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Climate litigation: Credibility analysis of the company's transition plan

Carbon footprint assessment analysis and simulation of the company's transition plan

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L'impact de l'activité humaine sur le réchauffement climatique est reconnu depuis des décennies. Cet impact se traduit déjà aujourd'hui en termes de sécheresses, inondations, vagues de chaleurs extrêmes, perte de la biodiversité, augmentation du niveau des eaux... Au vu de la trajectoire mondiale actuelle, ces évènements ne vont que s'intensifier et se multiplier davantage, engendrant ce que l'on appelle une double injustice. En effet, bien que toutes les régions du monde soient touchées, ce sont les populations contribuant le moins au réchauffement climatique qui sont le plus à risque d'en subir les conséquences. Depuis la Conférence de Stockholm en 1972, jusqu'aux dernières Conférences des Parties (COP), de nombreux accords ont été signés par une grande partie des pays du monde dans le but d'atténuer et de faire face aux conséquences de cet impact. Cependant, les mesures nécessaires trainent à être implémentées et un réchauffement de 1.5°C par rapport à l'ère pré-industrielle, fixé par le GIEC comme étant la limite d'un *réchauffement climatique dangereux*, est déjà projeté comme étant inévitable. Dans son dernier rapport, le GIEC insiste sur la vitesse à laquelle se ferme notre fenêtre d'opportunités pour agir et sur l'insuffisance des flux financiers dirigés vers ces mesures nécessaires, alors que la majorité des solutions existe déjà [1].

Face à d'une part l'inaction des instances de pouvoir et d'autre part les activités toujours plus émettrices en gaz à effet de serre (GES) des grandes multinationales, les citoyen · e · s et organisations se tournent de plus en plus vers la justice, menant à des affaires judiciaires regroupées sous le nom de *contentieux climatiques*. Bien que les premières affaires aient vu le jour dans les années 2000, le contentieux climatique a connu un tournant avec l'introduction de l'affaire *Urgenda* [2] aux Pays-Bas en 2013, et la décision de la Cour d'Appel en 2018, obligeant l'Etat des Pays-Bas à réduire ses émissions de GES d'au moins 25% par rapport aux niveaux de 1990 [3]. Dans les nombreuses affaires qui ont suivi ou sont toujours en cours, on peut citer par exemple l'affaire *Shell* [4] aux Pays-Bas et *Klimaatzaak* [**?**] en Belgique. Que ce soient des affaires dirigées vers un Etat ou une firme, des arguments similaires sont souvent utilisés. La responsabilité civile, le droit à la vie privée et familiale et le droit des futures générations sont souvent invoqués. Des éléments du droit de l'environnement interviennent aussi fréquemment, comme les principes de précaution et de prévention.

Dans les questions climatiques, la science est au centre de l'argumentaire juridique, ce qui fait du contentieux climatique un sujet interdisciplinaire par essence. Nous sommes trois étudiant · e · s en droit et quatre étudiant · e · s en ingénierie civile, associés autour de deux sujets de mémoire communs : la construction d'arguments au service de contentieux climatiques contre l'Etat belge d'une part, contre une grande multinationale d'autre part. L'objectif était de construire des arguments techniques par les étudiant · e · s

ingénieur · e · s, pour fonder les arguments juridiques construits par les étudiant · e · s en droit. Des réunions régulières sous différentes formes (en plénière, avec tout le groupe de travail, mais aussi entre étudiant · e · s travaillant sur le même sujet d'une même discipline) ont été organisées tout au long de l'année. Chaque thèse aura bénéficié de retours réguliers afin d'assurer sa pertinence dans les deux disciplines concernées. Les réunions auront aussi permis de confronter les idées et les points de vue, et elles se sont avérées particulièrement riches et diversifiées dans un tel contexte.

Ce groupe de travail interdisciplinaire s'inscrivant dans le contexte du contentieux climatique est un projet innovant à l'UCLouvain. Les différentes questions de recherche investiguées auront suscité beaucoup d'intérêt, notamment lors d'un colloque sur la justice climatique ayant eu lieu au début de l'année, auquel chaque groupe a eu l'occasion de présenter son approche initiale. Cette expérience nous aura permis de récolter de nombreux avis externes sur le sujet. Outre les éléments de réponse qu'elles apportent aux questions de recherche initiales, ces thèses auront aussi débouché sur de nombreuses autres questions à approfondir qui, nous l'espérons, pourront être traitées dans un cadre semblable dans les prochaines années.

Abstract

In a context of climate urgency, climate litigations are used to denounce the climate inaction of public or private parties. In order to support a legal case against a company for climate inaction, this master thesis details a study of the credibility of its transition plan according to the net zero emission target by 2050.

The company's carbon footprint for the year 2021 was assessed based on the company's annual report and the GHG protocol. This assessment, as well as the company's disclosure and the Net Zero Emissions scenario (which is used as a reference by the company), serves as the foundation for the tool created that simulates the company's transition plan. An additional simulation has been conducted in order to propose a pathway to net zero emissions. To support the obtained results, an estimation of the company's allocated carbon budget is conducted to determine whether the company is exceeding it.

