil or any intermediate refining steam. In order for oil refineries to create cleaner products, greener means of feedstock is vital. The process of transforming crude oil to various products generates environmental hazards due to toxins that are released to the atmosphere. Other byproducts of the refining processes occurring in the refineries are industrial discharge and waste (IPIECA, 2014). Enforcement of International Maritime Organization's 2020 sulfur cap makes it a necessity for refineries to use various desulphurization methods to satisfy the requirements. Road and air transportation fuels are also going through a similar but even more disruptive situation with the content of the fuels. With the increasing need for greener fuels produced by oil refineries, the feedstock that can be utilized to produce green fuels needs to be developed and implemented to the oil refining industry. Having a wide range of products have always been favorable for oil refineries for profit margin concerns and capitalizing on the decarbonization wave in the energy sector may be possible with sustainable feedstock and necessary facilities to be able to process this new type of feedstock into green fuels (The Oxford Institute of Energy Studies, 2020).

3.3 Chapter Synthesis

This chapter provides the technological and environmental challenges that the oil refining industry is currently facing and considering the advancements in the transportation sector, global environmental legislation and demand for refined products, these challenges have to be tackled in a comprehensive manner in order to enable the integration of oil refineries into future energy systems. With the aid of desk research, technological and environmental challenges that hamper the pathway to the relevancy and integration of oil refineries into future energy systems were inspected. Departure from conventional fuels in transportation, emergence of electric vehicles, digitalization and technical limitations of not up to standard refineries were determined to be the technological challenges that oil refining industry is currently facing. As the environmental challenges that the oil refineries are currently up against, environmental impact of oil refining operations, feedstock of refineries, transportation fuel products and plastics were expressed and elaborated on. The oil refining industry is in a transition period as the golden age of oil draws nearer, the necessity of oil-related products in transportation and energy comes close to diminishing. Greener and more sustainable alternatives of status quo oil refining products and operations are emerging while negative implications of the oil refining industry such as pollution and promotion of fossil fuel usage are put under the spotlight. In order to move forward in compliance with the trends of decarbonization and digitalization of future energy systems without facing risks of closure due to decreasing profit margins from their products, oil refineries have to prepare technological and environmental developments to combat against the corresponding challenges and to relevant in future energy systems. Following chapter investigates the current developments that the oil refining industry is formulating and planning so that oil refineries can take upon an integrated role in future energy systems.

4. Current Developments in the Oil Refining Industry

This chapter answers the second research question of “*What are the developments that oil refining industry is currently undertaking and planning to undertake in the near future to combat the challenges of international environmental legislation, emission goals and technological advancements?”.* Section 4.1 describes the technological developments in the oil refining industry that are happening or being planned to happen with the emergence of decarbonized and digitalized future energy systems. Section 4.2 illustrates the environmental developments in the oil refining industry with respect to global environmental legislation and carbon emission considerations. Section 4.3 synthesis the chapter’s findings and argues for how these findings can be utilized in the analysis chapters further in the thesis.

4.1 Technological Developments

Oil refineries are facing an uncertain future in the energy systems as demand for traditional refining products such as transportation fuels is set to plateau and decline starting from 2035 and digitalization in business operations is set to become integral for efficiency and decision-making. There is an urgent need for adaptations to be held in oil refineries in order to have an integrated and relevant role in future energy systems without endangering their business by having a portfolio of products that are not in demand or are not satisfactory to today’s environmental standards of low carbon emissions and carbon footprints. The term coined by the oil refining industry and the academics that are on the periphery of the industry for the ideal concept of a refinery is “refinery of the future” (Speight, 2011). Refinery of the future is based on the philosophy of designing refineries to facilitate an evolution of product mix and deliver sustainable competitiveness in terms of the overall cash cost of production, capital efficiency, responsiveness to regulation and competition and the agility to manage molecules for the greatest profitability (Speight, 2011). Changing demand patterns, complex initiatives and exponentially increasing data capabilities will drive refineries to leverage Industrial Internet of Things (IIoT) technologies, machine learning and other techniques to create new insights for various job functions in the refineries, enhance the decision-making process and reduce employee and business risks. With the concept of the refinery of the future, better processed analytics, increased up-time, uninterrupted productivity, satisfied customer and safer workers would all be accomplished. In one of its first examples, Texas-based Texmark Chemicals undertook the challenge of transforming one of its refineries, starting with the question of “How can an 80 years old refinery can stay in business for 50 more years?”, by completely incentivizing Industrial Internet of Things technologies and the end result is new business lines and income sources such as dicyclopentadiene, 50 percent reduction in planned maintenance costs and avoidance of a 200 percent increase in insurance deductions. However, this transformation is an arduous process as unique infrastructure for connectivity, digitizing pipes, pumps, processes and utilities and simultaneous deployment of new technologies are necessary without disrupting 24/7 plant operation (Texmark Chemicals and HBE, 2020). If the oil refining industry aims to prepare their assets for the new energy order, process modification will be a primary thrust of development in refinery layouts. Modified processes should be designed to facilitate green feedstock in order to get cleaner fuels and other products or to integrate petrochemical plants to expand the portfolio of products that refineries have and prepare for the plateau of demand for conventional transportation fuels.

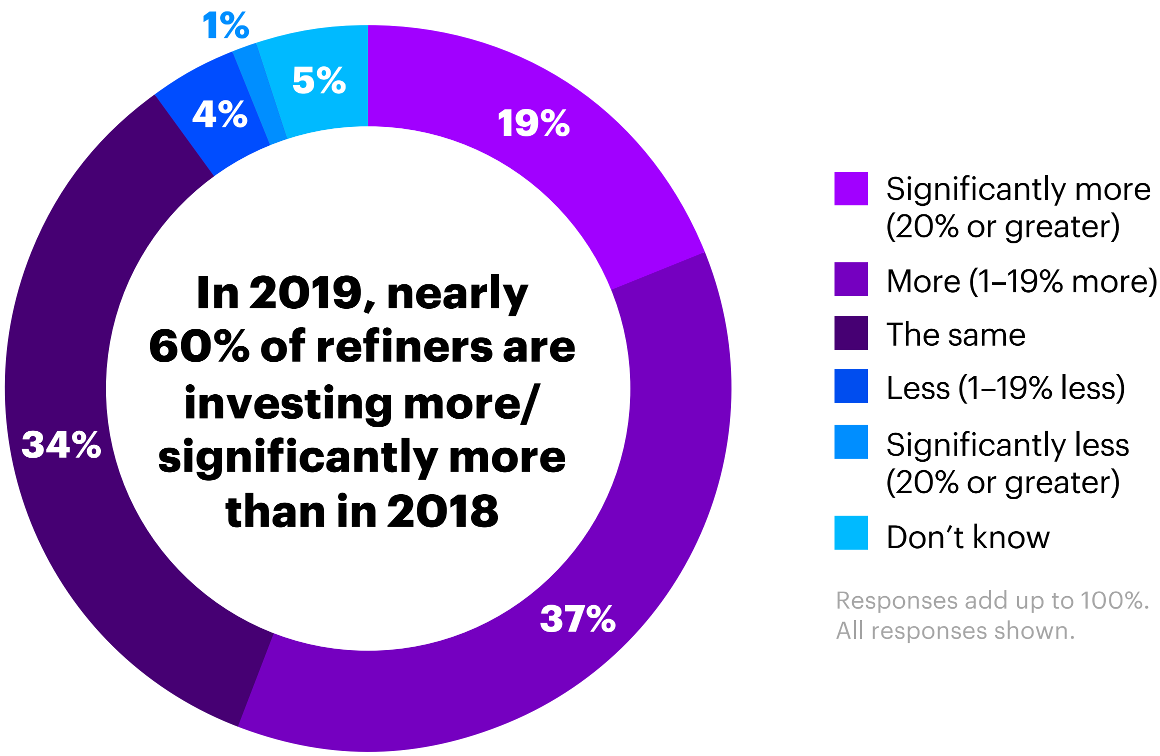

Figure 4.1: Refineries on how much they are spending on digital technologies (Accenture,2019)

With financial concerns compounding the problems the oil refining industry is facing, petrochemical products are indicated to become the next driver of demand for refinery products (Concawe, 2019). The relationship between the oil refining and petrochemical industries were once at an arm's length where refiners focused on producing various types of fuels and materials that made the refining cut, called naphtha, would be sold to operators of steam crackers to be converted into petrochemicals (Cayuela Valencia, 2013). Since petrochemicals were determined to be the salvation of the oil refining industry in terms of profit margins for the near future, it is expressed by industry leaders and economics that there would not be a clear demarcation of what is an oil refining plant and what is a petrochemical plant as the wave of mostly integrated complexes is already underway in China and India (Cayuela Valencia, 2013). In the past, refineries that were converting 15 to 25 percent of their products to petrochemicals were considered highly integrated. As a point of measure, the largest naphtha base ethylene crackers can only make 2 million tons of products per year whereas a petrochemical plant integrated refinery with 400,000 bbl per day can produce up to 10 million tons of products by cracking out only 50 percent of petrochemical products, which is not a technological limit at this point in time. When companies start to reconfigure their entire refinery layout with the sole focus on producing petrochemicals, the production is elevated to a refinery scale rather than a petrochemical plant, resulting in 5 to 10 times higher yields. The pure profit margin wise potential of petrochemical products compared to the projected decrease in demand for conventional refining products such as transportation fuels causes concern for scales and operations of oil refineries. Crude-to-chemicals model of integrated oil refineries has benefits on both sides of the coin as this model provides the production of the most profitable product while not requiring the massive scale and facilities of traditional refineries. Considering the estimate of 3 billion people graduating into the middle class in countries such as China, India and Indonesia by 2050, the surge in demand for petrochemical and plastics related products such as automobiles, packaging, synthetic fibers and pharmaceuticals is expected and the investors in oil refining are trying to capitalize on this market inefficiency.

Technologic advancements in other areas related to energy have been developed and utilized at various scales and some of these advancements provide better efficiency and lower environmental harm (Kanellakis et al., 2013). With the increasingly integrated structure of modern refineries, oil refining industry has the potential to take advantage of these technologies to facilitate an all-around role in energy systems. Carbon capture and storage (CCS) is the process of removing or reducing the carbon dioxide content of streams normally released to the atmosphere and transporting that captured carbon dioxide to a location for permanent storage (Ferguson & Stockle, 2012). Oil refineries would benefit from CCS units since CCS has the potential of decreasing refineries' carbon emission greatly but CCS integration requires many different energy system elements such as CO_2 compression and heat facilities, utilities and advanced interconnection that already in place oil refineries simply don't have (Maas, 2011). Furthermore, retrofitting old refineries for integration and advanced technologies purposes is proven to be a not viable investment, except for highly complex refineries with large capacities in which economies of scale may have a chance to satisfy this expensive investment. For some of the biggest competitors in the oil refining industry such as the United States and Europe, refineries with CCS may be unrealistic per the aforementioned technical and financial challenges of retrofitting, but new refineries can be planned in advance to include CCS facilities or piggyback off a larger carbon dioxide transport network that can enable integration with other sectors such as heating or manufacturing to prevent the release of greenhouse gases and instead use them for effective measures in the industry (Prism, 2019). The available heat generated from the refining sector also creates the opportunity for residual heating of households as seen in the Port of Rotterdam study where up to 430,000 households can be heated by the excess heat from oil refineries rather than ending up in plants' cooling water or being released to the atmosphere through cooling towers (Port of Rotterdam, 2017). The switch from natural gas to residual heat would decrease CO_2 emissions, allow effective usage of prospective waste energy and open more opportunities for integration of oil refineries in future energy systems in a critical role.

4.2 Environmental Developments

Environmental legislation and carbon emission goals are slated to be two of the defining policy agendas and all governments, industries and institutions must do their part in this global coalition against climate change and pollution. The oil industry is may be seen as the antagonist in environmental scenarios due to their involvement in widely publicized environmental scandals, promotion of fossil fuels in many aspects in life such as transportation, heating and industry.

However, there are significant developments happening in the oil refining industry in terms of adapting to the decarbonization principle that is equipped by already confirmed and set in stone laws, directives and goals of global and local authorities. The oil refining industry is the third largest greenhouse gas emitting industrial sector behind power plants and the petroleum and gas industry. Moreover, the oil refining industry ranks second in the highest greenhouse gas emitting sector per facility which convincingly underpins the need for change in the context of binding environmental legislation and emission goals such as Paris Agreement and European Union directives (Ritchie & Roser, 2020). Shareholder and public pressure also play a huge part in forcing oil companies to take action against their environmental wrongdoings as public perception emerges as a huge notion of demand and utilization with the rise and prevalence of social media, enabling and facilitating communication on a global scale. As an industry dominated by fossil fuels, which are practically viewed as the main cause of climate change, carbon emissions and pollution, oil refining industry has to clean and decarbonize its products, feedstock and operations.

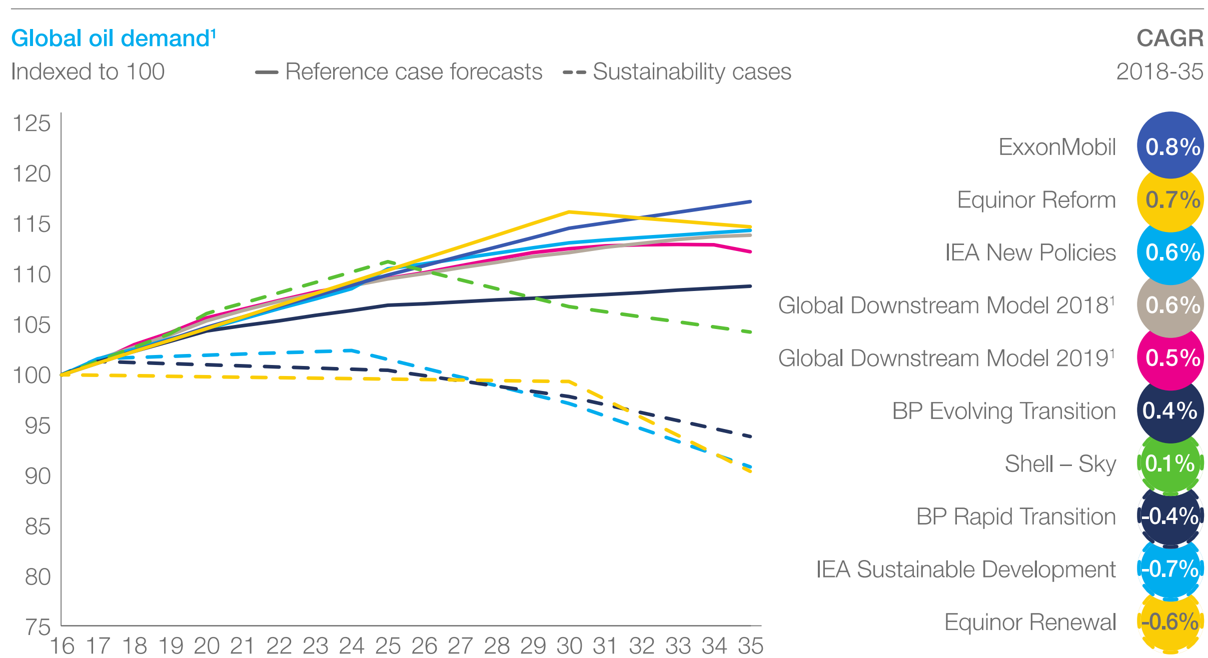

Figure 4.2: Global oil demand forecasts from various scenarios (McKinsey,2019)

Ever-changing quality of crude oil, global volatility of geopolitics and emergence of new alternatives for feed supply look to cause a shift in oil refineries approach to feedstock (Nomikos & Pouliasis, 2011). As the oil refining industry prepares for the new age of energy, the future crude slate is expected to consist of heavier sourer crudes, natural gas liquids and biomass. In order to take advantage of multiple types of feedstock with respect to environmental legislation and carbon emission goals, the introduction of products and components that have low-carbon content is important and can be a defining role for oil refineries in future energy systems (FuelsEurope, 2018). Developments in the area of feedstock processing are crucial for the future of the oil refining industry as the profitability and competitiveness of the industry mostly come from its products originating from that feedstock. Conventional transportation fuels becoming outdated and globally labeled as the source of climate change and pollution drives the oil refining industry to cleaner alternatives such as electricity base fuels like hydrogen and biofuels. Both of these options have the opportunity to create an integrated value chain of operations with the inclusion of prospective assets of future energy environments such as distribution networks, electric vehicles and other industries. Since maritime fuels have already been hit by the IMO legislation regarding desulphurization, it created a pathway for other conventional transportation fuels to reduce their content of environmentally hazardous ingredients and demand forecasts for these fuels reflect the expected plateau and decrease despite the upcoming immense economic and population growth of middle class in developing countries (Alabdullah, 2020). Another environmentally critical product of oil refineries is plastics, which are forecasted to be driving the demand for refined products and become the primary driver of profit while the demand for traditional fuels plummets. Plastics recycling and product switching are initiatives that are being taken against plastic consumption which results in pollution and harm to wildlife. Legislation and goals to reduce plastic consumption are already underway with the impetus of EU's Strategy for Plastics in Circular Economy ensuring half of all plastic packaging used to be either reusable or cost effectively recycled by 2025 and all of the plastic packaging to adhere to same these standards by 2030 (Barnes, 2019). This situation also creates opportunities for oil refineries to internalize plastic recycling for their own operations, allowing for more integration with industry and waste management in terms of effective and environmentally conscious usage of plastic products.

Refinery operations becoming more complex and technologically advanced allows refineries to convert their processes to more efficient and environmentally sound means. Environmental due diligence of refineries has been improved with new technologies regarding flaring and cracking being customized for less polluting agents and waste. With carbon pricing emerging as a policy option to minimize emissions, environmentally configuring the operations of the oil refining industry also becomes a financial investment as well as an environmental one. Waste management of oil refineries also have implications for the environment (IPIECA, 2014). Typical wastes generated by oil refineries are process waste which consists of handling and processing wastes, maintenance and operational waste which consists of construction waste, spills and residues and commercial waste from packaging materials, food and office waste (IPIECA, 2014). If the refinery complex includes a medical facility, then the medical waste is also included in the waste properties of that refinery (IPIECA, 2014). Providing enhanced data collection, analysis and monitoring, digitalization in the oil refining industry is viewed as one of the key solutions for refineries to manage their waste more effectively. In addition, integration with local facilities such as water management, heating and recycling plants contribute not just more efficient waste management of materials but energy as well.

A state-of-the-art example of an oil refinery which is environmentally conscious is Total's conversion of Grandpuits refinery into a zero-crude platform. Equipped with renewable diesel production primarily intended for the aviation industry, bioplastics production, plastics recycling and two photovoltaic solar plants, this plant plans to discontinue crude oil refining in 2021 and storage of petroleum products in 2023. Given France's environmental goals set for 2040 and European Union's carbon neutrality policies, this retrofitted refinery administers clean petrochemical products, clean fuels for an industry that is lagging behind road and maritime transport in terms of environmental steps, renewable energy generation and recycling opportunities to minimize its negative impact on the environment. Moreover, Total gave its promise to complete this transformation without layoffs and aims to present internal mobility and early retirements for its workers, which is very important for environmental justice concerns in the age of digitalization taking over and experienced workers in the industry being treated unjustly by oil companies. Even though this massive transformation cost 500 million euros, the benefits and opportunities the new Grandpuits refinery creates are vital for the prospects of the whole refining industry, considering the scale and potential of oil refineries in decarbonized and digitalized energy systems in an integrated role.

4.3 Chapter Synthesis

This chapter presented the technological and environmental developments occurring the oil refining industry in the face of technological advancements, global environmental legislation and carbon emission goals. The idealized version of “refinery of the future” expresses the implementation of Industrial Internet of Things and other digital technologies to enhance refineries’ efficiency, decision-making, insights and management of assets. With the upcoming demand plateau of conventional transportation fuels due to the emergence of electric vehicles and an environmentally conscious approach to fossil fuels, refineries turned their attention to petrochemical production to be able to financially sustain their businesses. Integration of oil refineries with petrochemical plants is considered a requirement for the current refining industry due to the expected increase in consumption and demand of petrochemical products such as plastics which is equivocally seen as the next driver of refined products market. However, plastics also create environmental issues of pollution and destruction of maritime wildlife which is also expected to follow the trend of plastics stemming from highly populated developing countries starting to have massive clusters of middle class in their demographics, who are demanding refining products such as conventional transportation fuels, plastics and other various petrochemical products. Technological advancements that have the potential to optimize the oil refineries’ operations also include carbon capture and storage, residual heat integration, digitalized waste and asset management in order to improve the overall efficiency and environmental responsibility of the refining industry. The feedstock is an important component in oil refining industry for environmental concerns as the determining factor of composition of the product that is generated from that feedstock. Crude supply and quality have been a nagging issue and more advanced and cleaner alternatives of feedstock such as biomass and natural gas liquids are being implemented to refineries for cleaner operations and products. Even though conventional transportation fuels are gradually being phased out by automotive and oil industries, greener fuels such as electricity-based fuels like hydrogen and biofuels are being produced to comply with global environmental legislation and emission goals. These advanced and clean fuels also provide the opportunity for cross-sectoral engagement and value chain generation for industries that are aiming to contribute to the environmental transition happening in energy systems.