The main results of this study demonstrate that the company does not consider all the emissions for which it is responsible and does not set sufficient targets to reach net zero emissions by 2050. The alternative scenarios proposed show that in order to reach the defined objective, the company should drastically decrease its fossil fuel activity, consider decarbonized molecules as a transitionary energy source and increase its electricity production.

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List of Abbreviations

ADEME Agence de l'environnement et de la maîtrise de l'énergie.

APS Announced Pledged Scenario.

ATR Auto-thermal reforming.

BOG Boil-off gas.

BOR Boil-off rate.

BtB Business to Business.

BtC Business to Consumer.

CCGT Combined Cycle Gas Turbine.

CCS Carbon capture and storage.

CNG Compressed natural gas.

COP Conference of the Parties.

DEU Document d'enregistrement universel.

DWT Deadweight tonnage.

EACOP East African Crude Oil Pipeline.

EDGAR Emissions Database for Global Atmospheric Research.

EP Exploration and production.

ETBE Ethyl Tert-Butyl Ether.

ETS Emissions trading system.

EU European Union.

GCU Gas combustion unit.

GHG Greenhouse Gas.

GVW Gross Vehicle Weight.

GWP Global Warming Potential.

IEA International Energy Agency.

IPCC Integovernemental Panel on Climate Change.

IPIECA International Petroleum Industry Environmental Conservation Association.

LCOE Levelized cost of energy.

LHV Lower Heating Value.

LNG Liquefied natural gas.

MS Marketing and services.

NBS Nature-based solutions.

NGO Non-Governmental Organization.

NZE Net Zero Emissions.

RC Refinery and chemistry.

ROE Return on equity.

SDA Sectoral Decarbonization Approach.

SMR Steam methane reforming.

STEPS Stated Policies Scenario.

TPI Transition Pathway Initiative.

VLGC Very Large Gas Carriers.

Global context of the climate litigation

It has been known for several decades that climate change has been significantly accelerated by human activity. Thanks to the tremendous work of scientists from all across the world and to the summary work of the Integovernemental Panel on Climate Change (IPCC), the complex reality of climate change can be translated into a concrete warning: if the rise of the mean global temperature compared to preindustrial levels was to exceed 2°C by 2050, climate change would seriously endanger human life on Earth by affecting food safety, significantly increasing water scarcity and the risk of extreme heatwaves and other hazardous meteorological events [22].

The expression of climate change through this understandable limit led to the Paris Agreement, an international treaty on climate change adopted by 196 parties during the Conference of the Parties (COP)21[1] in 2015. It has been created in order to legally bind the signing parties to maintain the rise of the mean global temperature far below 2°C and limit it to 1.5°C for 2050. This objective can be translated into a decrease of 45 % in emissions by 2030 and a total net reduction of emissions by 2050 [24].

Another way of approaching this complex phenomenon is the concept of planetary boundaries, which has been theorized by a group of 28 scientists from the Stockholm resilience center [25]. The concept of planetary boundaries regroups a set of nine boundaries that represents nine processes involved in the functioning of the Earth system. The nine boundaries are climate change, biodiversity erosion, the phosphorus and nitrogen cycle, land use changes, chemical pollution, freshwater cycle, atmospheric aerosol loading, stratospheric ozone depletion and ocean acidification.

Crossing one of these boundaries increases the risk of perturbating the earth system in an irreversible way and corresponds to a high uncertainty zone, in which it is impossible to predict the evolution of Earth and the consequences [26].

Since May 2022, six out of nine planetary boundaries have been crossed [27]. The last IPCC report also relates the current state of urgency: immediate emission reductions are needed in all sectors in order to remain under 2°C by 2050 and a radical emissions decrease is needed within the next 3 years.

Despite the fact that several COPs and treaties signatures took place since the

[1]The COP (Conference of the Parties) refers to an annual conference reuniting the signatory states in order to define global climate objectives [23]. The first COP was held in 1995.

Kyoto Protocol in 1992, the measures taken by the government are clearly not sufficient compared to the urgency of climate change, mainly because the decision-makers refuse to take any measures that could compromise economic growth. Indeed, the Paris Agreement and the conclusions of the different COPs show that the global strategy adopted is relying on technical innovation to maintain economic growth while decreasing emissions [28]. However, scientific work on the subject demonstrates that economic growth is not compatible with the significant decrease in emissions that is urgently required[2].

This lack of responsiveness from the political power to the climate emergency led several organisms such as Non-Governmental Organization (NGO)s, scientific organizations and citizens to speak out and denounce this inaction [30]. After the Kyoto Protocol in 1997, these denunciations took the form of climate litigation, which consists of a litigation (often carried by civil parties) in which climate change is at the heart of the case brought to the court [31]. This way of denouncing climate inaction from public and private parties has been recognized by the last IPCC report as a way of attenuating climate change [31].

Two major events in the short history of climate litigation have led to the development of these climate lawsuits [30]. The first was the *Urgenda case*, in which the Dutch government was taken to court for failing to set sufficient emission reduction targets. This case led to a historical decision: for the first time in history, a judge recognized that a state was responsible for climate inaction [32]. The second determinant event was the establishment of the Paris Agreement in 2015. This agreement binds all the signatory parties to respect the national objectives of emission reduction and designates citizens and companies as legitimate interlocutors to enforce these commitments. These entities are therefore in a position to use the Paris Agreement to take legal action against states that do not comply with it, which is exactly what climate litigation stands for [30].

These climate lawsuits have multiplied since the Urgenda case and are also taking legal action against private parties. In 2019, the environmental organization Milieudefensie has taken action against the oil and gas company Shell in the Nederlands for not taking enough measures to be aligned with the Paris Agreement [33]. In 2021, another historical decision was taken: Shell was recognized guilty and condemned to reduce its emissions by 45 % within 10 years.

It is in the context of climate litigation against private parties that this master's thesis was written. In order to support a legal case against the oil and gas company

[2]Being able to combine a radical decrease in emissions and economic growth would include decoupling. In this case, decoupling refers to dissociating economic growth and environmental pressures such as climate change and the use of resources. This dissociation is not only highly unlikely since economic growth includes an increase in energy and materials consumption, but also never happened in the past in a lasting and sufficient way. Another theory is that technological innovation will lead to a sufficient decrease in emissions. Again, there is no example in history of technical innovations that would have decreased emissions in a significant way. Even when a decrease in emissions was observed, it was marginal compared to the reduction levels needed. Moreover, increasing efficiency often leads to a *rebound effect*, a situation where an increase in the efficiency of the way of using a given resource results in an intensification of its use [29].

TotalEnergies, a detailed study of the credibility of its transition plan has been realized and is described.

This master's thesis is structured as follows:

- Chapter 1 gives the company's vision towards a sustainable future by developing the company's long-term vision and its main ambitions.
- Chapter 2 describes the carbon footprint assessment realized for the year 2021 and contains all the assumptions and computations made. A discussion on uncertainty related to the assessment is also provided.
- Chapter 3 contains the methodology, the hypothesis and the results of the simulation of the company's transition plan. This study is completed with alternative scenarios and discussions about the uncertainty associated to certain energy sources.
- Chapter 4 consists of the company's carbon budget assessment and its comparison with the cumulated emissions generated by the company.
- Chapter 5 provides a more economic point of view: financial indicators are developed and the company's investments are analyzed. The case of a fossil fuel company that was able to realize a full transition towards renewable energies is briefly studied.
- In chapter 6, the main results and conclusions are discussed and a more in-depth look is given at certain points briefly covered in the previous chapters.

The following elements have been used for the reader's comfort:

> The description of the content of each chapter will be displayed as follows

Key messages will be framed at the end of each chapter

Chapter 1

Company's vision towards a more sustainable future

> Before diving into a detailed analysis of the company's transition plan, it is essential to introduce this oil and gas company and understand its global impact as well as its ambition in moving towards a more sustainable strategy. In this section, the company's vision will be presented to provide an overview of its objectives. Then, a first analysis of the company's targets will be realized to assess the feasibility of the set ambitions.

1.1 Who is the company ?

TotalEnergies, formerly known as Compagnie Française des Pétroles, then Total, was founded in 1924. The company is one of the largest oil and gas companies in the world and is present in more than 130 countries. According to the *Carbon Majors Report* [34], the company is part of the top 50 fossil energy companies which in 2015 emitted the most GHGs emissions. To give an order of magnitude, the top 50 alone represent 50% of global industrial GHG.

Over the years, the company kept acquiring shares or whole companies directly linked to the energy sector such as SunPower Corp. (solar energy), Direct Energie (gas and electricity) and ENGIE's LNG business (LNG). The company is present from exploration to production, refining and marketing of petroleum products, as well as in the production and marketing of natural gas and low-carbon electricity. In order to emphasize its transformation into a multi-energy company, Total changed its name to TotalEnergies in 2021, claiming its ambition to become a major player in the energy transition. Indeed, the company is significantly increasing its presence in the renewable energy sector, with investments in solar, wind and biofuels.

1.2 Environmental vision for 2030 and 2050

1.2.1 Main ambitions

In order to become an important actor in the energy transition, the company expresses its will to make a deep change in its production and sales while still being able to meet

the needs of the growing population [5]. The main goal of the company is to achieve net zero emissions by 2050, based on the International Energy Agency (IEA) scenario [35]. The IEA defines net zero as the point at which the GHG released into the atmosphere is balanced by the amount removed from the atmosphere.

The company's strategy is based on three different axes [5]:

- Contribute to the growth of decarbonized molecules, which include biofuels, biogas, hydrogen, and synthetic fuels that combine hydrogen and carbon. By participating in these sectors, the company is committed to achieving its goal of producing 25% of its energy from decarbonized molecules by 2050.
- The electrification of energy use[1] which requires a massive increase in renewable energy production. To achieve this, the company is strategically involved in the entire renewable energy value chain, from production to sales, with the objective of becoming one of the top five global producers by 2030. Looking ahead to 2050, the company aims to have 50% of its energy production derived from renewable sources.
- The use of carbon sinks to absorb the CO_2 produced by residual fuels. The company intends to propose two services to its clients in order to compensate for residual emissions generated by the use of their products: a carbon storage activity and the production of e-fuels.

1.2.2 Multi-energy company

Integrated strategy

The model followed by the company is based on integration along the whole value chain of energy: the company is active from the exploration and production of oil and gas and electricity to energy distribution, transport and storage. This integration extends to include refinery, liquefaction, petrochemical operations, and trading. By adopting this integrated strategy, the company can be more resilient when the raw material prices are high and can benefit from the added value in the downstream sector when the prices are low [5].