In order to examine the oil refining industry's role and relevancy in future energy systems, the technological and environmental developments should be evaluated with the challenges the industry is facing in the context of global environmental legislation and technological requirements of the day and age. Aligning the technological and environmental challenges to the corresponding developments and reactions from the oil refining industry in a systematic way would assist in guidance for preparing for the integration of oil refineries in decarbonized and digitalized energy systems. Thus, in the next chapter, Qualitative Content Analysis will be utilized to align these technological and environmental challenges and developments to create meaningful criteria for further analysis by scenario building, which will be conducted with the aim of envisioning the integration and relevancy of oil refineries in future energy systems.

5. Evaluation of Challenges and Developments in the Oil Refining Industry

This chapter answers the third research question of "*How does the developments in the oil refining industry respond to the current challenges with respect to scenarios, forecasts and trends for the future energy systems?*" by utilizing Qualitative Content Analysis. Section 5.1 showcases the data analysis conducted with QCA. Section 5.2 illustrates the findings of the analysis. Section 5.3 discusses the finding of the conducted analysis with respect to quality criteria of objectivity, reliability and validity. Section 5.4 concludes this chapter with a reflection on the findings and how this part of data analysis translates to scenario building.

5.1 Application of Qualitative Content Analysis on the Uncertain Future of Oil Refining Industry Case

The data analysis process of QCA was detailed in Section 2.2.2 of this thesis. The stages that will be accomplished in this chapter is illustrated in Figure 5.1 as a reminder of this research's commitment to textbook approaches due to qualitative analyses' requirement for validity, reliability and objectivity.

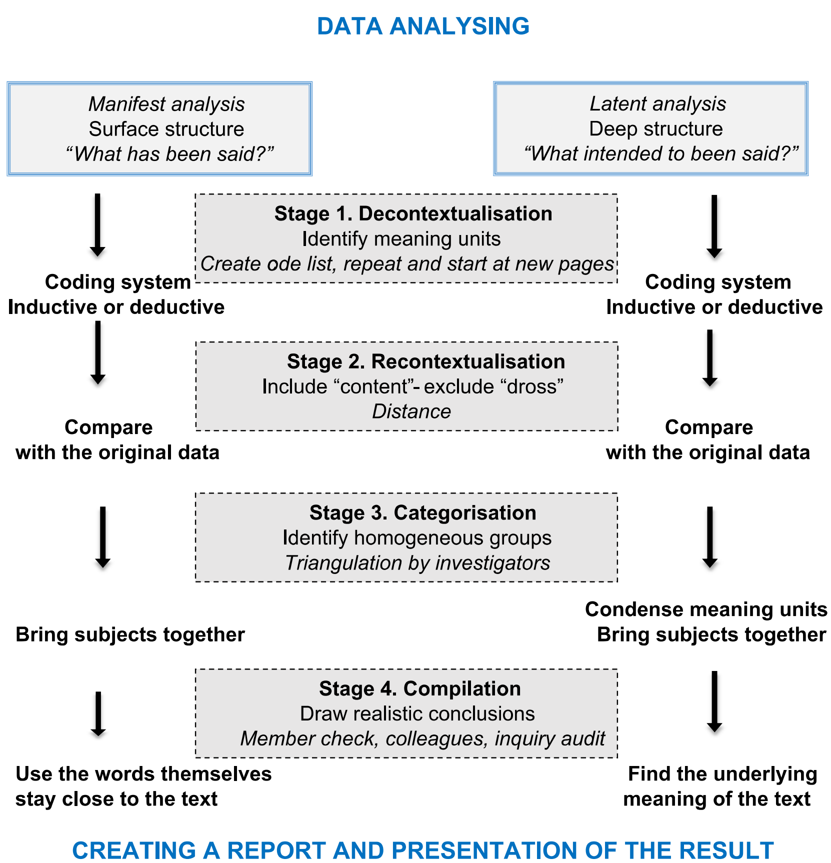

Figure 5.1: An overview of data analysis process of Qualitative Content Analysis (Bengtsson,2016)

5.1.1 Decontextualization

In order to become fully immersed in the issue of the uncertain future of oil refineries and create comprehensive meaning units from all available perspectives, academic articles, company reports, science institute documents, government directives and newspaper articles were investigated. Meaning units are determined from these resources with the criteria being prominence in literature and other resources with respect to the specific research topic of the future of oil refining industry. Private and public resources on the future of oil refining industry contains very comprehensive information, starting from the background of the oil refining industry in certain regions or globally, explaining the current situation and trends, pointing out the challenges the industry is facing and giving an outlook for certain periods such as 2030 and 2050. With the abundance of these types of comprehensive guide-like resources, distinguishing meaning units for this research's purpose is difficult as all the aspects of oil refining industry is mentioned and elaborated in these papers. Academic literature is more focused in its research scopes and subjects but topics being focused also lead to dissimilation of meaning units as they share less focal points and shared insight in the context of the future of oil refineries, it separately specializes on different aspects of the issue. Still, academic literature contributes greatly to generate benchmark ideas regarding meaning units. Newspaper articles assist with great insights on the future of oil refineries as they are the first to break news, share insider information and publish opinion pieces that may be controversial and not scientific but create discussion and self-questioning. Lastly, scenarios and forecasts belonging to various organizations also showcase where the oil refining industry's focus and priorities are at, thus aiding in the decontextualization process of QCA.

Since the uncertain future of oil refineries is a comprehensive issue with many facets such as financial, social, political, technological and environmental aspects involved, it is important to stay focused on the research objective in the data analysis steps of Qualitative Content Analysis, starting with the decontextualization step where the meaning units are generated. To establish the systematic approach taken with the vision of the research objective, the literature is filtered according to those which contain pathways, strategy recommendations and conclusions that consist of direct references to integration of oil refineries in future energy systems. This selection process also aids the analysis to stay focused in terms of the perspective of oil refineries since many factors involved with the integration procedure also has major and minor involvement from other actors that we can't control or we don't aim to provide the roadmap to. The systematically reduced literature include Refinery 2050: Conceptual Assessment (Concawe, 2019), Digital Transformation Initiative Oil and Gas Industry (DTI, 2017), Vision 2050 (FuelsEurope, 2018), Global Downstream Outlook to 2035 (McKinsey, 2019), Shaping the Oil Company of the Future (Prism, 2019), Refinery of the Future (Speight, 2011), Decarbonization Pathways for Oil and Gas (The Oxford Institute of Energy Studies, 2020), Industrial Decarbonization and Energy Efficiency Roadmap Action Plan (UKPIA, 2017), Energy Outlook 2020 (BP, 2020), Oil in 3D: The Demand Outlook to 2035 (Barclays, 2019), The Unprecedented Expansion of Global Middle Class (Brooking, 2018) and Refinery 2050 (CIEP, 2018). Selection of these meaning units was done in a process in which utilized the analysis of the selected literature for this research for prominence and prevalence of concepts that are analyzed and investigated in the context of the future of oil refineries.

Meaning units selected from these aforementioned resources on the future of oil refineries are:

- Forecasted plateau of demand for transportation fuels in 2035
- Environmental impact of refinery operations and waste
- Environmental impact of conventional refining feedstock and products
- 3 billion people graduating into middle class increasing the demand for refinery products
- Integration of oil refineries with petrochemical plants and plastics being seen as the next driver of demand for refinery products
- Utilization of digital technologies such as Industrial Internet of Things (IIoT) advanced sensors, monitoring and data analysis
- Global agendas of becoming economies with net zero greenhouse gases by various time periods
- Emergence of cleaner feedstock and fuels
- Improving layout configuration with more efficient operations, environmental facilities such as plastics recycling and CCS

5.1.2 Recontextualization

During the recontextualization process, the researcher gets the opportunity to check whether a critical aspect of the research subject is being neglected and forgotten. Also, since immediately following this stage of data analysis is condensing the meaning units, it is important to leave out the “dross” in the analysis done and allow for enough distance with the noncontributing information with respect to the research question of the uncertain future of oil refineries.

Condensed version of meaning units are as follows:

- Plateau of demand for fuels
- Emerging middle-class population
- Petrochemical integration
- Digitalization
- Decarbonization
- Layout configuration

5.1.3 Categorization

The main rule for identified categories is that they should be internally homogenous and externally heterogeneous, meaning that no meaning unit should fall between two categories or included in two categories at the same time. In the research area of the integration of oil refining industry into future energy systems, academic literature and other various resources showcase the two categories clearly. First one is the current challenges the industry is facing in the context of international environmental legislation, technological advancements in transportation and energy and emission goals. Second one is the developments and plans the oil refining industry is currently undertaking in order to satisfy environmental and technological standards of the future while financially surviving. In this research, the categories are labeled as drivers of the refinery of the future and agenda for the refinery of the future and satisfying the coherency with this thesis' research questions. Another reasoning for these labels for categories is that the term "refinery of the future" is convincingly prominent in literature but is not available as a meaning unit because "refinery of the future" reflects the ideal properties of what a refinery should be capable of and the intrinsic relationship of this term with meaning units on both sides of categories makes the term against the rules of categorization. On the other hand, "refinery of the future" also reflects what this thesis aims to investigate about oil refineries and category labeling was done under these convictions. Table 5.1 showcases the condensed meaning units with their respective categories.

Drivers for the Refinery of the Future	Agenda for the Refinery of the Future
Emerging middle-class population	Petrochemical integration
Layout configuration	Digitalization
Plateau of demand for fuels	Decarbonization

Table 5.1: Condensed units and their categorization

5.1.4 Compilation

One final check recommended by pioneers of QCA is to check the time frames of the meaning units and their respective sources of literature in order to inspect the correspondence of whether the findings are from older literature and are obsolete with respect to other meaning units. This research's objective is to prepare a roadmap for interaction and relevancy for oil refineries in future energy systems and the resources this thesis feeds off from rarely date further back than 2013 because the constraints that force the oil refining industry to take action against carbon emissions and environmental legislation were not set in stone and relevant data can be traced from newer literature with current perspectives.

First insight to notice in the categorized meaning units table is that there are intrinsic cause and effect relationships between the drivers of and the agenda for the refinery of the future. For example, petrochemical integration, which is deemed integral for an oil refinery's financial competitiveness and survivability, is caused by the emerging middle-class population, the plateau of demand for fuels and layout configuration drivers altogether. This relationship can be established vice versa as decarbonization agenda for the future of refineries are caused by increased consumption of refined products such as plastics and fuels, layout configurations of established refineries not being able to respond to today's operational challenges such as waste management, asset management and refining processes and traditional transportation fuels being phased out. Secondly, comparing the initial meaning units and condensed meaning units and examining the union of concepts in the recontextualization process shows how integrated these concepts are and that is an affirming sign for this research in which the aim of utilizing QCA is to systematically analyze the resources at hand to deduce meaningful criteria for evaluating the future of oil refineries with respect to scenarios and forecasts in scenario building method. Finally, compiling meaning units that capture the essence of the research provide further data analysis to be more precise and systematic as QCA's involvement to align and compile the findings of the conducted desk research create a clear perspective to investigate scenarios, trends and forecasts. The final forms of meaning units are convenient to research about and these condensed forms also correspond to terms that are being used in industry and academia alike. The compiled end-product reflects the core of this research which are the research questions regarding the uncertain future of the oil refining industry and going through a systematic reduction of literature in this research area clarifies the conducted desk research, shines a light on further analysis to be conducted and reinforces the alignment of this thesis. After the compilation of meaning units with respect to their designated categories and gathering insights upon the research itself and the research area, the results of the analysis are presented in a table that expresses initial meaning units, condensed meaning units, their respective categories and themes in Section 5.2, which is a method of presentation suggested by the academics involved with QCA.

Examining the previously mentioned documents with respect to the importance they put on certain criteria for explaining the forecasts, trends and outcomes, the two criteria were generated as *demand for refined products* and *carbon emissions of refineries.* For example, two of the four chapters of Vision 2050 are carbon abatement and demand for refining products. Excluding the introduction section, the report of Refinery 2050 consists solely of demand for refined products, low carbon potential of future products of refineries and CO2 efficiency of refinery operations, all of which are reflected on the two criteria that were determined in the QCA. One last example is the book Refinery of the Future, which can be considered dated relative to the other literature mentioned above. The tenth chapter of the book hosts a description of the "refinery of the future" and this description consists of high demand for products, conforming to environmental regulations and continued technological development of refining processes. Similar situations apply to the other literature considered in this analysis as well. With the aspect of human creativity and commitment to the research objective, meaningful criteria of *demand of refined products* and *carbon emissions of refineries* were generated and directed to scenario building to be inputted into its analysis procedures.

5.2 Presentation of results

Table below illustrates the findings of the data analysis made by QCA with the headings of meaning unit, condensed meaning unit, category and themes within the context of this research.

Meaning Unit	Condensed Meaning Unit	Category	Theme
Forecasted plateau of demand for transportation fuels in 2035	Plateau of demand for fuels	Drivers for the Refinery of the Future	Current challenges in the oil refining industry
3 billion people graduating into middle class increasing the demand for refinery products	Emerging middle-class population		
Improving layout configuration with more efficient operations, environmental facilities such as plastics recycling and CCS	Layout configuration		
Integration of oil refineries with petrochemical plants and plastics being seen as the next driver of demand for refinery products	Petrochemical integration	Agenda for the Refinery of the Future	Current developments in the oil refining industry
Utilization of digital technologies such as Industrial Internet of Things (IIoT) advanced sensors, monitoring and data analysis	Digitalization		
Environmental impact of refinery operations and waste	Decarbonization		
Environmental impact of conventional refining feedstock and products			
Global agendas of becoming economies with net zero greenhouse gases by various time periods			
Emergence of cleaner feedstock and fuels			

Table 5.2: Illustration of results from the data analysis done by Qualitative Content Analysis

5.3 Discussion of Results

Objectivity, reliability and validity of the results are of utmost importance, especially in a qualitative research approach. This data analysis process satisfies the objectivity principle by feeding off the resources from all perspectives such as oil companies, governments, organizations and academia to compile a shared understanding of the subject of the uncertain future of oil refineries. A step-by-step explanation of research and data analysis processes also provide transparency of the research conducted in this thesis, reinforcing the objectivity of the QCA application in this chapter. Reliability reflects the stability of the analysis and consistency of the conditions of data analysis process. During the QCA process, research scope and boundaries are specifically determined for the aim of this research which is the uncertain future of oil refineries. Another way that this data analysis process applies the reliability principle is the explicit showcase of resources and procedures, which can be found in the Appendices chapter of this thesis, in the data collection stage of QCA. Using the same methodology described would lead to similar results of data collection, with the exception of human creativity input in data analysis, thus, confirming the reliability principle of the data analysis. Lastly, the validity criteria are accomplished in this data analysis process with the consideration of research questions in decontextualization and recontextualization stages and the commitment to "measuring what ought to be measured". In the context of integration and relevancy of oil refineries in future energy systems, the findings of QCA are plausible and appropriate with respect to the research resources included in this thesis, therefore confirming the presence of validity in the data analysis conducted by QCA.

Aside from utilizing a systematic approach to the resources at hand, the other reasoning behind the application of QCA in this research is to generate meaningful criteria for the evaluation of scenarios and forecasts in scenario building analysis. In order to establish narratives for scenario building and satisfy the alignment and synergy of the criteria, utilization of QCA with scenario building amplifies the systematic process undertaken in this (Yamasaki & Spreitzer, 2006). The research subject is a macro level social phenomenon which is the area in that QCA excels as a method of data analysis and sustains symmetrical causation for the data analysis process. With the reduction of the data, it is observed that in order for oil refineries to survive and play a part in future energy systems, they need to be able to create profitable products and value chain operations while undergoing disruptive changes in terms of integration, decarbonization and digitalization requirements of the current day and age. For oil refineries to have a defined and contributing role in future energy systems, demand for refined products should be satisfactory in the context of competitiveness and survivability of oil refineries with respect to changing market conditions for fuels and other refining products while satisfying the global environmental legislation and emission goals by cleaning their operations, feedstock and products. Aligned with the main research question and sub-questions, the two criteria that are integral for the oil refining industry's integration and relevancy in decarbonized and digitalized energy systems are determined as *demand for refined products* and *carbon emissions generated by refineries*.

5.4 Chapter Synthesis

This chapter presented the data analysis process of QCA conducted in this research. Stemming from the desk research that was made to find out the challenges and developments surrounding the oil refining industry in terms of its integration and relevancy in future energy systems, collected data was analyzed through decontextualization, recontextualization, categorization and compilation stages. Meaning units with respect to the resources at hand were determined, condensed, categorized and compiled in a way that captures the essence of the research question adopted in this thesis and these findings are illustrated on Table 5.2. With the research flow utilized in this research, QCA generated meaningful parameters that will set the basis for scenario building analysis that will occur in Chapter 6 of this thesis and the parameters determined to be integral in preparing a roadmap for integration and relevancy of future oil refineries were *demand for refined products* and *carbon emissions generated by refineries.* In the next chapter, these two propositions will be evaluated and reflected upon by scenario building in the context of various scenarios and forecasts that are employed in the literature on the issue of the future of oil refineries, their competitiveness and their environmental considerations.

6. A Roadmap for Relevancy and Integration of Oil Refineries in Future Energy Systems

This chapter answers the fourth research question of "*What steps should the oil refining industry take in the short and mid-term to have a sustainable role in the decarbonized and digitalized future energy systems?"* with the preparation of a roadmap for relevancy and integration of oil refineries in future energy systems. Section 6.1 introduces the scenario building analysis that is to be conducted further down in the thesis. Section 6.2 and Section 6.3 showcases the application of the method on the two criteria generated by QCA, *demand for refined products* and *carbon emissions of refineries*. Section 6.4 discusses the findings from the bilateral analysis of the two criteria. Section 6.5 delivers the research objective of this thesis, the roadmap. Section 6.6 investigates the research quality principles of objectivity, reliability and validity on the scenario building data analysis process. Section 6.7 concludes this chapter with the synthesis of the work done through scenario building.

6.1 Application of Scenario Building

The flow of this research follows that the outcomes of QCA are in the form of meaningful criteria that can set the benchmark and lead to the objective of this thesis through scenario building where scenarios for the future of oil refineries will be analyzed and investigated to come up with a roadmap that has the potential to lead to integration and relevancy of oil refineries in decarbonized and digitalized energy systems. The two criteria determined with the data analysis of QCA were *demand for refined products* and *carbon emissions generated by refineries*. Demand for refined products such as fuels and plastics illustrates where the profit margin will lay in the future while examining the concerns of competitiveness and survivability of oil refineries which are facing a plateau of demand for their traditional products. Carbon emissions generated by refineries tackle the environmental aspect of the issue in consideration with clean operations, feedstock and products and this criterium will be analyzed in conjunction with the emission goals and environmental legislation that the energy industry must oblige to.

The application process of scenario building was previously explained in this thesis in Chapter 2.2.3. Following sections showcase the procedure of scenario building applied to the two criteria generated by QCA separately and after the analysis of both criteria, a synthesis of the findings will be realized and guide the roadmap that is to be prepared as the research objective and the final deliverable of this thesis. The roadmap in this thesis refers to a not so unlikely scenario case that has the potential to lead to integration and relevancy of oil refineries in future energy systems. It will contain an action plan that is aligned with the time periods of projections of demand for refining products and carbon emission generated by refineries with the compilation of various scenarios, forecasts and trends related to the issue of the future of the oil refining industry.

6.2 Demand for refined products

The main products that oil refineries of today supply routinely are transportation fuels such as gasoline, diesel and kerosene and if integration with a petrochemical plant is realized, plastics are also a highly in demand product. Asphalt, tar, lubricants, paraffin wax and sulfur related products are also produced by refineries but the importance of these products in terms of demand and profitability is marginal. The main driver of demand for refined products is the emergence of middle-class population in highly populated developing countries who are experiencing economic growth like China, India and Indonesia. This is described as the most rapid expansion of the middle class at a global level and middle-class is set to become the majority of the global population for the first time in history in the next few years. The increase in size also directly correlates to the spending that the middle-class generates. Already accounting for 35 trillion dollars, global spending by middle-class is projected to increase by another 29 trillion dollars by 2030, taking a third of the share in global economy (Kharas, 2018).