Multi-energy strategy

The company intends to diversify its energy sales mix in the next few years. As shown in Figure 1.1, by 2030, the energy mix of the company's sales could be composed of 50% of natural gas, 30% of oil products, 15% of mainly renewable electricity and 5% of biomass and hydrogen [5].

[1] Electrification means shifting from fossil fuels to electric power as the primary energy source for diverse applications.

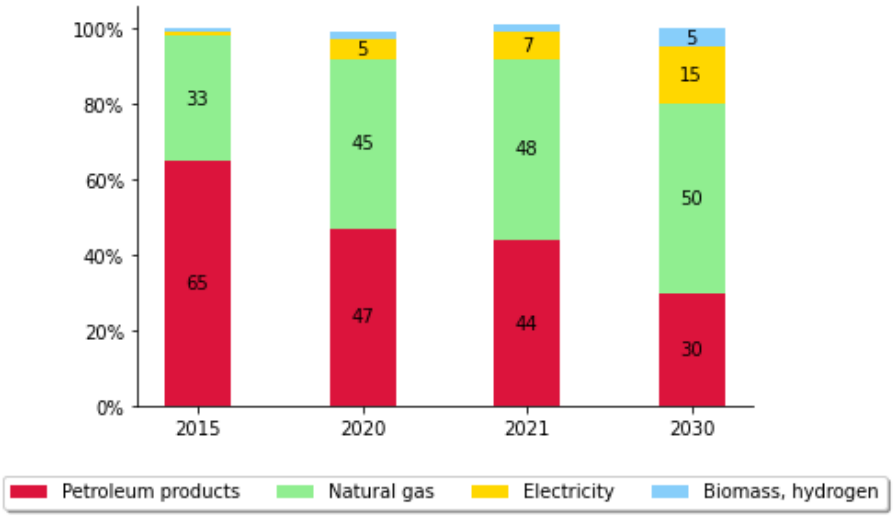


Figure 1.1: Energy mix of the company's sales per year (%) [5]

In terms of renewable energies, the company's ambition is to become a world leader in production. In 2021, the company invested 25 % of its net investments, which corresponds to 3 G$, into renewables.

The company is also investing in decarbonized molecules such as biofuels (the company's ambition is to produce 5 Mt/year in 2030), biogas (5 TWh/year in 2030 on a worldwide level), hydrogen and synthetics liquid fuels.

In terms of oil production, the company expects a peak in production within the next decade. Therefore, the company is planning on reaching its maximum oil production before decreasing it.

1.2.3 Net zero emission by 2050

The company's main ambition is to reach net zero emissions by 2050. In order to reach this objective, the company has set targets to achieve and aims to work on several levers.

Reduction targets

The annual report [5] provided by the company sets out all its emission reduction targets. A summary of all the objectives to which the company has committed itself can be found in the Appendix A.

It should be noted that the different targets depend on the geographical area. Given that the company is mainly based in Europe, it defined more precise and more drastic targets in this geographical area. For Europe, the company also aims to follow the 2030 objectives of the European Union (EU) which are to reduce GHG emissions to at least 55% below 1990 levels by 2030. In their ambitions, the company quantifies its emissions in terms of net emissions. A net target means that the company uses offsets, which means

that the target takes into account the emissions but also the possible compensations using natural carbon sinks such as forests, regenerative agriculture and wetlands.

The last point to raise is that scope 3 for the company is not defined in the same way as in the GHG protocol. The company's scope 3 emissions are limited to *category 11 (Use of sold products)* out of the 15 categories that should be taken into account according to the Technical Guidance for Calculating Scope 3 Emissions of GHG protocol [36]. For more information about the scope 3 categories, refer to the Appendix B which encompasses a comprehensive list of all these categories as defined by the GHG protocol.

To avoid confusion, the company's scope 3 emissions are referred to as *reduced scope 3*.

The most important ambitions to remember are shown in Table 1.1. In order to have a good understanding of the table, note that scope 1 corresponds to direct emissions from owned sources and scope 2 corresponds to indirect emissions that are associated with the production of electricity, heat or steam purchased and consumed by the company.

Based year	Target year	Geographic zone	Net emissions	Reduction target	Company emissions scope[2]
2015	2030	Global level	No	-2,5%	Scope 3
		Europe		-30%	
2015	2050	Global level	Yes	-100%	Scope 1 & 2, operated activities + Scope 3
		Europe			Scope 1 & 2 & 3

Table 1.1: Key emissions reduction goals for 2030 and 2050 compared to the geographic area

The Table 1.1 shows that, in 2030, there is an important difference in the reduction targets depending on the geographical area. In Europe, the company is preparing for a decline in oil demand of more than 30%. In reaction to this decrease, the company wants to reduce its oil sales, therefore the reduction in sales of petroleum products will focus particularly on Europe in order to reduce the *reduced scope 3* emissions. One should keep in mind that the company does not intend to reduce its oil production globally. Indeed, as shown in Figure 1.2, in order to decrease its sales, it will reduce its purchases of oil products from third parties.

[2]The company's scope 3 (*reduced scope 3*) refers only to category 11 of GHG protocol

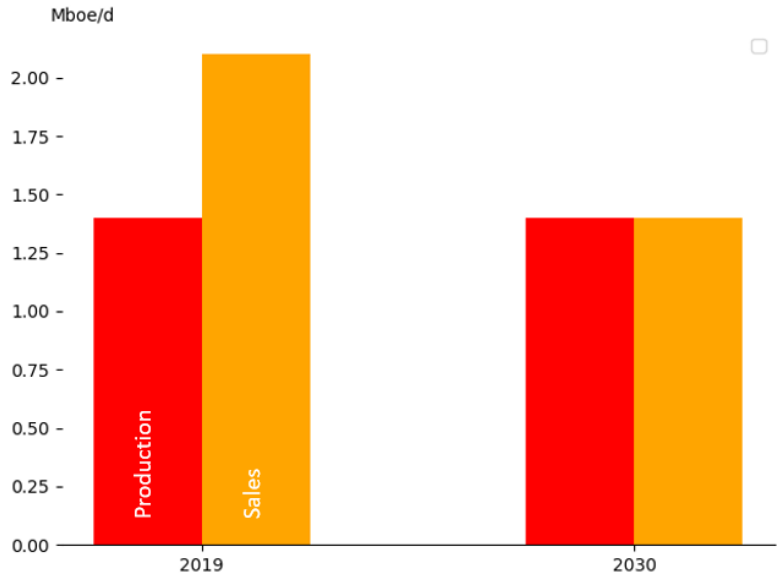


Figure 1.2: Oil production and sales of oil products for the years 2019 and 2030 (Mboe/d) [5]

At the global level, the reduction target is less important than for Europe. In fact, for the rest of the world, *reduced scope 3* emissions are still increasing. However, thanks to the reduction at the European level, the global level is decreasing. This is justified by the fact that the company intends to provide developing countries with its products. It is therefore increasing its energy supplies in these regions of the world. Since the company is mainly active in Europe, the global *reduced scope 3* GHG emissions associated with the use of energy products by its worldwide customers will result in a reduction of at least 2.5%.

For 2050, in Europe, the company aims to achieve carbon neutrality (or net zero emissions) of energy products along their entire value chain, from production to use by customers. On a worldwide level, the company wants to achieve carbon neutrality for its operated activities corresponding to part of scope 1 and 2, and for the indirect GHG emissions related to the use of energy products by its customers (*reduced scope 3*).

Levers to reach net zero by 2050

Several levers have been identified by the company to significantly reduce GHG emissions [5]. In order to reduce scope 1 and 2 emissions, the company is focusing on developing emission reduction projects on industrial sites using the best available technologies.

The levers considered by the company are:

- The improvement of energy efficiency in order to consume less energy. This involves optimizing the various stages of the production chain. This improvement also means identifying and making better use of waste heat sources.
- The reduction of methane emissions by 80% in 2030 compared to 2020 (see Table A.1). To achieve this reduction, the company intends to act to reduce leaks,

vents and gas flaring.

- The development of CCS, a technology that captures and stores carbon dioxide emissions from industrial processes, to reduce emissions associated with their facilities. In 2021 alone, the CCS project development budget was 100 M$. The company aims to expand storage capacity of about 10 $MtCO_2$ per year by 2030 and to reach 50 to 100 $MtCO_2$ at the beginning of the year 2050.
- Investments in natural carbon sinks such as forests, regenerative agriculture and wetlands. With an average annual investment budget of another 100M$ between 2020 and 2030, the company aims to build up a stock of 100 million tons of sequestered CO_2 and develop the annual capacity to produce at least 5 million tons a year from 2030.

1.3 Is the company on track for net zero emissions by 2050 ?

The ambitions of the company may give the impression that it is evolving in the right direction in order to reach the net zero emissions target. However, by comparing the targets and the recommendations given by the IPCC, one can realize that the targets set by the company are not sufficient. Some writers of the IPCC 2022 report actually accused the company of instrumentalizing their work [37].

The 2022 IPCC report points out the importance of GHG net emissions and the notion of cumulative GHG emissions. It clearly states that fossil energy consumption should drastically decrease because each additional ton of GHGs in the atmosphere contributes to additional warming. Another risk of increasing fossil energy production is that it could lead to a carbon lock-in for several decades, which would make it even harder to decarbonize the energy system. Carbon lock-in is a phenomenon that occurs when fossil-fuel systems are implemented and delays the transition to low-carbon systems [38]. As an example, if a company invests in an oil-fired power plant, it commits itself to generate a certain amount of GHG emissions for the lifetime of the infrastructure, which results in carbon lock-in.

Despite these recommendations, the company is still dedicating 50% of its investments from 2022 to 2025 to maintaining oil projects and developing 7 new ones in Exploration & Production. The multi-energy strategy held by the company clearly shows that the company is not considering a reconversion in renewable energies but is merely extending its activities in renewable energies, by dedicating only 25% of its investments to renewable energies during the same period. Of the remaining 25%, 20% is allocated to the development of the gas sector, while the remaining 5% is allocated to the decarbonized molecules.