Even though demand for conventional fuels is set to hit a plateau in the next ten to fifteen years, the immense growth and consumption projected to come from these areas alongside the ever-increasing investments in petrochemical integration of oil refineries create opportunities for profit and market relevancy for oil refineries. With the increased opportunity to spend for a huge chunk of the global population, more automobiles, fuels and plastics are set to be sold in the near future in order to correspond to the increase in demand. Thus, the initial impact of the emergence of the middle-class population would result in an increase in demand for refined products. However, there is a reason behind the industry's designation of plastics as the next driver for refined products market as environmental legislation regarding fossil fuels, carbon emission sanctions and technological advancements in transportation are projected to stop the increase in demand for conventional transportation fuels and hinder its progress to a plateau. So, the initial effect on the emerging population of middle-class on the demand for refined products would be an increase for a period of time until technological advancements in transportation and the establishment of carbon emission sanctions overturn the increase in demand for conventional transportation fuels. After that, the performance of plastics and improvements in cleaning, promoting and selling transportation fuels could become integral to the profitability and survivability of oil refineries.

Any scenario building analysis must take into account how the economic cycle related to the research subject will evolve with respect to technological, environmental and suchlike factors for scenario validity. In order to identify an inclusive time horizon, trajectories of demand for fuels and petrochemicals are investigated separately to find snapping points and then create a time horizon to illustrate the trend for both of these demand components together. An important point in defining a collective time horizon is the projected peak demand for transportation fuels. The oil refineries' current challenges are compounded with the effect of COVID-19 pandemic and this intense period of inactivity and inefficiency may have caused the demand for transportation fuels to have already peaked around the current period of 2020 (Burchardt et al., 2020). Considering the scenarios applied in BP's Energy Outlook 2020 report, 2025 is a healthy estimate for the peak demand for transportation fuels as in all three scenarios, transportation fuels reach their peak demand in mid to late 2020s (IEA, 2020). On the other hand, petrochemicals are poised to experience consistent growth in demand throughout the time periods considered in demand for transportation fuels. Currently accounting for around 15 percent of the demand for oil products, petrochemicals are set to take up more than a third of total oil demand by 2030 and nearly half of total oil demand by 2050 (IEA, 2018). Considering the projected stability of increase, demand for petrochemicals does not create a concern for determining a coherent time period. The time period determined in this analysis will 2020 to 2050, with attention to grasping the peak of transportation fuels around 2025 and capitalizing on opportunities there if they present themselves in the roadmap.

At this point of the analysis, a research objective, an analysis of causes and effects of the demand for refining products criteria and the contextual time horizon is at the disposal. Compiling the expected trends and events in a structured way to investigate the future competitiveness of oil refining industry is the aim of this step in the scenario building process. The trajectory of demand for refining products is mostly covered while determining the time horizon as the expected trends are demand for transportation fuels to peak around 2025 and demand for petrochemicals to experience constant increase. Critical trends and scenarios that are investigated in this data analysis process are provided below.

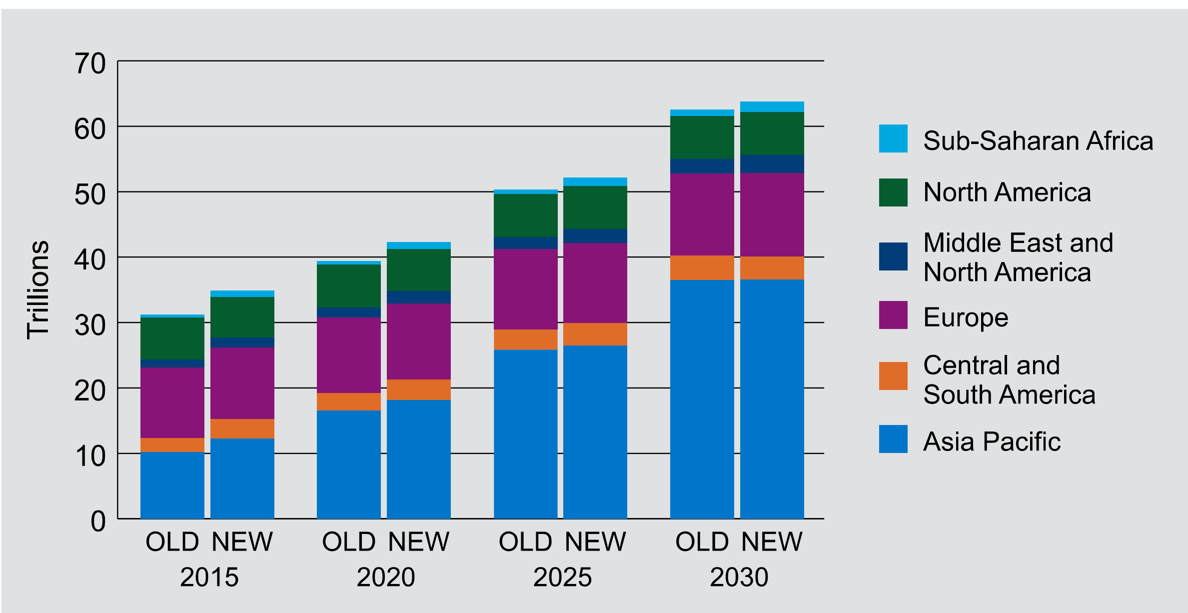

Figure 6.1: Middle class consumption expenditure by region (Brookings, 2017)

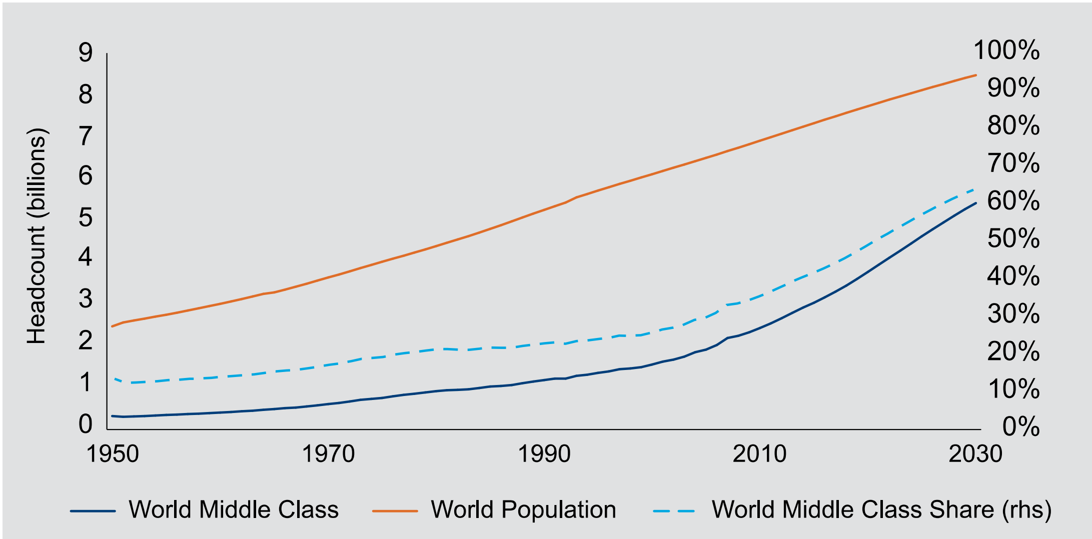

Figure 6.2: Estimates of the size of global middle class (Brookings,2018)

Country	2015	Share (%)	Country	2020	Share (%)	Country	2030	Shares (%)
U.S.	4.7	13	China	6.8	16	China	14.3	22
China	4.2	12	U.S.	4.7	11	India	10.7	17
Japan	2.1	6	India	3.7	9	U.S.	4.7	7
India	1.9	5	Japan	2.1	5	Indonesia	2.4	4
Russia	1.5	4	Russia	1.6	4	Japan	2.1	3
Germany	1.5	4	Germany	1.5	4	Russia	1.6	3
Brazil	1.2	3	Indonesia	1.3	3	Germany	1.5	2
U.K.	1.1	3	Brazil	1.2	3	Mexico	1.3	2
France	1.1	3	U.K.	1.2	3	Brazil	1.3	2
Italy	0.9	3	France	1.1	3	U.K.	1.2	2

Table 6.1: Middle class consumption for top 10 countries in trillion dollars (Brookings, 2018)

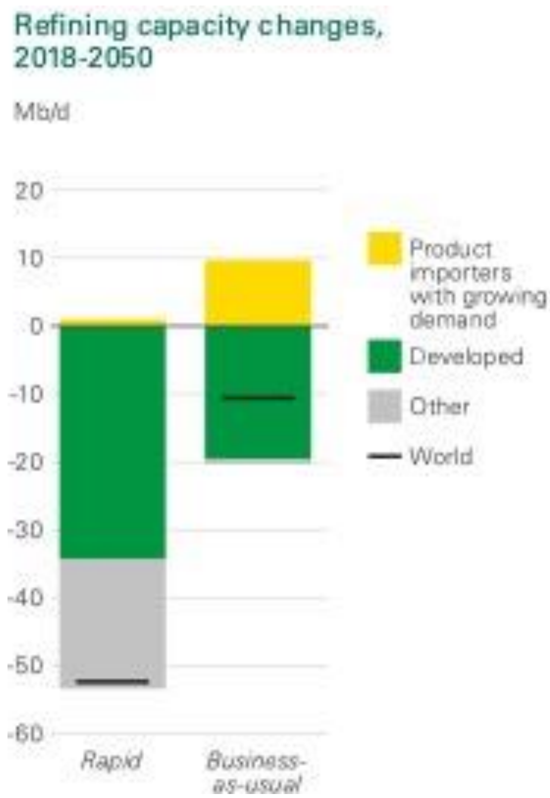

Figure 6.4: Refining capacity changes (BP,2020)

The forecasts from the Brookings study (Brookings, 2018) in Figure 6.1, Figure 6.2 and Table 6.1 reflect the expansion of the middle-class is imminent and this expansion not only translates to population growth but also consumption. China and India's meteoric rises show that oil refinery and petrochemical plant investments in these areas are for matching the upcoming demand rise in fuels and petrochemicals. BP's business-as-usual scenario also confirms this trend by forecasting growth in refining capacity in developing countries.

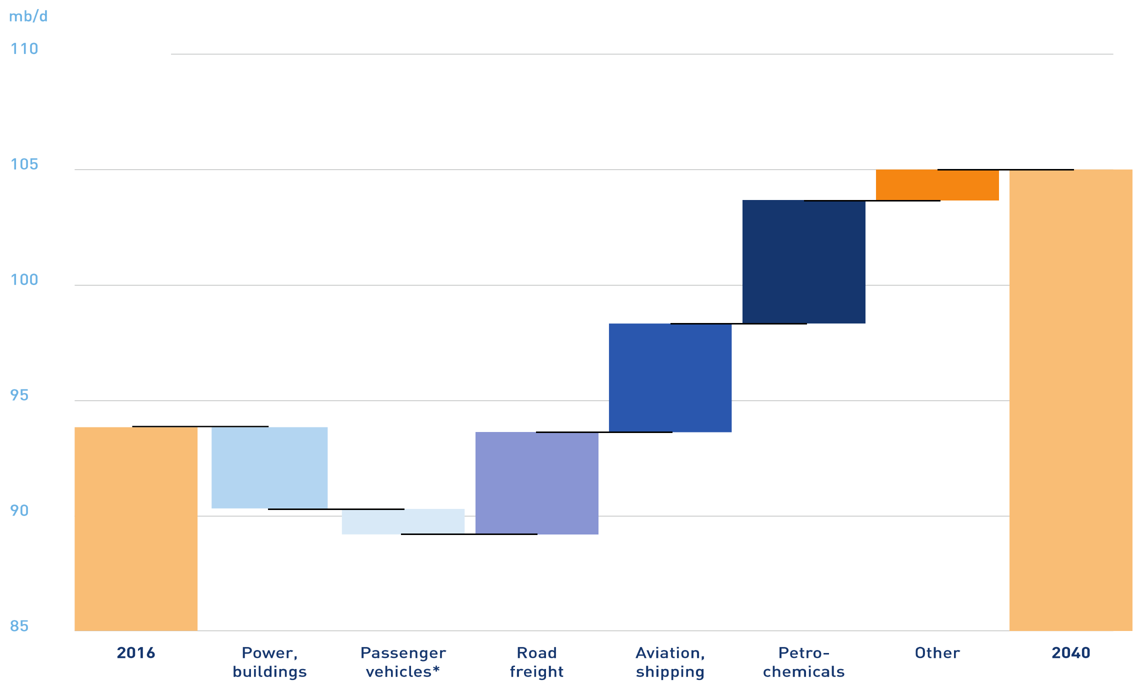

Figure 6.5: Changes in world oil demand from New Policies Scenario (FuelsEurope, 2018)

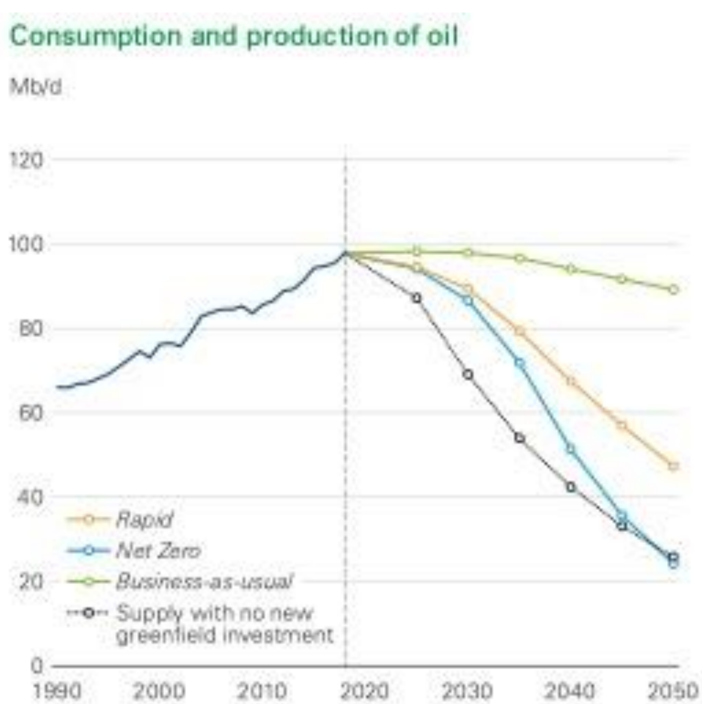

Figure 6.6: Consumption and production of oil (BP,2020)

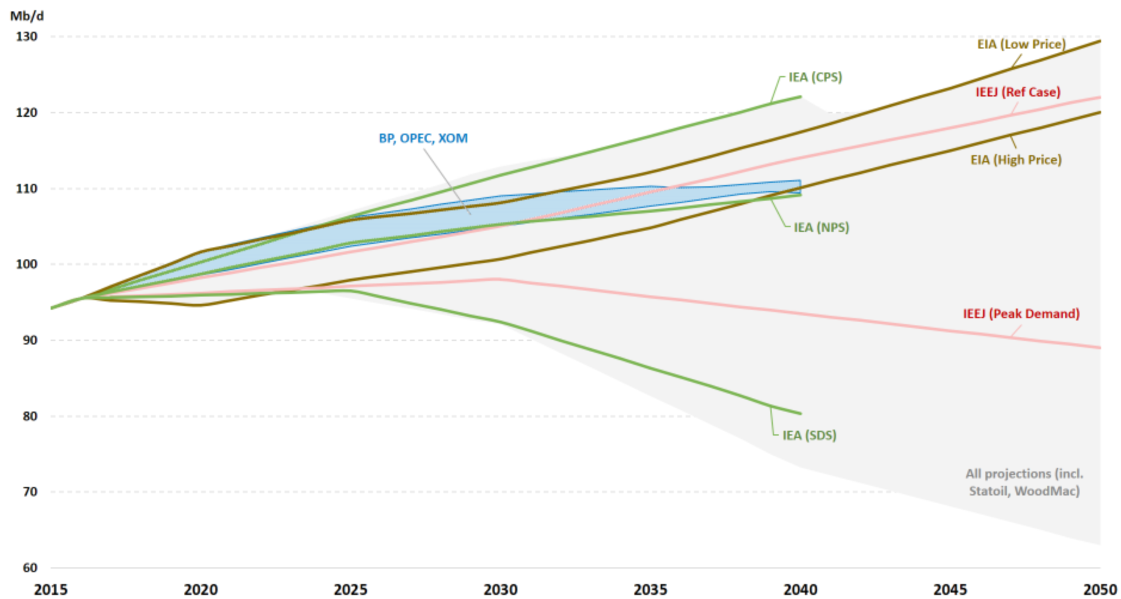

Figure 6.7: Projections of global oil demand (CIEP, 2018)

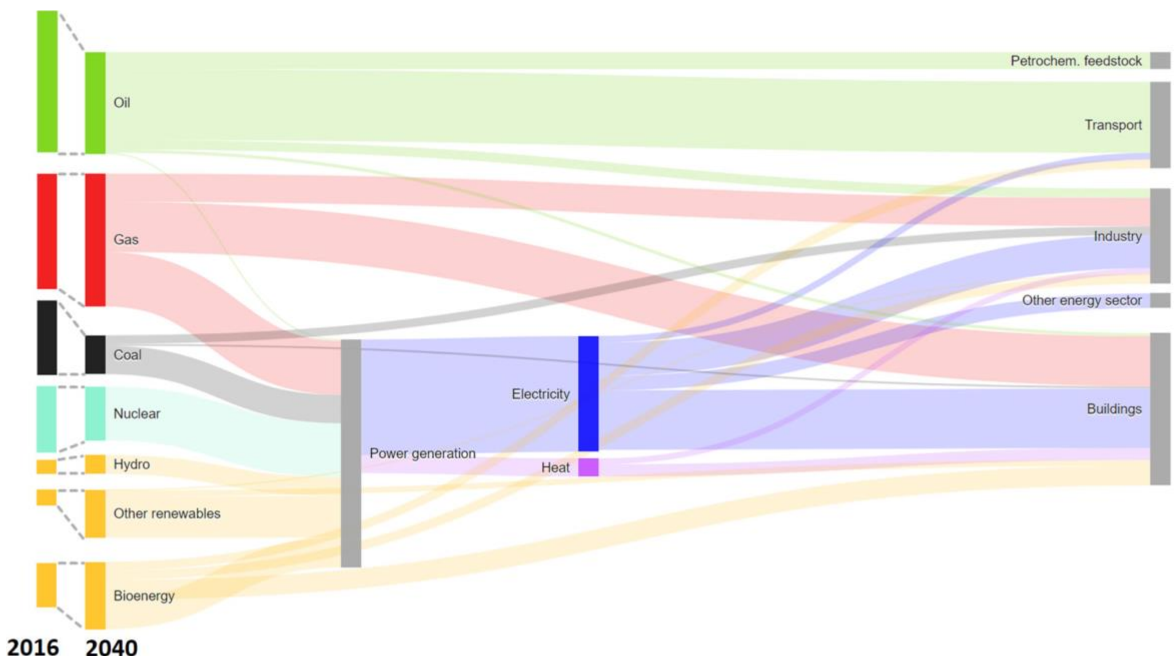

Figure 6.8: IEA New Policy Scenario for Europe in the year 2040 (CIEP, 2018)

Demand Scenarios	Evolution of demand for refining products (oil & bio based) EU refining system. (Key considerations)	Oil intake potential reduction due to changes in demand (*)
2030 Reference Scenario	Scenario assuming similar complexity in the sites and no changes in total demand ratio of refining products. Energy efficiency measures continuing the historical rate of improvement.	
A. 2050 Oil-based Scenario	Moderate energy efficiency improvement in vehicles and limited electrification in passenger cars. Total demand for jet increase. Small decrease in demand for petrochemicals.	≈20% vs 2030 Ref
B. 2050 Sustainable Scenario	High energy efficiency improvement in vehicles and increased penetration of electric vehicles in the passenger car segment. Total demand for jet increase. Small decrease in petrochemicals demand. Major reduction in non-road diesel & heavy fuel oil.	≈30%. vs 2030 Ref
C. 2050 Highly electrified Scenario	Passenger car heavily electrified (remaining consumption due to PHEV). Demand for diesel is reduced due to substitution with non-liquid fuel products. Demand for jet increases in the same levels as scenarios A/B. Major reduction in non-road diesel and no domestic demand for heavy fuel oil. Due to these changes in product ratios (fuels and non-fuel product ratio), serious unbalances are expected in the refining system to fully fulfil the domestic demand.	≈45% vs 2030 Ref

Figure 6.9: Evolution of demand for refining products (Concawe,2017)

Above projections from a variety of different sources illustrate that oil is not completely being phased out anytime soon. Only in scenarios that contain a lot of assumptions for technology, cooperation and commitment, as in the case of BP's net-zero and rapid scenarios in Figure 6.6, a dramatic fall in general oil demand is observed. Oil is slated to be relevant, so are the oil refineries, but capitalizing on these conditions with efficient utilization of resources and confirming to environmental standards would determine the level of integration for oil refineries. The question that arises now is how would this demand for oil distribute in terms of its products and which products can create opportunities for profit and utilization for oil refineries. In order to answer that question and get a wider look at the portfolio of prospective demand for refining products, more scenarios are assembled.

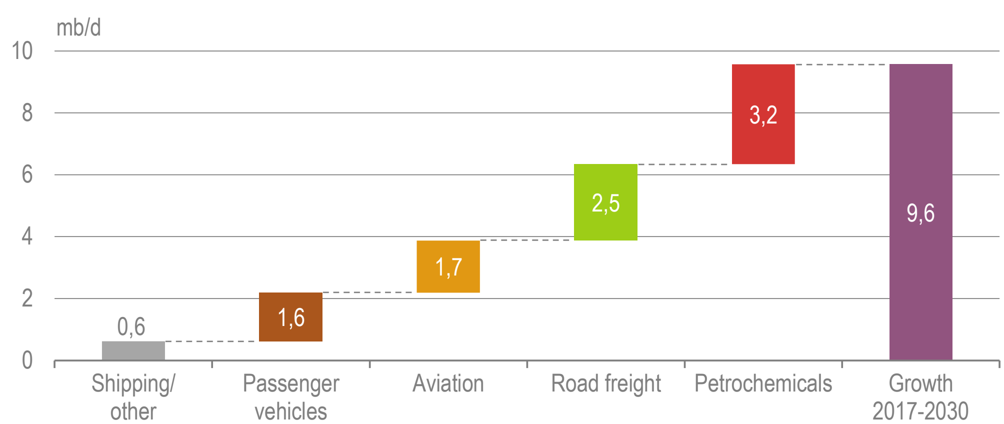

Figure 6.10: Oil demand growth to 2030 (IEA,2018)

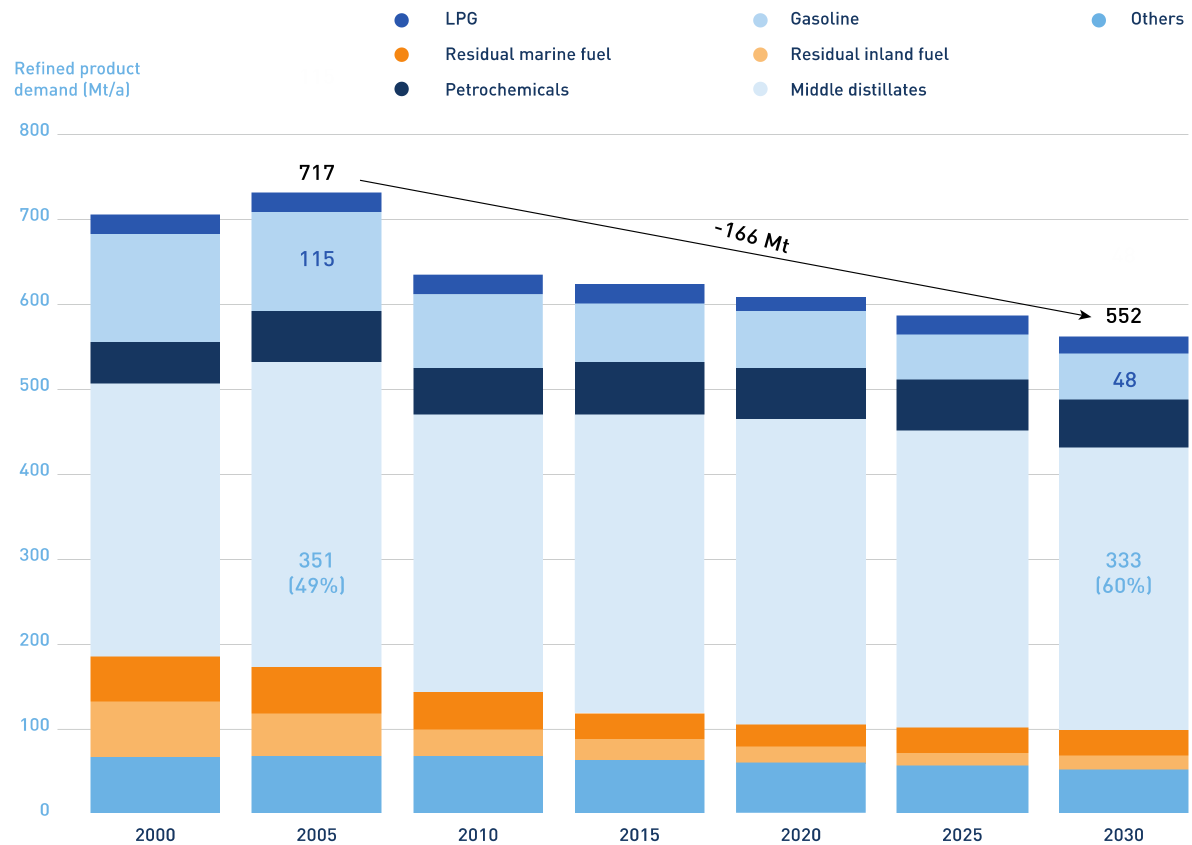

Figure 6.11: Total demand for refined products in EU-27+2 (FuelsEurope, 2018)

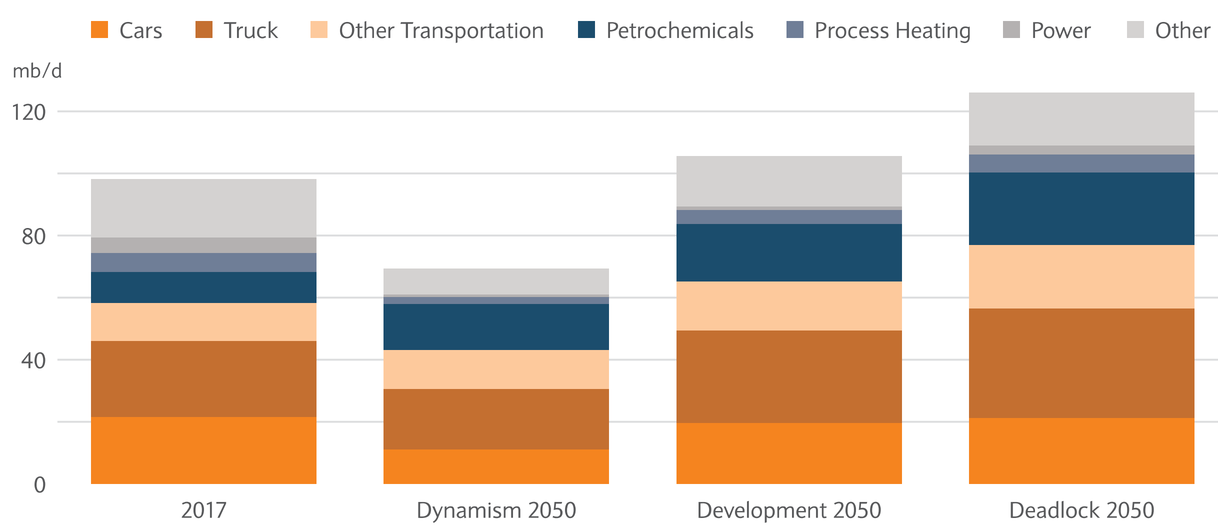

Figure 6.12: Oil demand projections for different scenarios (Barclays,2019)

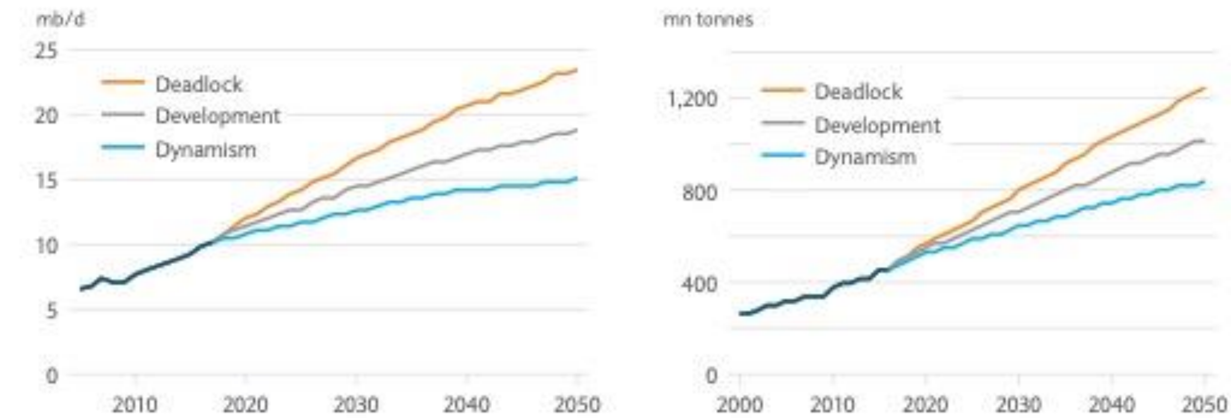

Figure 6.13: Demand on oil from petrochemicals and petrochemicals production to 2050 (Barclays,2019)

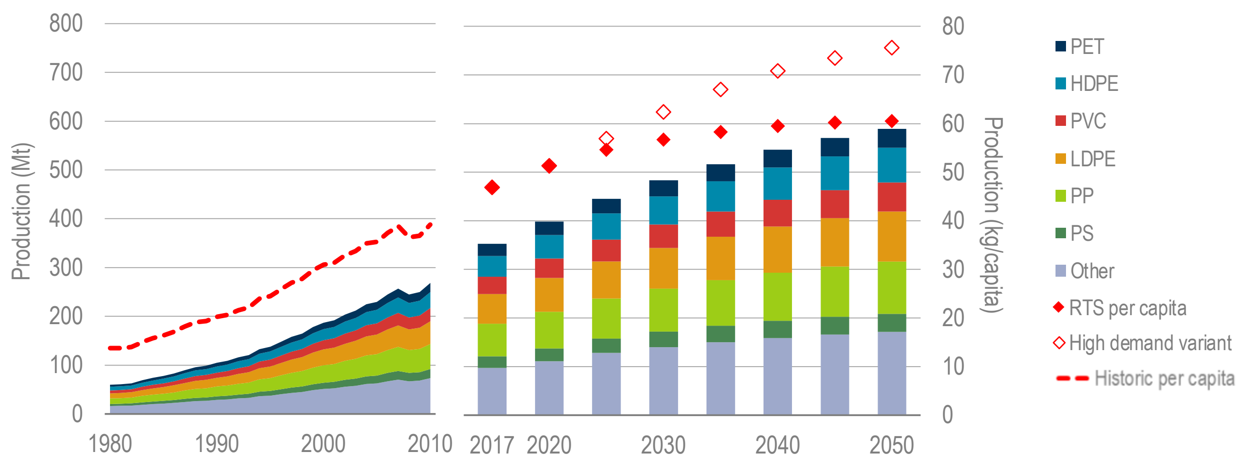

Figure 6.14: Trajectory of key petrochemicals (IEA,2018)

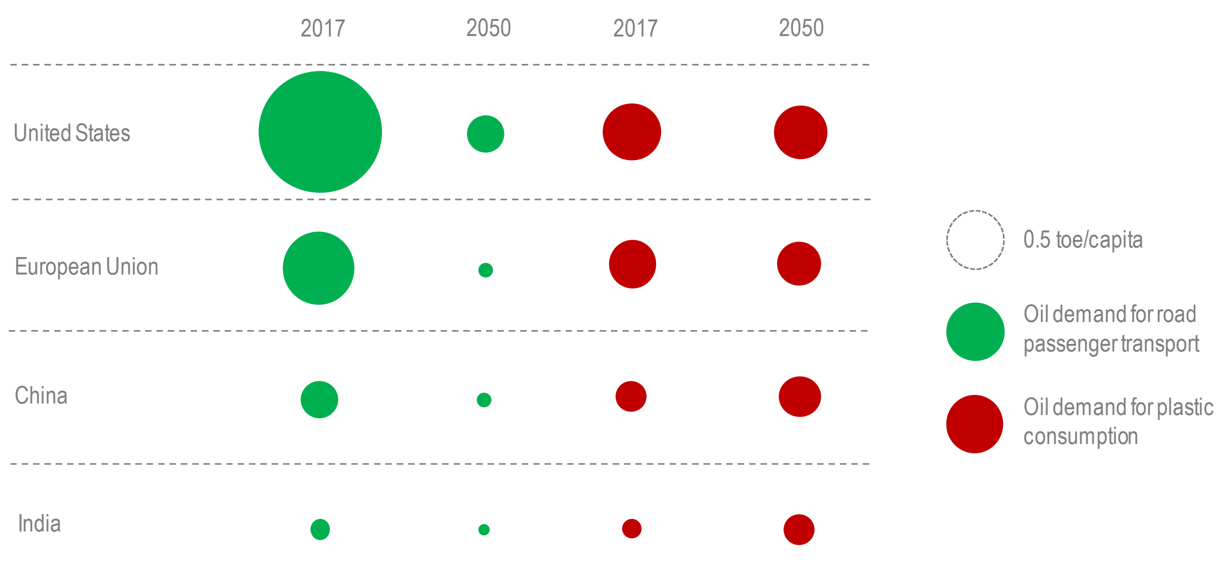

Figure 6.15: Oil demand from road transport versus petrochemicals (IEA,2018)

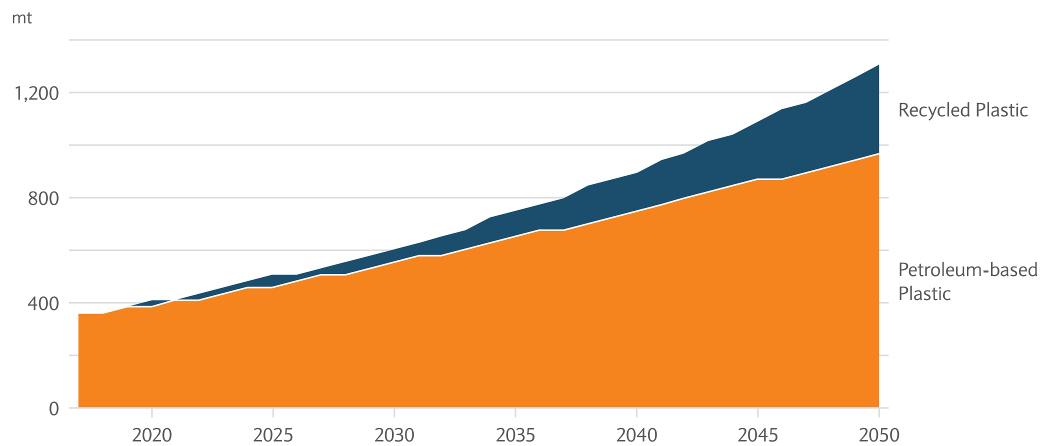

Figure 6.16: Global plastics forecast – development scenario (Barclays,2019)

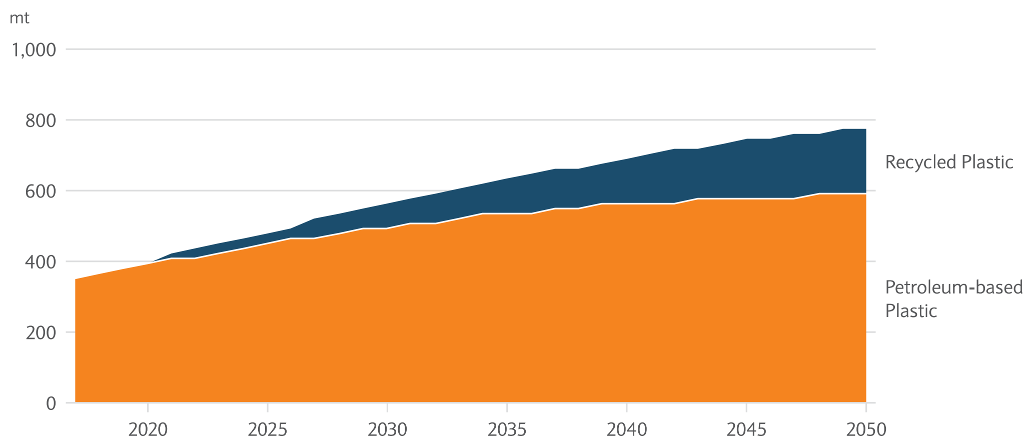

Figure 6.17: Global plastics forecast – dynamism scenario (Barclays,2019)

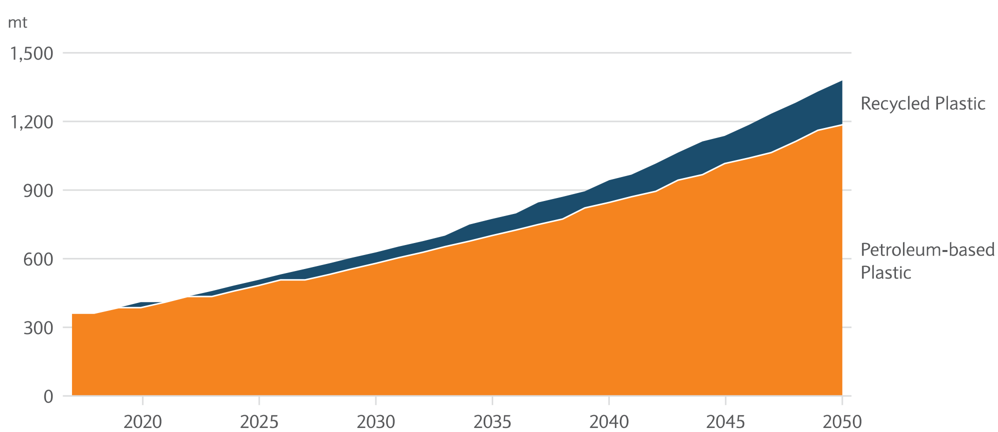

Figure 6.18: Global plastics forecast – deadlock scenario (Barclays,2019)

These projections solidify the statement that the oil refining industry's expectations regarding petrochemicals being the next driver of demand for refined products. New refining capacities, that are being unlocked in Asia and the Middle East, are equipped with more effective equipment and contain petrochemical plant integrations to produce plastics and other petrochemical products. This petrochemicals production boom, in particular plastics, also has environmental implications on the environment as seen in the Barclays studies (Barclays, 2019) with massive discrepancies in rates of plastic recycling between the optimistic and progressive scenario called development and more realistic and interpolation of current trends scenario called deadlock. By looking at these forecasts that are made by industry leading companies and organizations, petrochemicals will be accompanied by fuels for road, maritime and air transport in the product mix but the environmental standards and emission goals force these fuels to become greener and cleaner in terms of feedstock and carbon content.

The penultimate step of the data analysis process of scenario building is configuring the scenarios which mean making assumptions for when the data is discrete or pointing out bifurcations that can have an impact on the scenario building. One assumption that has been made during the process of scenario building for the demand of refined products is the designation of 2025 as the date of peak demand for transportation fuels. This point can help initial prospective actions in the roadmap that have the potential to capitalize on the last projected increase period of fuels. Drawing the conclusions step will be done coherently for both criteria in Section 6.4 where the final form of the scenario building will take place with respect to comprehensive scenarios and forecasts.

6.3 Carbon emissions generated by refineries

Carbon emissions are the central parameter for evaluating environmental performance for governments, industries and companies alike. With the upcoming targets of international carbon emission goals, measures that lower and sustain emissions in business need to be implemented throughout the energy industry. Decarbonization is the umbrella term given to reduction and elimination of all sources of carbon dioxide from energy sources in order to achieve zero net emissions and this philosophy is designated to be the only solution to climate stabilization (Virta Globa, 2018). Even though global actors have varying agendas and timelines for the implementation of decarbonization measures, imposed emission goals and environmental legislation is projected to result in a net decrease in emissions period for the foreseeable future. Decarbonization has an innate impact on various aspects of the energy and transportation industry that have intrinsic relationships with the oil refineries such as phasing out fossil fuels, emergence of electric vehicles and legislation on harmful content in transportation fuels. Therefore, the inevitable adoption of decarbonization in all aspects of industry and business is the main driver for reducing carbon emissions in oil refineries challenge that the industry is facing.