Furthermore, the company expresses its targets in terms of the carbon intensity of its sold products. This means that the emissions resulting from the production and use of a product are divided by the total energy sold by the company. This way, just by buying renewable energy, the carbon intensity of the company decreases even though the net

emissions remain the same. Therefore, this indicator does not give any information about the net emissions of the company which actually increases since the company keeps investing in fossil fuels. Since the company (as shown in Figure 1.1) is diversifying its energy mix, the relative part of petroleum products decreases, which leads to a decrease of net carbon intensity as shown in Figure 1.3.

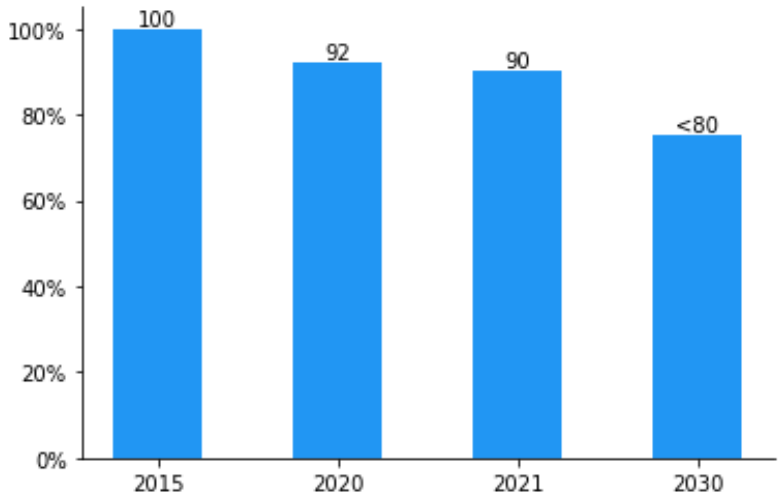


Figure 1.3: Carbon intensity of energy products sold per year (%) [5]

This way of representing the emissions could lead the inattentive reader to think that the company's production emissions are decreasing, which is not the case. While the carbon intensity is indeed decreasing, petroleum production will increase between 2021 and 2030 as well as gas production (see Figure 1.4), which will inevitably lead to an increase in absolute emissions.

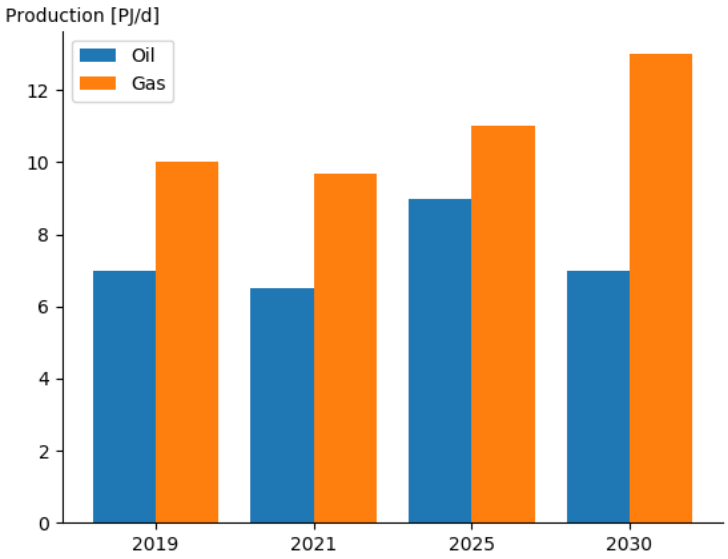


Figure 1.4: Company's production of petroleum and gas per year (PJ/d) [5]

The company's vision of the energy transition is mainly based on the development of LNG, which the company identifies as a key energy for the transition, even though the IPCC report calls for a significative reduction of gas investments. Indeed, gas leaks liberate methane, which has a global warming potential that is 28 times higher than the global warming potential of CO_2.

Another pillar of the energy mix of the company is the development of biofuels. Biofuels are solid, liquid or gaseous fuels derived from plants or animal waste. According to the NZE scenario, the development of biofuels will play an important role as a substitute for oil. However, one should keep in mind that burning biofuels does generate emissions: a study realized by the European Commission stated that biodiesel could increase Europe's transport emissions by almost 4% [39]. Indeed, the production of biofuels can include land use change and deforestation, which can impact the emissions generated. According to Agence de l'environnement et de la maîtrise de l'énergie (ADEME), in the most pessimistic scenario of biofuel production[3], the production of bioethanol could generate 4.8 kg of CO_2e per liter, which represents almost the double of emissions generated by refined products [40]. The production of first-generation biofuels[4] could also present a threat to food security: harvesting energy crops instead of food crops could, in the worst case scenario, decrease the food production. Another problem that could arise would be an increase in the food price when the crops are not sufficient [42].

According to the company, the remaining CO_2 emissions generated by the use of their sold products would be absorbed thanks to the use of CCS technologies and Nature-based solutions (NBS). Relying on these techniques can be dangerous for many reasons.

Before diving into these possible issues, it is important to remind that CCS technologies are recommended by the IPCC as an option to reduce emissions in sectors that cannot be decarbonized such as the cement process or the production of chemicals [1]. Therefore, they are not intended to compensate for the emissions generated by the company's sold products. This underlines the fact that the company should decarbonize its energy production before resorting to these mechanisms, instead of relying on them to be able to generate more emissions.

The first issue that the development of the CCS technology faces is the uncertainty around cost. In 2019, the cost of CCS for processes with dilute gas streams such as cement production and power generation was estimated to be 40-120 USD/tCO_2e. According to the company's ambition of

- A storage service of 10 Mt CO_2/year in 2030 would cost between 400M$ and 1200M$ per year

[3]The most pessimistic scenario defined is called "CAS maximal" and corresponds to the replacement of one hectare of humid tropical forest by one hectare of sugar cane or oil palm by assuming that the CO_2 emissions generated would be affected to the sugar cane with a 20 years smoothing period

[4]A biofuel of the first generation is a biofuel derived from the reserves contained in plants such sugar, starch and vegetable oils [41]

- A storage service of 50 $MtCO_2$/year[5] in 2050 would cost between 2G$ and 6G$ per year
- A storage service of 100 Mt CO_2/year in 2050 would cost between 4G$ and 12G$ per year

If the annual investments planned between 2022 and 2025 are similar to the investments of 2030, the investment planned for CCS would represent between 2.7% and 8% of the total investments of the company in 2030 and between 13.7% and 41% in 2050 for a storage service of 50 $MtCO_2$.

Despite the economic aspect, another major challenge is the scaling-up of CCS plants. Today's average CCS plants capture around 1.5 $MtCO_2$/year, which means that the company should build around 67 facilities in order to reach its target of 100 $MtCO_2$/year in 2050 [43]. This represents almost double the number of facilities currently installed worldwide: there are around 35 commercial facilities installed nowadays [44].

It is important to note that CCS does not capture carbon emissions in the atmosphere but at the end of production chains, which represents a minor part of the total emissions of oil and gas projects. About 80% of the emissions come from the final combustion of oil and gas, which are not addressed by the CCS technology. This means that once CO_2 emissions are emitted, they will contribute to global warming in an irreversible way. CCS technologies are recommended in the IPCC report only in the case where they are accompanied by a decrease in net CO_2 emissions, while the company uses these technologies to produce more CO_2 emissions.

The company based part of its strategy on NBS. They consist of either increasing carbon storage (by reforesting or agroforesting) or avoiding GHG emissions, for example by limiting deforestation and restoring coral reefs and sea grass. However, the IPCC reports state that planting trees in places where they are not already growing presents a risk to biodiversity and increases vulnerability to climate change, resulting in an increase of CO_2 emissions. Despite that, carbon sequestration in vegetation through reforestation and agroforestry presents several risks: climate change could reduce the ability to absorb more carbon or could even lead, as has been the case in the last few years, to wildfires which would re-emit all the carbon sequestrated.

The company aims to absorb between 5 and 10 tons of CO_2 per year in 2030, based on NBS. The company's strategy would be to create a stock of 100 million tons of sequestrated CO_2 before 2030 and to create a capacity of production of 5 million credits each year from 2030 onwards. To give an order of magnitude, one can estimate the number of hectares of forest that would be needed to absorb between 5 and 10 Mt of CO_2 per year, which corresponds to the objective of the company from 2030 onwards. By considering that it is possible to plant 2500 trees per hectare [45] and that one tree can absorb approximately 25 kg of CO_2 per year [46], it would be needed to plant between 80 000 and 16 000 ha of trees, which is equivalent to 40 000 - 80 000 football fields,

[5]The company's ambition by 2050 is to propose a CCS service between 50 and 100 Mt to its customers [5]

in order to reach the objective of compensation. Adding to this that most trees take between 20 and 30 years to reach an average height and since younger trees absorb less CO_2 than older trees [47], this ambition seems completely unrealistic. Moreover, trying to put it into place seems impossible to do in a way that would avoid all the risks stated above.

Therefore, one of the most efficient ways of improving the natural carbon sink capacity is to decrease GHG emissions and to preserve the existing forests which represent significant carbon sinks. By increasing fossil fuel and gas projects, the company does the opposite: it increases net GHG emissions and contributes to deforestation by investing in oil and gas projects. For instance, the company is currently working on a project called East African Crude Oil Pipeline (EACOP) in Ouganda, which should be the longest heated pipeline in the world with a total length of 1444 km. It will cross 16 protected natural areas, lead to deforestation, the increase of net GHG emissions and an important carbon lock-in [48].

In conclusion, when comparing the company's targets to the IPCC recommendations and the Paris Agreements, one can notice that the company is not at all on the right track to achieve net zero emissions by 2050. Despite the increase of electricity and decarbonized molecules planned by the company, its significant investments in fossil energies compromise the net zero target. Moreover, the company intends to compensate its emissions by putting in place unrealistic targets that could actually lead to a higher vulnerability to climate change and an increase of CO_2 emissions.

In order to verify these assumptions, a deeper study of the credibility of the company's transition plan is realized in the next chapters.

The first step of this study is the assessment of the company's carbon footprint. Indeed, before analyzing the company's targets, it is important to estimate its main emission sources in order to verify the adequacy of the targets.

The second step, which is based on the first, is a simulation of the company's targets from 2021 to 2050. Since the company based its long-term strategy on the NZE scenario provided by the IEA, the latter will be used as a reference when hypotheses are needed.

Finally, the last step consists of the computation of the cumulated emissions generated by the company from 2019 to 2050 in order to compare it with a computed allocated carbon budget.