Oil refining is the third highest carbon emitting industrial sector through its operations, waste, feedstock and products and due to the high share of emission caused by oil refineries and the oil industry in general, the implications for this industry is greater than their other energy operations counterparts. With carbon emission and environmental legislation starting to being imposed upon the energy sector, oil refineries must undergo a transformation of their feedstock and products by making them greener and more sustainable. The effect of decarbonization is also felt in industries that are related to the oil refining industry such as the transportation sector where conventional fuels are becoming obsolete in road, air and maritime transport and are being replaced by their cleaner counterparts such as e-fuels, biofuels and low sulfur content fuels. The emergence of electric vehicles also has implications for demand for fuels and emissions caused by these fuels and more common electric vehicles get in public and private transport projects an overall improvement in carbon emissions but a negative impact on the products of oil refineries if they don’t adapt to the environmental and technological standards of current philosophies of decarbonization and digitalization in the energy sector.

Determining a time horizon for oil refineries’ carbon emission trajectories is relatively convenient compared to the first criteria analysis in Section 6.2, demand for refined products, due to the trend of carbon emissions that need to be accomplished for global climate stabilization. In order to achieve environmental integrity and climate stability, the energy industry and subsequently the oil refining industry needs to decrease carbon emissions relentlessly until the goal of net-zero emissions are reached. Coincidentally, the scenarios and forecasts made by oil companies, governments and academia alike determine 2050 as the target date of becoming businesses and economies with net-zero emissions. The competence and coherence of scenarios is of utmost importance for the analysis of scenario building conducted in this research and thus, 2020 to 2050 is designated as the time horizon of this scenario building.

Meaningful and insightful scenarios and trends are assembled in consideration of the carbon emission of refineries criteria and the main research goal of the research that is the integration and relevancy of oil refineries in future energy systems. Scenarios involving decarbonization of transportation technologies are also intrinsically relevant to the carbon emission of oil refineries with implications for cleaner feedstock and products. Thus, those scenarios and forecasts are also assembled alongside decarbonization trends in the oil refining industry. Critical scenarios and forecasts considered in this data analysis process of scenario building are illustrated below.

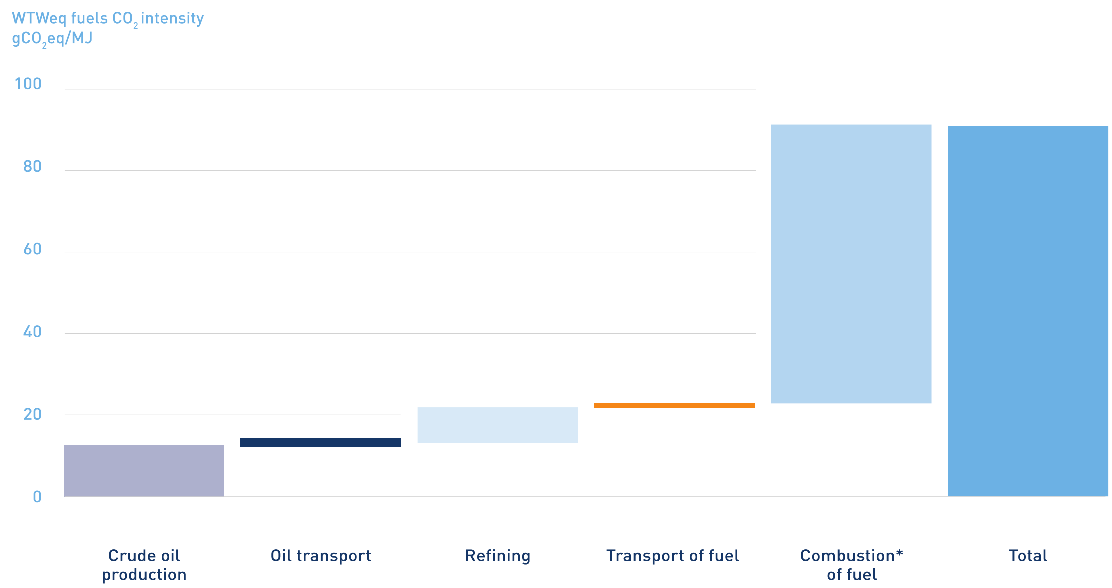

Figure 6.19: CO2 emission from production and usage of fuel (FuelsEurope,2018)

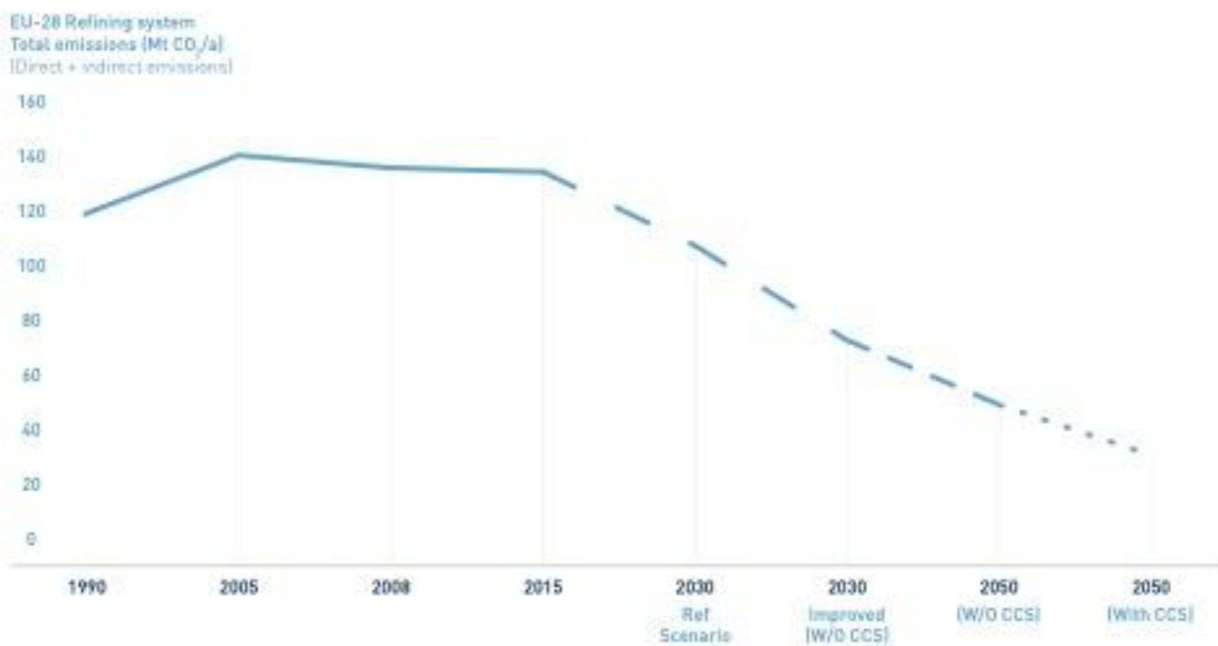

Figure 6.20: EU-28 refining system total emissions (FuelsEurope,2018)

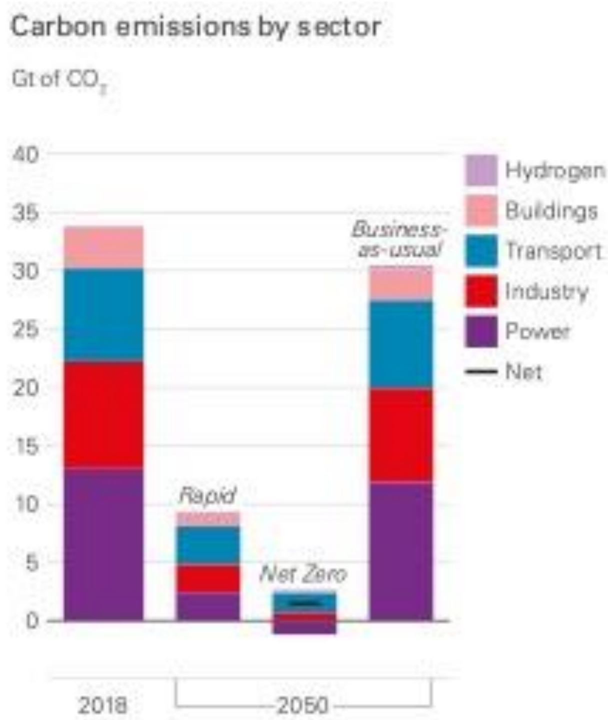

Figure 6.21: Carbon emissions by sector (BP,2020)

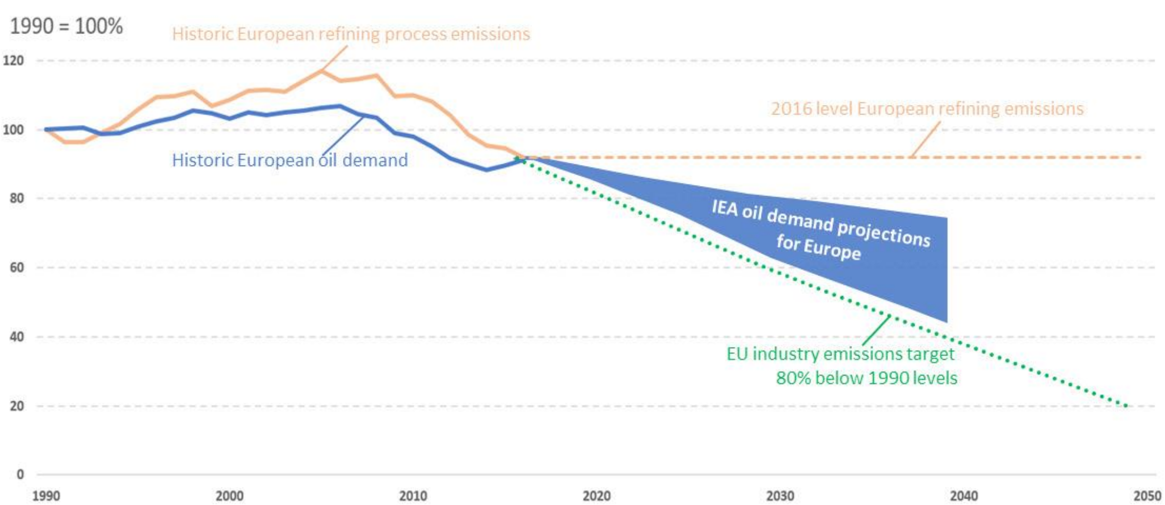

Figure 6.22: European refining process emissions and oil demand (CIEP, 2018)

The transportation sector is the intermediary that enables the oil refining industry's emissions as seen from the share of combustion of fuel in the total emissions that refineries generate. One of the most striking differences between scenarios is seen in Figure 6.19 where the emission goals that the EU set for 2050 are reflected in the net-zero scenario and the business-as-usual scenario reflects the interpolation of current trends into the future. This difference signals the disastrous situation that all industries are facing in terms of carbon emissions and significant transformations are required in these sectors with the implementation of decarbonization philosophies and tools.

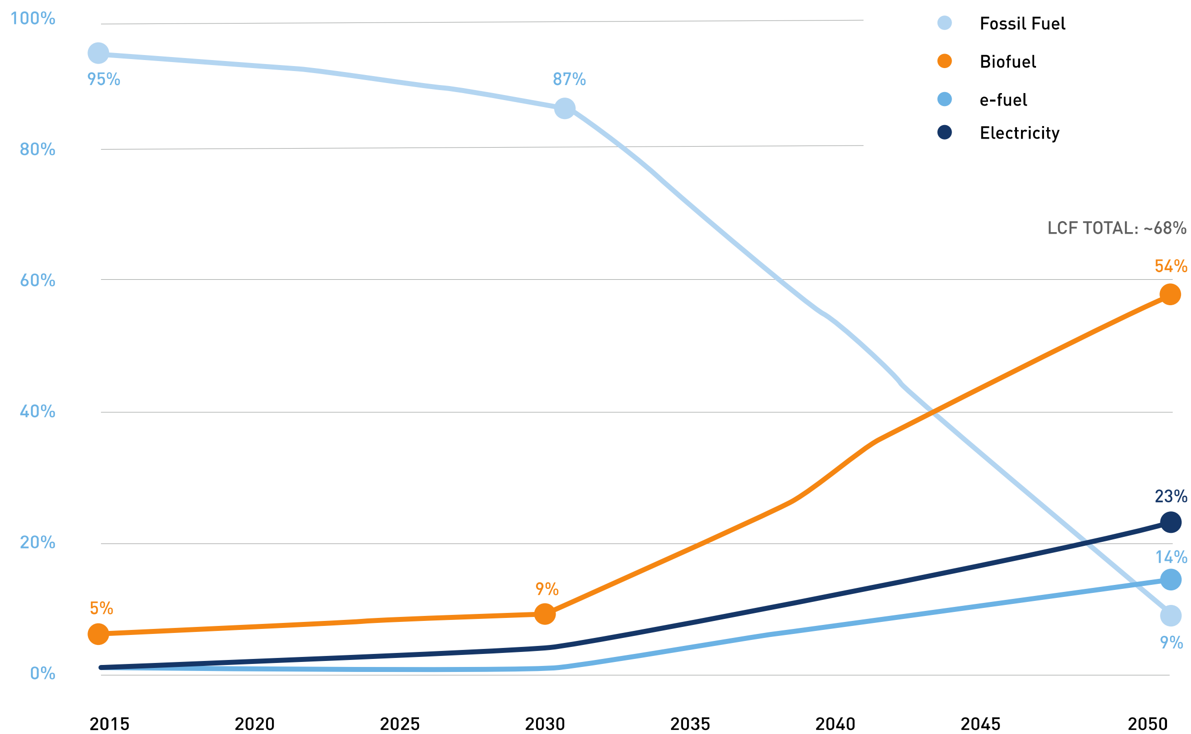

Figure 6.23: Fuel share by energy in low-carbon fuels scenario (FuelsEurope,2018)

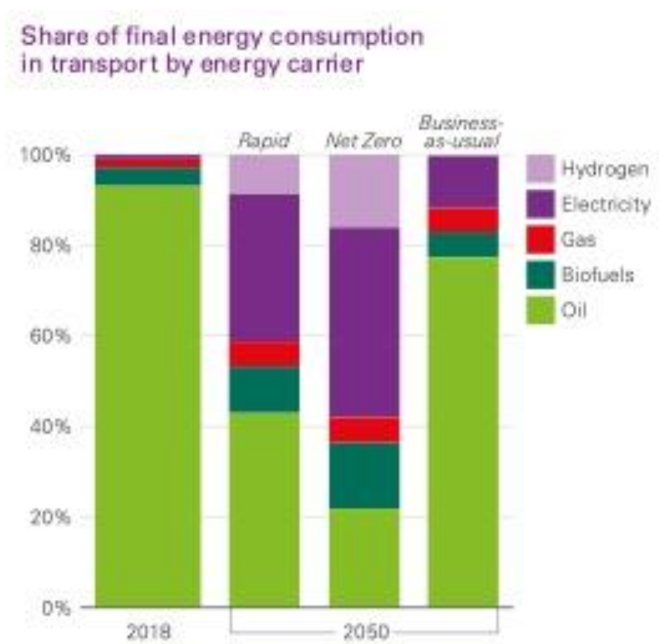

Figure 6.24: Share of final energy consumption in transport by energy carrier (BP,2020)

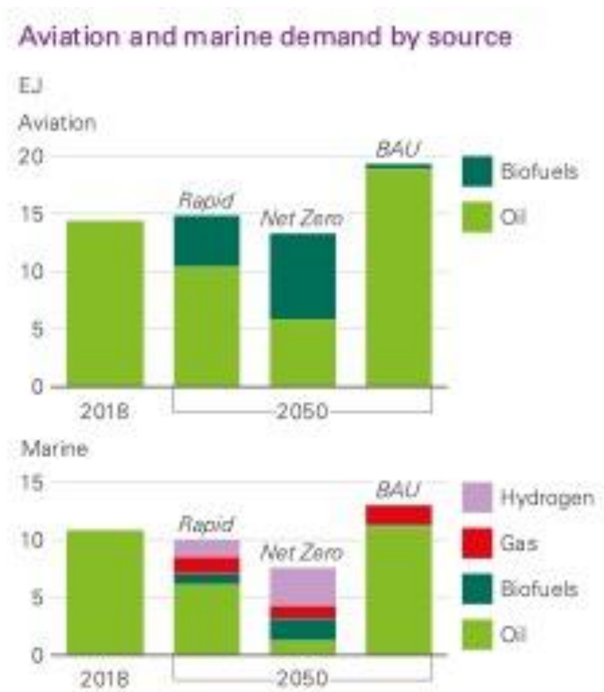

Figure 6.25: Aviation and marine demand by source (BP,2020)

Cleaner and greener fuels are one of the strategies that the oil refining industry is preparing in conjunction with the transportation sector. Various types of environmentally conscious fuel alternatives such as biofuel and e-fuel are looking to take a considerable share among the road transport fuels. This situation does not seem to apply to aviation and marine fuels as seen from Figure 6.23 wherein business-as-usual scenarios fuels that are oil based are experiencing an increase in demand for the 2050 projections.

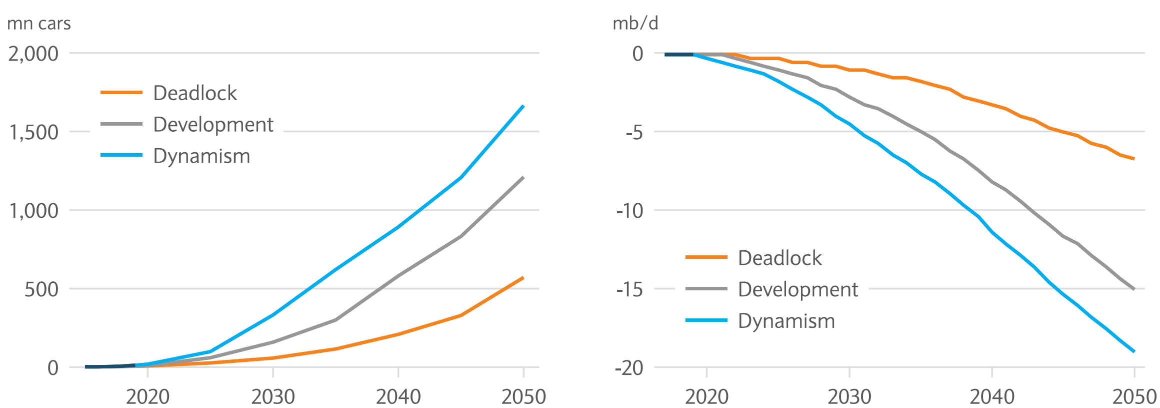

Figure 6.26: Number of electric vehicles and electric vehicles oil demand to 2050 (Barclays,2019)

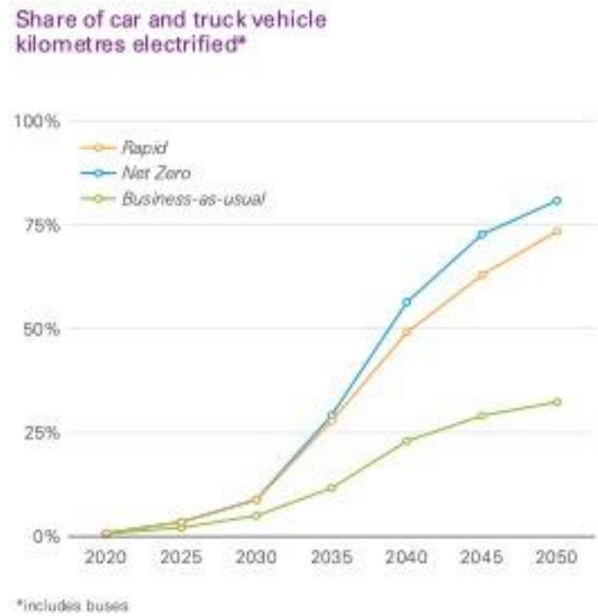

Figure 6.27: Share of car and truck vehicle kilometers electrified (BP,2020)

Electric vehicles are another action option that impacts oil refining and transportation industries all together with the phasing out of combustion engines and decreasing the share of fossil fuels in the market.

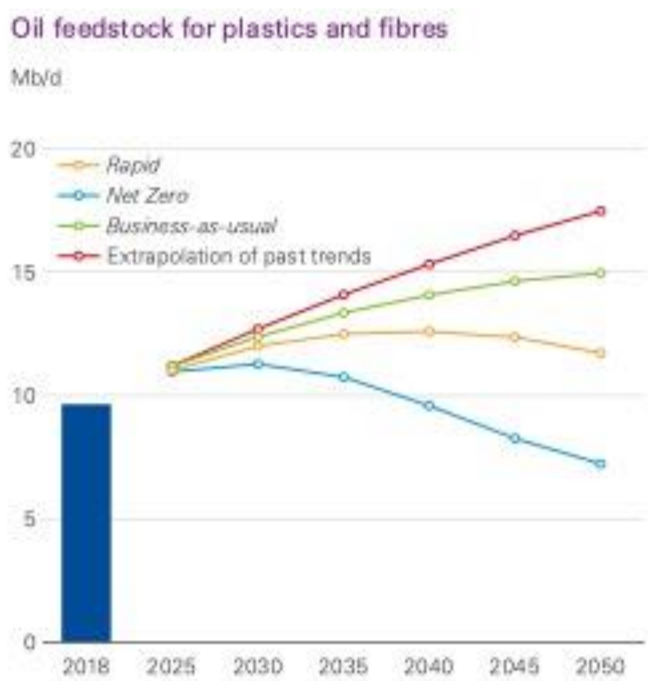

Figure 6.28: Oil feedstock for plastics and fibers (BP,2020)

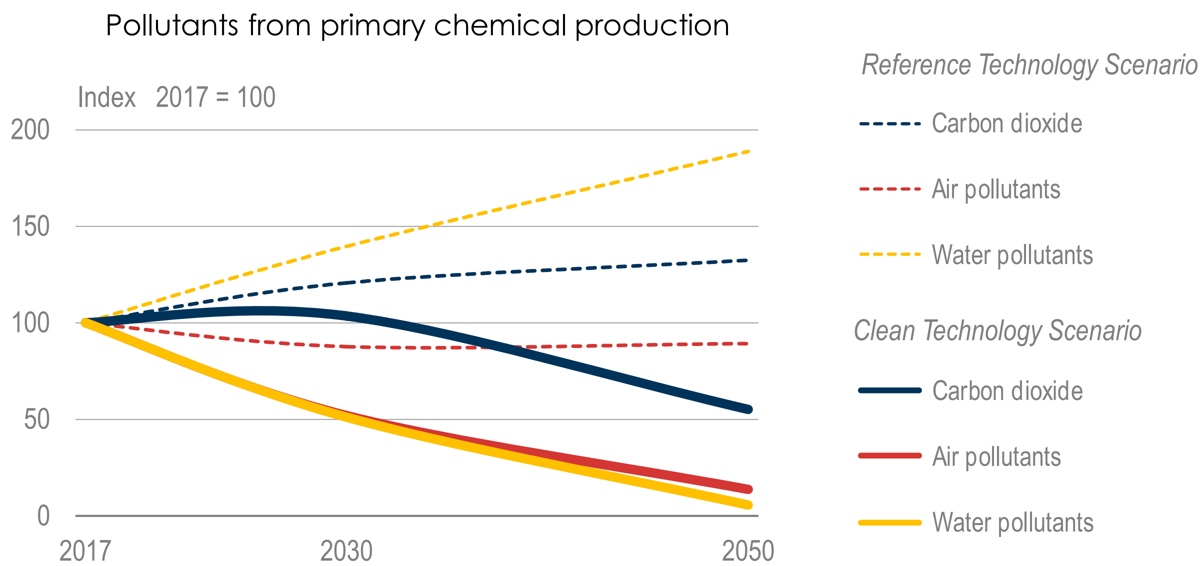

Figure 6.29: Projection of pollutants from primary chemical production (IEA,2018)

Pollution and harm to wildlife are massive environmental concerns that plastics have been responsible of and these problems are only going to get worse as the global middle-class population increases alongside the plastics demand and consumption. Oil is slated to stay as the main feedstock of plastics and in the reference technology scenario in Figure 6.27, which is based on another business-as-usual scenario (IEA, 2018), water pollution caused by plastics increases relentlessly.

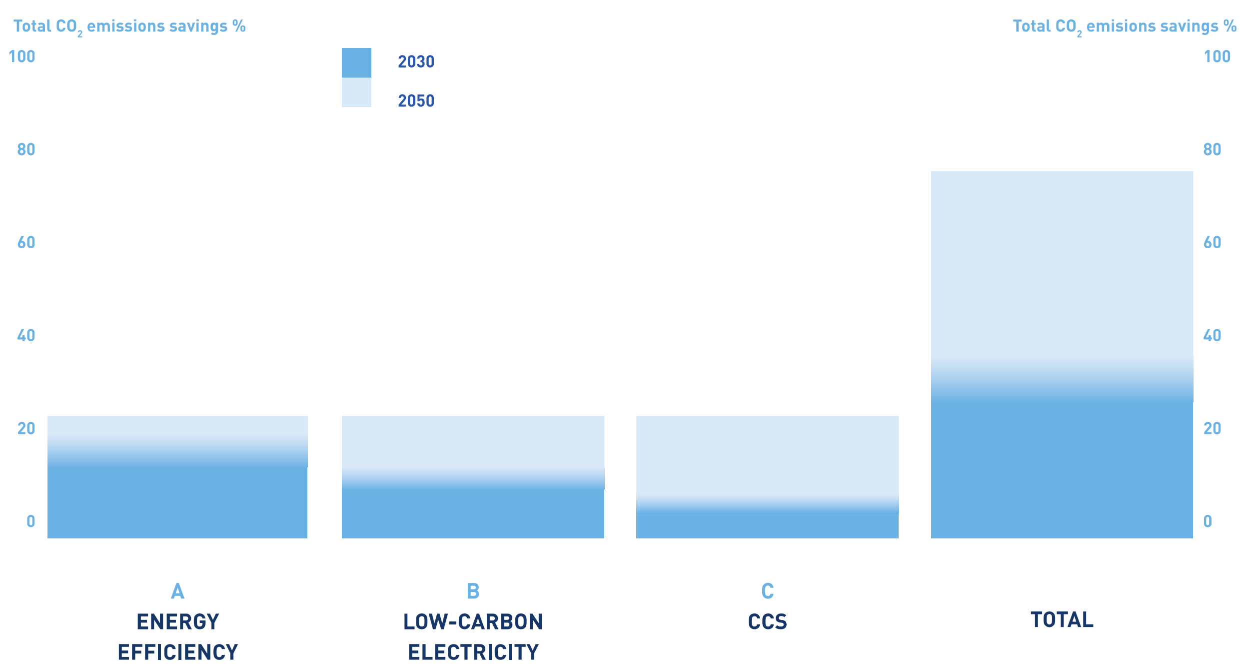

Figure 6.30: Total CO2 emission savings by technology (FuelsEurope, 2018)

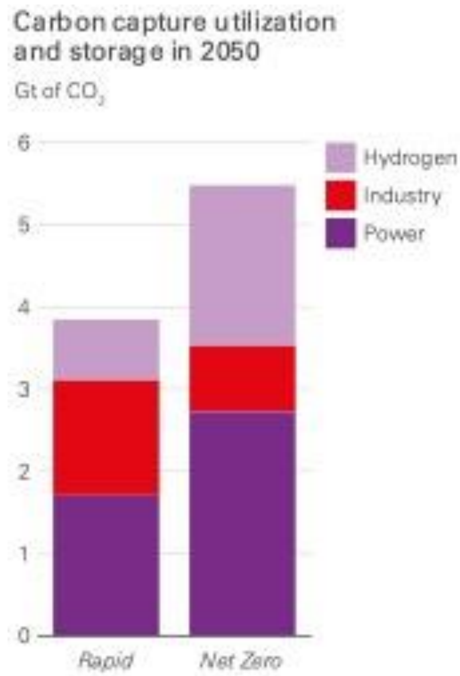

Figure 6.31: Carbon capture utilization and storage in 2050 (BP,2020)

#	Technology (CO_2 efficiency)	Demand Scenario: 2030 Reference Scenario (Example) Max abatement potential % CO_2 savings EU refining system (Scope 1 & 2)		
		2030 improved	2040 (interpolation)	2050
1	Energy Efficiency	≈15%	≈20%	≈20%
2	Use of Low-Carbon Energy sources	≈10%	≈15%	≈25%
3	Carbon capture (and storage) (CCS)	≈1-2%	≈10%	≈25%
Total (1+2+3)		≈ 25%	≈ 45%	≈ 70% (*)

Figure 6.32: Potential of emission mitigation technologies (Concawe,2017)

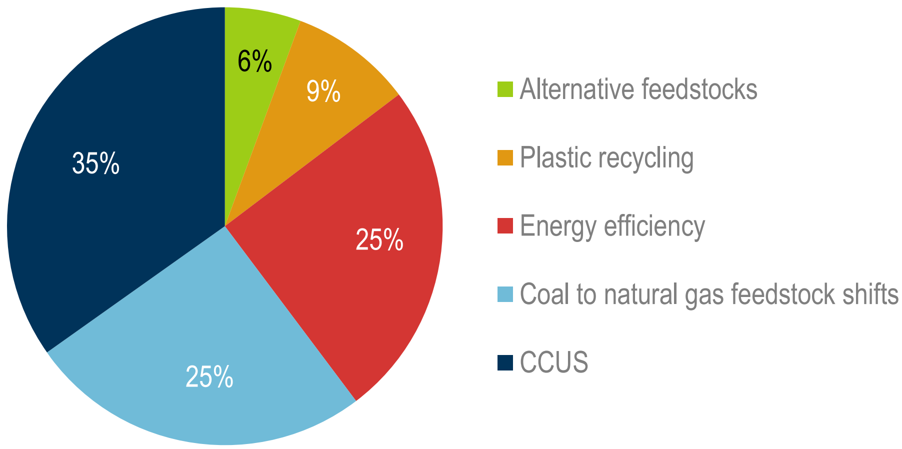

Figure 6.33: Contribution to cumulative CO2 emissions reduction (IEA,2018)

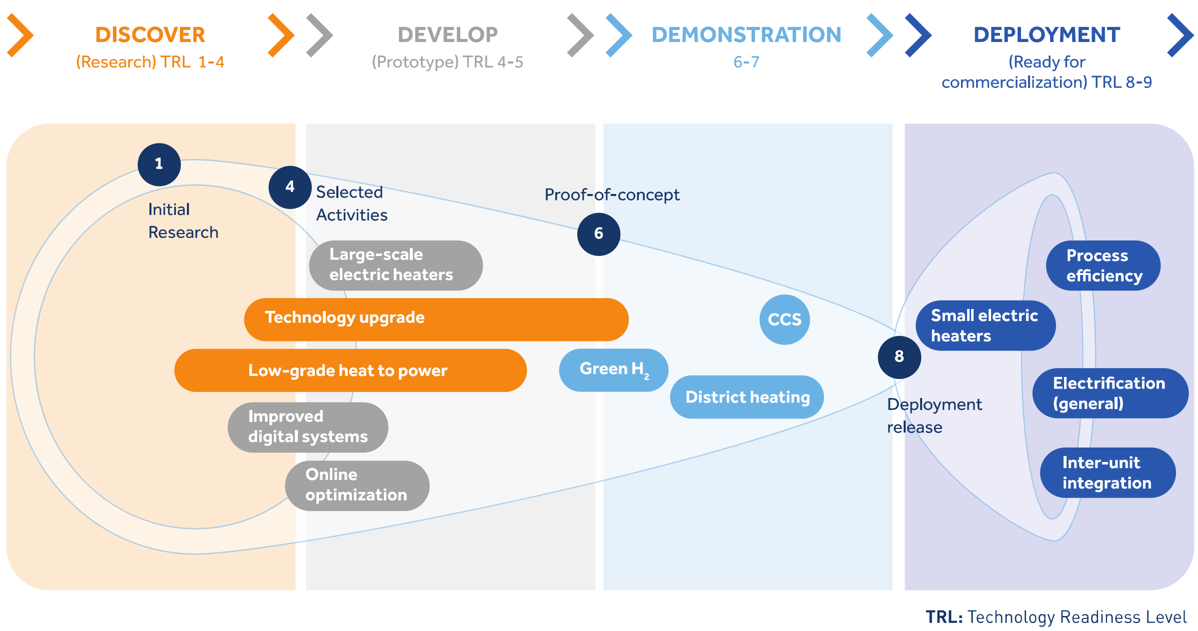

Figure 6.34: Examples of R&D Projects in the transition of refineries (FuelsEurope, 2018)

Technology	Description	TRL (*)	Timeframe for industrial application
1. Energy Efficiency	**Including (but not restricted to):** ■ **Refinery process efficiency:** ❑ Continuous improvement: through implementation of a combination of measures and projects involving some capital expenditure. Examples include fouling mitigation, catalyst improvements and hardware improvements such as new motors, heat-exchangers, etc.	6-8	Progressive uptake from now until 2040
	❑ Major capital projects: Larger efficiency improvements reflecting changes to the technical configuration of individual refineries (e.g. extensive revamps of existing facilities, new process plants).	3-8	By 2040
	❑ Inter-unit heat integration.	6-8	Progressive uptake from now until 2040
	■ **Energy Management Systems** combining equipment (e.g. energy measurement and control systems) with strategic planning, organization and culture.	6-8	Progressive uptake from now until 2040
	■ **Increased recovery of refinery low-grade heat** for export and electricity production.	3-6	2025-2030
2. Use of Low-Carbon Energy sources	■ Improved recovery of Hydrogen and LPG from fuel gas.	4-8	By 2040
	■ Increased use of imported low-carbon electricity:		
	❑ Use of electricity for general operations a/o rotating machines.	8	As grid becomes decarbonized, progressive uptake from now until 2050
	❑ Substitution of fired heaters by electric heaters.	4-8	As grid becomes decarbonized, progressive uptake from now until 2050
	❑ Production of hydrogen with electrolysers using imported renewable electricity.	4-6	As grid becomes decarbonized, progressive uptake from now until 2050
3. Carbon capture	Capture of a portion of the total CO_2 emitted by refineries The potential role of a CCS scheme together with steam reforming plants (SMR) to produce a low-carbon intensity Hydrogen is explicitly explored.	6-7	Major deployment in the 2030-2050 timeframe
4. Bio-processes	Progressive integration of sustainable bio-feedstocks, Power-to-Fuels and bio-blendstocks into the refinery. Negative emissions could potentially be achieved when combined with CCS.	3-7	2020+

Figure 6.35: Key mitigation Technologies (Concawe,2017)

Here, key emission mitigation technologies and their technological readiness are investigated. The industry and academia alike are in agreement that carbon capture and store will have an immense impact on emission mitigation but the major deployment of this technology is still some years away. The timelines provided for these mitigation technologies assist the roadmap to be generated in a defining way and allows for suitable sequencing and prioritizing of actions and strategies for the time periods of 2020 to 2030, 2030 to 2040 and 2040 to 2050.

Carbon emissions of oil refineries are idealized to have a persistent downward trajectory and even in pessimistic scenarios displayed in the compilation step of the scenario building, trends of emissions throughout the energy industry signal an overall decrease due to strict environmental legislation and commitment to emission goals by actors involved in the energy sector such as companies, governments and agencies. The expected consensus trend of decrease eliminates the issue of bifurcations or discrepancy of timelines of scenarios related to elements affecting carbon emissions thus there is no need for assumptions to thoroughly evaluate the emission criteria. Combining and evaluating the analysis and the outcomes for both criteria will be handled bilaterally in the following section and this step will conclude the analysis part before the generation of the roadmap.

6.4 Discussion of Results

After the analysis process of scenario building for the criteria, *demand for refined products* and *carbon emissions of refineries*, conclusions that are applicable to the roadmap are determined with respect to the research goal of integration and relevancy of oil refineries in future energy systems. First of all, in terms of the time horizon that the roadmap is set to cover, the only constraint that could have an impact on the timeline would be the shortly upcoming peak of demand for fuels. In scenarios that were based on business-as-usual developments, peak demand for transportation fuels occurs around 2025 and in scenarios that assume more rapid development of environmental and technological infrastructure of oil refineries, peak demand for transportation fuels has already happened and a constant downward trend has begun. For reports that utilize more than one scenario with different characteristics, the scenario that reflects the current developments the most, which are generally labeled as business-as-usual scenarios, are weighed more in terms of consideration because this thesis aims to generate a viable road map for the integration and relevancy of oil refineries in future energy systems and highly optimistic and ambitious scenarios when interpolated for many years into the future reflect unrealistic conditions and results. Second meaningful outcome derived from the compilation and investigation of scenarios and trends found in literature is that oil refineries need to transform their business model in order to adapt to the digitalized and decarbonized standards of future energy systems and it starts at an infrastructural level. Profit margins for conventional refined products like transportation fuels will not be satisfactory in the near future and more emphasis on producing petrochemicals and green fuels from clean feedstock is going to be a necessity. However, even plastics, the projected main driver of demand for refined products, have heavy environmental implications in terms of pollution and harm to wildlife. In order to facilitate a transition towards petrochemicals, the oil refining industry must lay the foundation for operations that enable the use of second-hand plastics and recycling because just focusing on the production of petrochemicals is not enough to satisfy the “refinery of the future” ideals. Lastly, cross-sectoral integration and communication is key for tackling climate stability and global environmental challenges. Because the industries and technologies that are responsible for shaping the future of digitalized and decarbonized energy systems are related so intrinsically that it becomes vital for these sectors to move forward with their developments in a coordinated manner. If the transportation sector makes the disruptive transformation to electric vehicles without establishing the foundation of electric fuels with the refining industry, the positive impact of electric vehicles will diminish compared to the expected impact of electric vehicles on carbon emissions. This complication is observed through the scenarios investigated in this research as the significant differences in emissions between "optimistic" or "rapid" scenarios and the "business-as-usual" scenarios are mentioned to be full cooperation and commitment from industry, governments and society. This thesis aims to approach this complication tentatively and tries to generate the roadmap to the integration of oil refineries with realistic expectations of action and commitment from all actors and elements involved.

Finally, a compilation of scenarios and trends that can act as the playbook for the roadmap will be generated with respect to the two criteria and other concepts that are related to these criteria. In the context of the time period of 2020 to 2050, oil refining products can be separated into three categories that exhibit different trends in the scenarios that are assembled. These three categories are conventional transportation fuels, green transportation fuels (e-fuel, biofuel etc.) and petrochemical products. With the exponential increase in population and spending of middle-class underway, petrochemicals are unequivocally determined to experience increases in investment for production, demand and consumption. Fuels, in general, don't exhibit the same trend in the scenarios evaluated as conventional fuels still have a little room to grow in demand before becoming obsolete and green fuels still have room to grow in terms of technological readiness, mass production and deployment before heavily impacting the carbon emission generated by the transportation sector. This inverse correlation may be the key niche that oil refineries which do not have petrochemical integration can take upon in future energy systems, promoting and developing clean fuels. In terms of carbon emissions of refineries, the path to eliminating emission from refinery operations are well defined in the scenarios that are compiled. With the utilization of energy efficiency, low carbon electricity and carbon capture and storage technologies, the refinery operations are projected to emit around 80 percent less hydrocarbons, contributing to the decarbonized energy systems of the future (Concawe, 2018). However, the share of refinery operations in the total emission generated by refineries is minuscule as the largest share comes from combustion fuels, which are planned to be phased out with the emergence of cleaner feedstock, fuels and electric vehicles. The other emerging problem that mostly evades the oil companies' agenda is the rush to petrochemicals. As previously mentioned, petrochemicals have the potential to become the most in demand product that refineries produce but petrochemicals, plastics in particular, have negative environmental implications that are not aligned with global environmental legislation and emission goals. In order to mitigate the environmental hazard generated by petrochemical production, second-hand utilization and recycling facilities are proposed as solutions throughout the researches inspected in this research. However, even in the "optimistic" scenarios, only a quarter of the produced petrochemicals can be reused or recycled in 2050. This situation showcases the industry's negligence towards the long-term environmental impact of petrochemicals because petrochemicals are the only hope of the oil refineries for competitiveness and profitability in the oil products market. The dependence of refineries for products that can create a value chain is inseparable from the challenges that the industry faces in terms of survivability but the attention and prospect petrochemicals are getting is not aligned with the net-zero emission philosophy that is idealized during the scenario building procedures.

One last thing to point out is the difference of agenda, resources and capabilities between energy systems of developed and developing countries (Chapman et al., 2016). In developing countries, matching the demand for refined products such as fuels and plastics is prioritized and this opportunity is used to build state-of-the-art refining facilities with petrochemical integration and digitalized infrastructure, planning to benefit from these plants in a variety of operations (UKPIA, 2017). On the other hand, developed countries are struggling to operate their tens of years old facilities and shying away from retrofitting those facilities to satisfy the standards of decarbonization and digitalization due to huge capital costs. One big advantage that developed countries have is the advancements already made in renewables and the environmental agenda that is being pursued with intensity in all branches of energy. Thus, even though the refinery capabilities of for example Europe is lacking behind their brand-new counterparts in Asia and the Middle East, the integrated infrastructural foundation and the priority of environmental concerns make the region lead the way in terms of constructing future energy systems (Ruble, 2019). In that sense, Europe can lead the way of integration of oil refineries in energy systems and the lessons learned from Europe's experience would guide the rest of the world in which more advanced refineries and infrastructure is being built.

6.5 The Roadmap

From the analysis done on the scenarios and forecast on the issues surrounding the oil industry and its interaction with energy and emissions, due to environmental legislation and technological advancements that are required to achieve emission goals, it is formulated that energy sectors will converge to integration and complete utilization of resources with the oil refining industry. The ideal of net-zero emissions not only just dictate the optimal use of resources but also the maximization of all generated products such as heat and plastics through various means and this can only be achieved in a fully integrated and connected energy system. In order to achieve the end goal of integration of oil refineries into decarbonized and digitalized energy systems, a micro to macro approach needs to be taken in the roadmap. Prioritizing the energy efficiency improvements, gradual use of low-carbon energy during operations and market introduction of clean feedstock and fuel would be the initial steps of the roadmap while environmental legislation on emissions gets incrementally stricter (FuelsEurope, 2020). These technologies and approaches are more ready for implementation and adoption in terms of technological readiness levels and capitalizing on the last periods of time where conventional refining products still have relatively acceptable demand would be crucial for financial stability and getting a return for the investments of previously mentioned technologies. Other sectors in relation to the refining sector are also expected to accompany the developments in oil refineries with the deployment of vehicles run on cleaner fuels, policy implementations regarding the content of air and maritime transport, the emergence of low-grade heat to power and technological advancements in recycling and reusing of petrochemicals throughout the earlier stages of the time period between 2020 to 2050. Unlike the assumed consensus of the petrochemicals as the next and only driver for demand, it is urged for refineries to use their facilities and platform to progressive transformation to low-carbon content feedstock and fuel because of the integration opportunities that provide with other industrial sectors and the possible snowballing of petrochemicals related environmental issues (CIEP, 2018). As the time horizon progresses, more sophisticated technologies for mitigating emissions, continually producing cleaner products, establishing connections between industrial clusters and increasing the overall system efficiencies are the projected events occurring in the oil refining industry. Development and deployment of carbon capture and storage facilities are viewed as a key factor in emission mitigation and the oil refining industry is one of the sectors that is aiming to benefit from this technology. Being integrated into an industrial cluster also enables the efficient use of facilities like plastics recycling, residual heating and CCS because of investing in a singular unit rather than employing those facilities to all types of plants and operations and the connectivity that integration allows alongside the digitalization of business makes for an oil refinery that is producing and promoting clean fuels while contributing to mitigating emissions at a high level. The illustration of an ideal "refinery of the future" is given below.

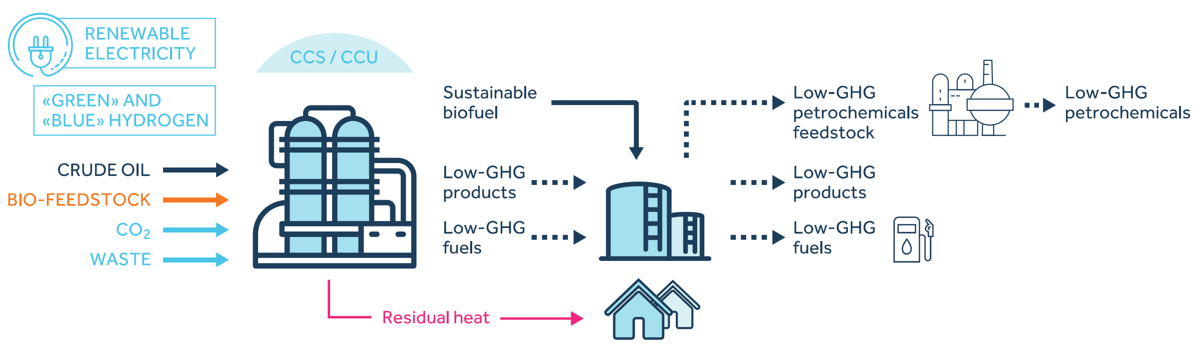

Figure 6.36: An illustration for the concept of "refinery of the future" (Concawe, 2019)

With the complete discussion of findings from the data analysis of scenario building alongside the scenarios that are investigated, the roadmap for integration and relevancy for oil refineries into future energy systems is created.

1) Improved CO2 efficiency of refining operations (circa 2020 – 2030)

- Adoption of more efficient technologies of refining operations
- Regulatory framework and strategy supporting improved participation and incentives
- Gradual introduction of low-carbon components to the product mix
- Capitalizing on the last period of competitive demand for conventional refining products
- Implementing digitalization measures such as Industrial Internet of Things (IIoT)

2) Relentless progression of emission mitigation (circa 2030 – 2040)

- Balancing petrochemicals production with recycling and second-hand utilization measures
- Processing low-carbon feedstock and blending higher ratios of low-carbon products
- Emergence of advanced refinery technologies like biorefineries and waste-to-fuel
- Involvement of hydrogen in refinery operations
- Cross-sectoral R&D programs to prepare for the upcoming integration

3) Integration of oil refineries into industrial clusters (circa 2040 – 2050)

- Advanced emission mitigation via carbon capture and storage
- Complete integrated cluster with residual heating and other industrial connections
- Exchanging of various feedstocks and semi-finished products for sustainable manufacturing
- Hub for production and distribution of low-emission energy products and raw materials
- Synergizing with the mass deployment of electric vehicles via e-fuels

6.6 Design Quality Criteria

In this section, the objectivity, reliability and validity of the outcomes will be investigated. Objectivity is ensured in this data analysis process by compiling and including scenarios and forecasts from government agencies, oil companies and third-party organizations. Bringing all available perspectives together created a united trajectory for the criteria considered in this research. Reliability is enabled in this data analysis process by conserving the stability and consistency of the analysis component throughout the scenario building exercise. It is also important to note that scenarios and forecasts gathered from various sources expressing similar trajectories even though the scenarios utilized in these resources did not include the same assumptions, reinforcing the reliability of the data collected and analyzed. Lastly, the validity of this research is accomplished by following the scenario building procedures through and through and generating results from the compilation of several sources concerning the same time period and parameters. The validity of a study refers to the principle of “measuring what is ought to be measured” and in this research, the objective of preparing a roadmap for integration and relevancy of oil refineries into future energy systems is echoed and accomplished with the results of the scenario building analysis.

6.7 Chapter Synthesis

This chapter provided the final deliverable of this thesis which is a roadmap for integration and relevancy of oil refineries in future energy systems shaped by the net-zero emissions ideal. The two criteria generated by Qualitative Content Analysis were *demand for refined products* and *carbon emission of refineries* and these two criteria were the inputs of scenario building analysis. Both criteria were inspected through scenario building procedures and with the assembly of relevant scenarios and forecasts, conclusions were drawn to feed the inception of the roadmap. By the compilation and inspection of various scenarios and forecasts from government agencies, oil companies and organizations, a comprehensive perspective for the future role of oil refineries was created for the time horizon of 2020 to 2050. The generated roadmap included a three step, micro to macro approach, from improving the efficiency of refinery operations to relentless progression of emission mitigation and finally reaching the end goal of integration of oil refineries into industrial clusters to minimize carbon emission while ensuring the survivability and relevancy of oil refining industry in a digitalized and decarbonized energy environment. In the next chapter, reflections on the data analysis process, interpretation of research outcomes and recommendations for decision-makers will be provided.

7. Discussion

This chapter presents a discussion on the research process and outcomes. Section 7.1 reflects on the data analysis process by reviewing the methods utilized throughout the research. Section 7.2 presents an interpretation of results in the context of global environmental efforts and the future of energy systems. Section 7.3 concludes the chapter with the recommendations for decision-makers on the research subject of the future of the oil refining industry.

7.1 Reflection on the research process

Qualitative research approach on energy studies is an emerging type of research that provides viable applicability to developing emission-free future planning of energy systems. Qualitative research requires more commitment to methodology and procedures of data analysis methods compared to quantitative studies in order to establish objectivity, reliability and validity of the results. For that reason, this research directly linked data collection of desk research to Qualitative Content Analysis and Qualitative Content Analysis to scenario building to create a systematic approach to the research boundaries confined in this thesis. Both scenario building and content analysis are situated in between conventional qualitative and quantitative logic of research and the combination of these methods allows to preserve the complexity of the research while bringing formalization to enable more accurate comparative analyses (Yamasaki & Spreitzer, 2006). In order to utilize these methods, relevant information and data must be collected and the method of data collection in this research was desk research. The collected data was from a wide range of sources such as companies, governments, agencies, the NGOS and academia and it consisted of various types of documents such as academic articles, newspaper articles, business journals, government papers, company reports and scenarios. This variety in form and source of data allowed the research to be inclusive for all perspectives and allowed the data analysis conducted to be comprehensive.

The main objective of the utilization of Qualitative Content Analysis in this research process is to filter meaningful criteria in the literature gathered by desk research regarding the integration of oil refineries in future energy systems so that scenario building can use these criteria for a more precise and focused analysis. Meaning units are the central point of Qualitative Content Analysis because the determined meaning units are further recontextualized, categorized and compiled to obtain meaningful criteria. The determination of meaning units was done by textual analysis on the obtained resources and investigation of mentions in literature acquired in the conducted desk research. Involvement of human creativity is also an important element of Qualitative Content Analysis during the condensation and categorization of meaning units as the input of the researcher makes the illustration of the research process coherent with the rest of the thesis. At the end of the Qualitative Content Analysis, the two meaningful criteria that were generated in the context of literature collected by the conducted desk research on the future of oil refineries were demand for refined products and carbon emissions of refineries. In the chapters covering the current challenges and developments the oil refining industry is facing during this energy transition period of decarbonization and digitalization, reducing emissions to the ideal level of net-zero while attaining financial stability was indicated as the constraint of establishing an integrated role for the oil refineries. Demand for refined products is crucial for the survivability of refineries considering the trends of conventional fuels and the expected emergence of green fuels and petrochemicals. Carbon emissions is currently maybe the most impactful criteria in energy systems due to environmental legislation and emission goals set in stone and mitigating carbon emission are designated as the number one priority of actions to climate stability. Investigating the scenarios and forecasts regarding demand for refined products and carbon emissions of refineries would result in a comprehensive perspective that results in analytical insights on the uncertain future of oil refineries in a digitalized and decarbonized energy environment. Generation of these two criteria through the textbook procedures of Qualitative Content Analysis reinforces the systematic approach this research wants to accomplish while being able to filter out the most critical components for the research goal of preparing a roadmap for integration and relevancy of oil refineries in future energy systems.

Scenario building is used in this research to come up with a viable roadmap for integration and relevancy of oil refineries in future energy systems. Through the procedures of the analysis conducted with scenario building, scenarios and forecasts that are abundant in the research subject of the future of oil refineries are assembled and investigated with respect to the criteria acquired through systematic reduction of literature by Qualitative Content Analysis. Employment of demand for refined products and carbon emissions of refineries as the starting point of scenario building allows for the continuation of the systematic qualitative approach and preservation of coherence throughout the data analysis process. Moreover, every scenario needs key variables and measures to clarify the implications for decisions and recommendations that are made with the final form of projections of these variables (Moniz, 2006). With the stages of scenario building, fundamental drivers for demand of refined products and carbon emissions of refineries were singled out, the effects of these drivers were investigated, the time horizon that the scenario building will operate in was decided, scenarios and forecasts that are related to the future of oil refineries are assembled and compiled, assembled resources were inspected for assumptions and bifurcations and conclusions were drawn from the analysis. The assembled and compiled forecasts and scenarios from various sources such as oil companies, government agencies and organizations reinforced the criteria, drivers and effects determined in the analysis and guided the research into obtaining critical information in the search for a roadmap for integration and relevancy of oil refineries in future energy systems. With respect to the time horizon of emission goals and the technological readiness of relevant advancements in the oil refining and other related industries, a three-step roadmap was generated. Scenario building provided great synergy with the research subject, objective and resources found and enhanced the systematic approach that qualitative studies required to attain, especially in research areas dominated by quantitative methods such as energy and its future. The roadmap that was generated corresponds to the research objective designated in this thesis and the methodological and analytical framework of this research enabled the objective by creating an approach with maximizing the effectiveness of resources in the research subject and creating a systematic qualitative research process that is fairly new in energy studies.

7.2 Interpretation of results

Defining the role and participation of oil refineries in digitalized and decarbonized future energy systems is an integral part of reaching the emission goals set globally. Utilizing the resources and establishing connections between industrial clusters allow for more efficient use of technologies and create a circular exchange of raw materials, products and information that maximizes the efforts of mitigating emissions in the energy sector. In order to reach that level of integration though, oil refineries have to be careful about financial security and stability as the demand for refined products such as conventional transportation fuels, clean transportation fuels and petrochemicals have to be taken into consideration alongside the environmental implications of these products.

The final deliverable of this research is in the form of a roadmap for the integration and relevancy of oil refineries in future energy systems with respect to the criteria of demand for refined products and carbon emissions of refineries. The roadmap consists of three stages that are determined by the timelines of technological readiness of emission mitigation technologies and projected demand for various types of refined products. In the short run where conventional transportation fuels are just about to hit their peak demand and there is a little notion for integration as of now, it is suggested for the oil refining industry to focus on improving the energy efficiency of their operations by achieving better yields, decreasing environmental hazard and improving data monitoring and analysis operations within the refinery. It is expected by oil companies and leaders in the field that Industrial Internet of Things has the potential to increase the overall performance of refineries by implementing digital technologies that enable better decision-making, asset management, waste management and data analysis in refining and these prospective benefits are vital for micro-operations and business of oil refineries. In addition, a regulatory strategic framework for the upcoming procedures that will eventually lead to the integration of oil refining in future energy systems should be initiated to prepare the administrative infrastructure.

With the improved performance and efficiency of refineries accompanied by technological advancements in transportation, the second stage of the roadmap consists of the relentless progression of emission mitigation. At this point in time, demand for conventional transportation fuels will have hit a plateau and petrochemicals are considered as the main driver of demand for oil refining industry. In this roadmap, it is suggested that the presence and prevalence of petrochemical integration should be supplemented with measures of recycling and second-hand utilization of petrochemical products, plastics in particular because a non-overseen explosion of plastics could have harsh implications on the environment. Refineries are forecasted to introduce low-carbon feedstock and fuels in their portfolio during this time period as well as the inception of biorefineries, waste-to-fuel technologies and hydrogen in refineries, which will all be steps taken in consideration of mitigating emissions. Lastly for the second stage of the roadmap, cross-sectoral research and development should be encouraged and facilitated in order to prepare the physical infrastructure of the upcoming integration of oil refineries in energy systems.

The last stage of the roadmap also reflects the research objective of this thesis, which is defined as the integration of oil refineries in industrial clusters. The benefits of integration and connections established in an industrial cluster is immense for oil refining industry and the energy sector alike. Deployment of carbon capture and storage technologies in an industrial cluster maximizes its efficiency and provides a more dynamic role for CCS. Facilitating the exchange of raw materials, semi-finished products and other components enhance the manufacturing process happening in these industrial clusters while managing excess heat, materials and waste in an optimal way with the connections to residual heating and waste management capabilities. Mass production and deployment of electric vehicles also correspond to this last time period in which refineries will have means of producing e-fuels and becoming a hub for production and distribution of low-carbon content products and feedstock (IEA, 2020). The final form of refineries described in this roadmap accomplishes the research objective as oil refineries obtain a relevant, distinct role in integrated, decarbonized and digitalized energy systems of the future. Contributing to emission mitigation greatly while producing and facilitating low-carbon components in transportation and energy is the ideal position that oil refineries should attain in the future and the roadmap illustrated in this thesis reflects on a viable path to this position with respect to scenarios, forecasts, literature and other resources obtained regarding the future of oil refineries.

7.3 Recommendations for decision-makers

The research process, the analysis and the outcomes of this study have connections and implications to policy and decision-making in the oil refining industry and the energy sector in general. The list of recommendations for decision-makers based on this thesis is provided below.

- For the global perspective on oil refineries, developing countries with plans of new refineries and enhanced refinery operations such as China, India and the Middle East should follow the developments in Europe closely and apply the lessons learned from the integration and transition period of Europe to their newly built, technologically more advanced refineries to reap the full benefits of these investments in terms of financial and environmental concerns.
- It takes a lot of preparation, infrastructure and coordination with other industrial sectors in order to achieve the ideal "refinery of the future". Thus, the steps for a regulatory framework and strategy for the future of oil refineries must be realized as early in the process as possible to ensure comprehensive planning and development of digitalized and decarbonized future energy systems.
- Petrochemicals are slated as the undisputed driver of demand for refining products and huge investments are already underway in Asia and the Middle East to satisfy this forecasted demand for petrochemicals. However, an uncontrollable rush to petrochemicals has the potential to impact the environment in terms of pollution and harm to wildlife. Thus, studies and practices for the implementation of recycling and

second-hand utilization of petrochemicals should accompany the efforts of deploying petrochemicals production means.

- Investing into digital technologies infrastructures such as Industrial Internet of Things and sensors have the potential to increase the efficiency and the performance of oil refineries very early on in the integration and emission goals timeline. With respect to the analysis and outcomes of this research, it is recommended for oil industries to adopt digitalization standards as soon as possible and equip their businesses with advanced data monitoring, collection and analysis prospects, asset and waste management opportunities, increased mobile communication and improved health and safety risks for workers.
- Investment security and financial stability in the oil refining industry are of utmost importance in order to realize the technological improvements and integration of refineries in future energy systems. Financial concerns of oil refineries are compounded with the effects of COVID-19 pandemic and securing the financial future of the refining industry should be another point in the agenda of decision-makers.
- Electric vehicles have the potential to transform public and private transport. Even though mass production and mass deployment of electric vehicles is still projected to be years away, it is a technology that contributes to emissions greatly so inevitably electric vehicles will take up a considerable market share of road transport. To capitalize on this emergence, oil refineries should be in coordination with automotive manufacturers to progress with them in terms of developing fuels and raw materials.

8. Conclusion

This chapter concludes the research by providing conclusions derived from the process and analysis conducted in this thesis. Section 8.1 expresses the answers to the research questions in hindsight. Section 8.2 illustrates the alignment of this thesis with Complex Systems Engineering and Management study program. Section 8.3 gives out recommendations and limitations for future studies that target the research subject of the future of oil refineries in digitalized and decarbonized energy systems.

8.1 Answers for the Research Questions

This research aimed to generate a roadmap for relevance and integration of oil refineries into future energy systems. To accomplish this aim throughout the research process, the main research question and sub-question were created to analytically solve the problem statement and approach the issue in a systematic way. In this section, the answers to these research questions that were investigated and analyzed in this thesis are discussed and led into answering the main research question of "*"How can oil refineries stay relevant and integrated to future energy systems with international environmental legislation, carbon emissions and technical advancements?"*.

SQ1: What are the current challenges that oil refineries face in the context of international environmental legislation, emission goals and technological advancements?

Oil refineries face a wide array of technological and environmental challenges while the energy industry is preparing for the upcoming transition period of emission mitigation and technological developments. Through their operations, feedstock and products, oil refineries are one of the highest emitting industrial sectors per facility and since carbon emissions are the most central parameter in current and future energy systems, they face the challenge of overhauling their facilities, businesses and production in order to adapt to the age of decarbonization. Digitalization is also an influential concept on energy systems as businesses implement digital technologies to their operations for improved decision-making, communication, data analysis and monitoring. Even though there are developments regarding new refineries opening in Asia and the Middle East, many refineries are old and outdated in terms of their operations and capabilities, thus presenting the dilemma of investing capital to retrofit old refineries or risking shutdowns due to low efficiencies (Reuters, 2020). Lastly, the transportation sector is intrinsically related to the refining industry and the developments in transportation in terms of electric vehicles and phasing out fossil fuels impact oil refineries greatly. With the projected plateau of demand for conventional transportation fuels, oil refineries face the challenge of financial stability and survivability due to their current portfolio of products not conforming the standards and necessities of day and age where tackling carbon emissions and achieving climate stability have become a priority on a global scale.

SQ2: What are the developments that oil refining industry is currently undertaking and planning to undertake in the near future to combat the challenges of international environmental legislation, emission goals and technological advancements?

In order to satisfy environmental legislation, global emission targets and technological standards of day and age while attaining financial stability, oil refining industry is preparing technological and environmental developments to accompany them into the future energy systems. Digital technologies such as the Industrial Internet of Things and advanced sensors have the potential to improve the refineries' decision-making process, optimize waste and asset management and enhance data analysis and monitoring means, therefore increasing the overall efficiency and performance of the refinery. Digital technologies also create new opportunities for communication and connection at a cross-sectoral level, creating the first steps to integration and sustainable use of resources and raw materials. As the demand for conventional transportation fuels is expected to reach its peak in the very near future, petrochemicals are slated as the next driver of demand for refined products and this trend is confirmed by the expansion of the middle-class population by 3 billion people by 2030. This middle-class section of the population is expected to experience a huge increase in consumption alongside the number of people graduating to middle-class and petrochemicals, in particular plastics, are viewed as the key demand component of this population, thus easing the financial security of oil refineries. In terms of environmental impact improvements, low-carbon content feedstock and fuels are the developments that will mitigate emissions resulting from refineries as the main source of refineries were emissions caused by combustion fuels. Other infrastructural technologies that are getting ready for deployment and will have an immense impact on overall emission from the energy sector are carbon capture and storage, plastics recycling and second-hand utilization facilities and increased involvement of biomass and hydrogen in feedstock and fuel production. Lastly, integration of oil refineries in industrial clusters provides the opportunity of using excess heat in residual heating and exchange of raw materials, semi-finished products and intermediaries to enhance manufacturing in clusters, resulting in an overall increase in performance and emission mitigation for sectors involved in the integrated cluster.

SQ3: How does the developments in the oil refining industry respond to the current challenges with respect to scenarios, forecasts and trends for the future energy systems?

The evaluation of current challenges the oil refining industry is facing and the corresponding developments are executed by Qualitative Content Analysis. Through the data analysis stages of QCA, which were decontextualization, recontextualization, categorization and compilation, the findings from desk research were systematically reduced to find meaningful criteria for projecting how will oil refineries fare against the challenges of decarbonization and digitalization in the context of the developments the industry is currently implementing or planning to implement. Two meaningful criteria that were generated in relation to the integration of oil refineries in future energy systems were demand for refined products and carbon emissions of refineries. Trajectories of these two criteria would give a comprehensive outlook on the future of refineries and allow the evaluation of financial stability, environmental performance and technological standards that integration into future energy systems would require. The alignment of challenges and developments by QCA allows the research to reflect on the opportunities that the current energy transition provides and the drawbacks that need to be worked on in order for the oil refining industry to have a contributing role in emission mitigation and industrial cluster integration. It is observed with the data analysis conducted that against the challenges that are impacting the whole energy sector in terms of operations and products, the oil refineries are preparing isolated solutions that in large does not contribute to global targets of technological advancements and environmental goals. The main objective for generating criteria by the systematic reduction done with QCA is to evaluate the prospects of these criteria in scenario building and with the utilization of scenario building comprehensive steps towards integration and relevancy of oil refineries in digitalized and decarbonized energy systems will be created.

SQ4: What steps should the oil refining industry take in the short and mid-term to have a sustainable role in the decarbonized and digitalized future energy systems?

The steps that the oil refining industry should take to have a defined, sustainable role in future energy systems and the compilation of these steps in the form of a roadmap was generated with the utilization of scenario building. In order to define the steps that should be taken by oil refineries, the systematic analysis approach of scenario building is adopted. For the two criteria designated to be meaningful and defining for the future integration of oil refineries in energy systems, demand for refined products and carbon emissions of refineries, fundamental drivers were singled out, the effects of these drivers are investigated, time horizons for the analyses were determined, relevant scenarios and forecasts are assembled and compiled, analysis processes were checked for assumptions and bifurcations and finally conclusions were drawn with respect to the research objective. The three-step, micro to macro roadmap for oil refineries to be integrated into future energy systems were i) focusing on improving CO2 efficiency of refining operations for the time period of 2020 to 2030, ii) relentlessly progressing on the issue of emission mitigation for the time period of 2030 to 2040 and finally iii) integrating into industrial clusters for the time period of 2040 to 2050. Considering the scenarios and forecasts from various sources, viabilities of solutions offered throughout literature, timelines and technological readiness of technological advancements in the periphery of energy efficiency and emission mitigation, this roadmap provides a realistic approach to oil refineries becoming a hub for low-carbon content feedstock and fuel production, distribution and promotion while contributing to emission mitigation in a cluster with connections to carbon capture and storage, residual heating and waste management.

With the compilation, inspection and reflection of all the research and data analysis conducted, the answer to the main research question can finally be given.

Main Research Question
"How can oil refineries maintain their relevance and establish integration into future energy systems with environmental legislation, carbon emissions and technological advancements?

In order for oil refineries to stay relevant and integrated to future energy systems that adopted digitalization and decarbonization philosophies and to have a distinct role in emission mitigation in these systems, they need to elevate their operations to the technological and environmental standards of the current age first and then make progressive steps towards integration into industrial clusters. With the adoption of more energy efficient technologies, gradual introduction of low-carbon components into the product mix and implementation of digital technologies such as the Industrial Internet of Things, oil refineries can signal their importance in relation to transportation and energy sectors. After that, oil refineries should relentlessly pursue how to contribute to emission mitigation more and more. Processing low-carbon feedstock, blending higher amounts of low-carbon products, investing in technologies like biorefineries, plastics recycling and waste-to-fuel and introducing hydrogen to refinery operations would be the actions oil refineries should take with respect to scenarios assembled through this thesis and the technological readiness of these developments. Finally, deploying carbon capture and storage facilities, establishing integration and connections with industrial clusters, waste management and residual heating and synergizing with the transportation sector about e-fuels for the emergence of electric vehicles have the prospects for the oil refining industry to become the hub of production, distribution and promotion of low-carbon content energy products and raw materials while contributing to the whole energy sector. The roadmap also expresses implications for the energy sector as a whole because accomplishing the steps of the roadmap would involve early discussions in the energy sector for inclusive regulatory framework, cross-sectoral R&D and common strategies that incentivize all actors. With the ideal of net-zero emissions in mind, oil refineries can become a central figure of decarbonized and digitalized energy systems of the future with a strong commitment to comprehensive energy strategies such as this roadmap and coordination among the whole energy sector.

8.2 Alignment with Complex Systems Engineering & Management

This thesis research was conducted as the completion of the master’s program Complex Systems Engineering and Management (CoSEM). In this program, innovations in complex socio-technical environments are explored and technical, institutional, economic, social and environmental knowledge acquired in the master’s program was utilized throughout this research. This thesis takes on a subject that is relevant to both public and private domains and it contains technical solutions that also involve technological complexity, management strategies and engineering approach which are all characteristics of a CoSEM thesis. Another emphasis of this research was the qualitative approach to an energy problem and the methodology utilized in the research consisted of a combination of Qualitative Content Analysis and scenario building. Creative but also systematic ways of dealing with complex design and engineering issues is a trademark of CoSEM studies and this research provides an example of that.

There are many ways that CoSEM studies and courses impacted the approach and the perspective taken in this research. The current situation, challenges and problems in the energy sector, analyzing energy issues from a technical, economic and institutional perspective and making informed choices about the design of energy systems was initially covered and showcased in SEN1522 Electricity and Gas: Market Design and Policy Issues. SEN1541

Sociotechnology of Future Energy Systems has been an influential course for this thesis as during the course technical, environmental and societal developments expected to happen in the energy sector were discussed, future energy systems were compared and analyzed and plausible transition pathways were drawn to those future energy systems, which is exactly the research objective of this thesis with the only difference being taking oil refining industry as a particular case. SEN1121 Complex Systems Engineering laid the foundation of how to approach a problem, how to conduct academic research and how to address complexities in systems. Finally, learning about research ethics in SEN1311 CoSEM Research Challenges guided this thesis' ethical considerations and systematic approach to satisfy research design quality criteria.

8.3 Recommendations and Limitations for Future Study

There are several research subjects that can be generated from the future of the oil refining industry and related operations for future study. The realized effect of public and shareholder pressure on environmental developments could result in an interesting study because of the possible outcomes that can drive more interactions between public and oil companies in terms of taking action against their environmentally hazardous businesses and operations. Another interesting choice of future study regarding the issues on the periphery of oil refineries and their future would be to investigate the actual performance of the refineries that are being built or developed in Asia and the Middle East in terms of efficiency, environmental impact, financial conditions and their integration levels with the local energy systems and facilities. Since the constructions and plans for brand new refineries are equipped with petrochemical integration and advanced refinery operations, their performance is crucial to the prospective integration of oil refineries into future energy systems in a contributing role. Lastly, the effects of the COVID-19 pandemic have impacted every aspect of life including the refineries and the whole of energy systems. Looking back into this time period to evaluate how much progress COVID-19 pandemic hindered in terms of energy transition and emissions would be an interesting study with outcomes that would be relevant for the scenarios to take place from now on.

On the other hand, there are some limitations that prevent the structure of future studies. More qualitative approaches to energy systems would be helpful in the academic literature as this area is fairly new and the development of complete methodologies, for example, an IAD framework like a model for qualitative energy cases, would be beneficial for academia and industry alike. Even though, the outcomes of this thesis in the form of a roadmap consisted of recommendations for action that are globally applicable, developed and developing countries are not on the same page in terms of agendas and policies, especially for environmental concerns. This situation limits the studies in the sense that academia might not be convinced that their message goes through or their calls for action may not be cared for by the decision-makers in countries with low priority on environmental developments. Last but not least, global politics have always been a determining factor for oil refining issues and global unrest between major oil producers or imports may result in catastrophic situations as seen in the minor incident of 2020 Russia – Saudi Arabia price war on crude oil. Without the guarantee for stability, an analysis conducted on crude oil prices and subsequent products from that crude oil may have mismatch with the actual situation due to the impact of geopolitics on oil and oil-related products.

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Appendices

Literature Review on Plastics

The subject of the literature review accompanying the thesis is determined as the investigation of the petrochemicals rush. A literature survey is conducted on scientific databases such as Google Scholar and Scopus to examine the prospects of the expected increase in petrochemicals production and demand. Keywords that were used stand-alone and in combination during the survey included “petrochemicals”, “plastics”, “pollution” and “oil”. 17 academic articles are included in this review and selected articles are compiled in terms of their shared theme at the end of this section.

Environmental Impact of Plastics

As the oil market is preparing to accept petrochemicals as the next driver of demand, succeeding conventional transportation fuels, this rush to petrochemical production creates some unwarranted implications to the environment. Even before reaching the expected high rates of production and consumption, synthetic oil-based plastics have caused accumulation of waste in the environment, particularly in marine biomes, which is a common place for plastics to end up in (Raddadi & Fava, 2019). The biggest threat to the marine environment comes in the form of microplastics and due to their namesake sizes, they are more difficult to identify and isolate (Kavya et al., 2020). Since the use of microplastics and nanoplastics are so widely common in a variety of fields that are prominent in regular life such as semiconductors, textile and cosmetics, there is a certain pessimism regarding how to deal with the effects of these everyday particles (Ruan et al., 2018). Moreover, the threat is not limited to marine wildlife because of the micro and nano scales that plastics present themselves in our current day and age. Conducted research showcased microparticles that can fit through any membrane which means these particles can be inhaled or digested easily by humankind, causing various health problems (Laskar & Kumar, 2019).

Recycling Technologies

Recycling of plastics has been around for a while, but the progression and prominence of the technology is no match to the rate of increase in production and consumption of plastics. Although recycling provides environmental and financial incentives, the options for end-of-life treatment for plastic waste are limited in practice (Garcia & Robertson, 2017). With established goals of all recyclable or reusable plastics by 2036 for Europe and 2040 for the United States, the efficiency of plastic waste management system and recycling processes must be increased to satisfy these set targets and reach 100 percent recovery of plastic waste (Cabanes et al., 2020). This situation led to a search for innovation and ideas, however, in terms of more frequent utilization of recycled plastics in various industries such as using recycled plastics as the material for a thermal resilient emergency shelter (Moreno-Sierra et al., 2020) and the reutilization of plastics in industrial processes of iron and steel industry (Devasahayam et al., 2019).

Biodegradable Plastics

At its core, plastics are manufactured from oil, an asset that is one of the main causes of climate instability and carbon emissions that is devastating the environment and forcing authorities to take action at a global scale. In order to eradicate the environmental impact of plastics from the start, biodegradable plastics emerged as an alternative that can have a shorter life span than regular plastics, reduce environmental stress and less harmful to wildlife (Thiruchelvi, 2020). Not only bioplastics remove fossil fuels from the manufacturing process, but they also enhance the perceived value of green self-identity, leading to higher behavioral intention from customers (Confente et al., 2020). But even the biodegradable version of plastics needs certain conditions environmental conditions to biodegrade and they shouldn't be designated as the technical solution to plastics pollution due to reliability issues (Shen et al., 2020). There are even discussions in the academic periphery that question the capability and validity of biodegradable plastics as an act of greenwashing (Zhu & Wang, 2020). Regardless, biodegradable plastics should be treated as a viable and cheap option for disposing of an item after it has fulfilled its role rather than the solution to the plastics pollution and waste problem (Havstad, 2020).

Petrochemical Integration of Refineries

Current developments of new refineries, which are based in Asia and the Middle East, are commonly accompanied with a petrochemical plant, in order to satisfy the expected demand of the emerging middle-class population and to ensure the financial stability of refineries by having various products. China is expected to remain as the world's largest chemical industry, experiencing 13.6 percent growth in its petroleum refining and petrochemical industry which corresponds to an increase of 1.85 trillion dollars between 2018 and 2019 (Yu, 2019). The integration between oil refineries and petrochemical plants is also subject to more optimization for better performance as seen in the study done by Li et al. (2007) that showcases an efficient way of transferring naphtha into ethylene cracker. Another prospective reform that could enhance the performance of the cooperation between an oil refinery and a petrochemical plant is the implementation of digital technologies that create a connected, information-driven environment (Yuan et al., 2019). However, there are also risks of corrosion failures of process equipment which is caused by the complexity of refining and petrochemical units and it is one of the main sources of risk in this described integration (Wu et al., 2013).

List of Literature

1) Environmental Impact of Plastics

- Raddadi & Fava, 2019
- Kavya et al., 2020
- Ruan et al., 2018
- Laskar & Kumar, 2019

2) Recycling Technologies

- Garcia & Robertson, 2017
- Cabanes et al., 2020
- Moreno-Sierra et al., 2020
- Devasahayam et al., 2019

3) Biodegradable Plastics

- Thiruchelvi, 2020
- Confente et al., 2020
- Shen et al., 2020
- Zhu & Wang, 2020
- Havstad, 2020

4) Petrochemical Integration of Refineries

- Yu, 2019
- Li et al., 2007
- Yuan et al., 2019
- Wu et al., 2013

Index of Resources Utilized in Qualitative Content Analysis and Scenario Building

This section consists of information regarding the scenarios and forecasts found in the literature that have the resources and potential to guide the scenario building analysis for compiling important actions to take in order to establish the integration of oil refineries in future energy systems.

Vision 2050

Vision 2050 is a study done by FuelsEurope and it utilizes low-carbon fuels scenario from the Riccardo study (Concawe, 2018) and new policies scenario from International Energy Agency's the World Energy Outlook 2017 to forecast trends related to oil refining industry. Some of the trends illustrated in the study focuses solely on Europe but using lessons learned from European oil refining industry which is surrounded by more technological opportunities and environmental leeway compared to other region's refining industry is important to compile outcomes that have the potential to be applied globally.

BP Energy Outlook 2020

BP's Energy Outlook 2020 utilizes three types of scenarios: rapid, net-zero and business-as usual. Rapid transition scenario is adjusted according to a 70 percent decrease in carbon emissions by 2050 that is realized by progressive policies, carbon pricing and sector-specific measures. Net-zero transition scenario reinforces the rapid transition scenario with significant changes in societal behavior to account for a 95 percent decrease in carbon emissions by 2050. Business-as usual scenario envisions a slower transition that assumes government policies, technologies and social preferences will evolve in a rate that is seen over the past with emissions in 2050 ending up 10 percent less than emissions in 2018. In this conducted research, more weight of consideration and relation was made into Business-as-usual scenario as the aim of this thesis is generating a viable roadmap for integration and relevancy of oil refineries and net-zero and rapid transition scenarios are full of assumptions and involves complete cooperation and commitment of actors on the periphery of energy systems.

Refinery 2050 Refining the Clean Molecule

Refinery 2050 is a study made by Clingendael International Energy Programme (CIEP) and this study includes four different scenarios regarding the role of oil refineries in 2050 energy systems. The first scenario is described as international competitive pressures lead to carbon leakage and this scenario puts carbon leakage as the main driver for reducing emissions. Second scenario to be utilized in Refinery 2050 study is called refining the clean molecule in which the focus of investment and research is to make refinery operations, feedstock and fuel greener. Third scenario that was used in the study is defined as refineries in a Europe of multiple decarbonation speeds. Last scenario to be considered in the Refinery 2050 report is the strategic refinery in which calls for integration with other energy systems and technologies are made and incentivized.

The Unprecedented Expansion of Global Middle Class

This study was made by Brookings Institution, a nonprofit organization devoted to independent research and policy solutions. Imminent explosion of population of middle class is well documented and has an impact on a lot of consumption and emission trends.

The Future of Petrochemicals

This study was handled by International Energy Agency (IEA) and it inspects the today and the future of petrochemicals, their trajectories and their environmental impact. Two different scenarios are utilized in this research, reference technology scenario (RTS) and clean technology scenario (CTS). RTS is a scenario that is the interpolation and extension of current trajectories of petrochemical industry. CTS provides an alternative sustainable scenario with plastics recycling is a key element of enhancing performance and reducing environmental impact of petrochemicals

Oil in 3D: The Demand Outlook to 2050

This study is performed by Barclays Research team and concerns with the trends related to oil industry and oil related products for 2050. 3D refers to the three scenarios adopted in this research which are called dynamism, development and deadlock. Dynamism is the best-case scenario for the oil industry with the assumptions of global concentrated effort of reducing emissions. Development is the business-as-usual scenario where current trajectories and trends are extended. Deadlock is the worst-case scenario where developments are hindered by low priorities of low-carbon policies in global agenda and little technological adoption. For generating the roadmap for the thesis, development scenario is weighed more as it reflects a more realistic approach to future trajectories unlike optimistic and pessimistic scenarios.

Concawe's Input to the EU Long Term Strategy – EII Initiative

This study is conducted by Concawe, a division of the European Petroleum Refiners Association and its members consist of 40 companies that are operating petroleum refineries in the European Economic Area. The research consists of four scenarios; 2030 Reference Scenario, 2050 Oil-based Scenario, 2050 Sustainable Scenario and 2050 Highly Electrified Scenario that are illustrated and differentiated in Figure 6.9.

Digital Transformation Initiative Oil and Gas Industry

This study is conducted by Digital Transformation Initiative, which is a project launched by World Economic Forum and the report is made in collaboration with Accenture, an independent consulting firm. The contents of this study consist of digitalization pathways for oil industry, prospective benefits of digitalization in oil refining industry and case study examples of implemented digital technologies' effect on oil and gas operations.

Global Downstream Outlook to 2035

This study is conducted by McKinsey, an independent consulting firm. The contents of this study include current market outlook and trends, projections for refining industry and demand for refined products.

Shaping the Oil Company of the Future

This study is conducted by Prism in collaboration with Artur D. Little, an independent consulting firm. The contents of this study include insights into strategies and action that can be taken for refining industry to prepare themselves against the technological and environmental challenges of the future energy systems. This report also includes case examples from oil conglomerates such as Shell and Total, documenting their recent efforts into decarbonization and digitalization.

Decarbonization Pathways for Oil and Gas

This study is conducted by The Oxford Institute for Energy Studies, a recognized independent center of the University of Oxford. The contents of this study include a compilation of different perspectives on various issues regarding decarbonization in oil and gas industry from a wide range of different researchers. As the scope of this thesis, oil and oil refining related issues are taken into consideration from this anthology like document.

Industrial Decarbonization and Energy Efficiency Roadmap Action Plan

This study is conducted by United Kingdom Petroleum Industry Association, an organization that is closely linked with the government, Department for Business, Energy & Industrial Strategy. It contains strategy recommendations for the future of oil and oil refining in specific timelines determined by technology and policy readiness.