Key messages of chapter 1

1. The company considered is part of the 50 companies that emitted the most GHG emissions in 2015.
2. The company's strategy in order to achieve net zero by 2050 is based on three different axis:
   - Contribute to the growth of decarbonized molecules.
   - Increase of renewable energy production.
   - Use of carbon sinks to absorb CO_2 produced by residual fuels.
3. At first sight, before analyzing the company's ambitions in a quantitative way, the company does not seem to be on the right track to achieve net zero emissions in 2050. Its short-term targets go against the guidelines given to reach net zero emissions in 2050 and set unrealistic targets:
   - The company is dedicating 50 % of its investment to maintaining and developing oil projects and focuses part of its long-term strategy on natural gas, which goes against the IPCC guidelines and is likely to lead to carbon lock-in[6].
   - The company relies on biofuels whose production can lead to an increase of CO_2 emissions if it includes land use change and deforestation.
   - The company aims to capture 100 $MtCO_2$/year in 2050 with CCS, which would mean to double the number of facilities currently installed worldwide, and between 5 and 10 tons of CO_2/year in 2030, which would mean planting the equivalent of 40 thousand and 80 thousand football fields.

Chapter 2

Carbon footprint assessment for 2021

A carbon footprint assessment is a tool that helps compute all the GHG emissions related to a company (or another type of establishment). Its main objective is to allow the company to quantify the emissions for which it is responsible in order to decrease them in the most adequate way. Therefore, realizing a carbon footprint assessment is the first necessary step to address GHG emissions.

One should note that the company did realize a carbon footprint assessment. However, due to a lack of transparency, it cannot be assured that the company took into account all of its main emissions. Hence, the next chapter provides a complete carbon footprint assessment that will then be compared to the one realized by the company itself.

> In this section, the carbon footprint assessment of the company considered is realized for the year 2021, based on the most recent reports provided by the company and on assumptions when needed. A discussion about the uncertainties related to this kind of assessment is then provided. Finally, the difference between the carbon footprint computed and the company's assessment is addressed and analyzed.

One has to keep in mind that the activities of the company have been slowed down during the year 2021 because of COVID-19. As a result, the computed emissions will be lower than those of a regular year.

2.1 Computation of emissions

The categorizing of the emissions is based on two main documents:

- The GHG protocol, which provides standards and tools for businesses and governments to measure and manage their emissions [49].
- The report *Estimating petroleum industry value chain (Scope 3) greenhouse gas emissions* written by the International Petroleum Industry Environmental Conservation Association (IPIECA) [50], which is a global not-for-profit oil and gas industry association for environmental and social issues. It created a report based on the GHG protocol, with an approach specific to oil and gas industries.

The data used was mainly found in the DEU and Factbook reports of the company for the year 2021 [17][5]. Since some information was lacking, hypotheses were made and are developed in the following sections. Some of the hypotheses made are based on a Greenpeace report [6]. Most of the emission factors used come from the database of ADEME.

The emissions can be divided into three distinct categories :

- Scope 1 covers direct emissions from sources owned or controlled by the company.
- Scope 2 corresponds to indirect emissions that result from the generation of electricity and heat used by the company.
- Scope 3 corresponds to the remaining indirect emissions associated with the company such as the use of the product by a customer or the purchase of products from a supplier.

Scope 3 is usually the most important one, especially for oil and gas companies. According to the GHG protocol [49], the scope 3 emissions can be divided into 15 categories (which are described in Appendix B). It will therefore be the main point of attention in this section, even though some emissions will be counted in scope 1. Note that the scope 2 emissions are not considered in the calculated carbon footprint, as they represent a negligible part compared to scope 1 and 3 emissions.

In the carbon footprint assessment realized by the company, the only category taken into account is category 11 (Use of sold products). The company justified its choice by claiming that this category was responsible for the larger amount of emissions. In order to verify this statement, other important categories were taken into account:

- Category 1 - Purchased goods and services
- Category 2 - Capital goods
- Category 4 - Upstream transportation and distribution
- Category 9 - Downstream transportation and distribution

Because of a lack of information and considering that the categories cited are the largest, no other category of scope 3 has been considered. For more information about the scope 3 categories, refer to the Appendix B which encompasses a comprehensive list of all these categories as defined by the GHG protocol.

This section will focus mostly on the emissions generated through the whole production chain of oil and gas, but also on the emissions coming from petrochemical products, electricity production and biofuels. The emissions are computed by following the production chains. They are then distributed according to the different categories defined by the GHG protocol.

You will find the main information and assumptions in this report. For more complete details you are strongly advised to consult the following Excel sheet.

2.1.1 Oil operations

The value chain of oil and petroleum products is composed of different steps and is represented in Figure 2.1. The first one is oil extraction, which consists of searching for and extracting oil. Crude oil is then usually stored temporarily and then shipped, often via pipeline, to a refinery where it is processed, after which it can be sold [51]. This part of the process, from extraction to transport, is handled by the division Exploration and production (EP) of the company and is qualified as the upstream phase. The crude oil is then converted into different products such as gasoline, diesel fuel, jet fuel, kerosene, hexane, bitumen and petroleum coke [52]. After the refining part, the refined products are either sold or, for the products used for petrochemistry, sent to a petrochemical division in order to be converted into petrochemical products such as monomers and polymers. The products can be sold right away or through the division Marketing and services (MS) of the company.

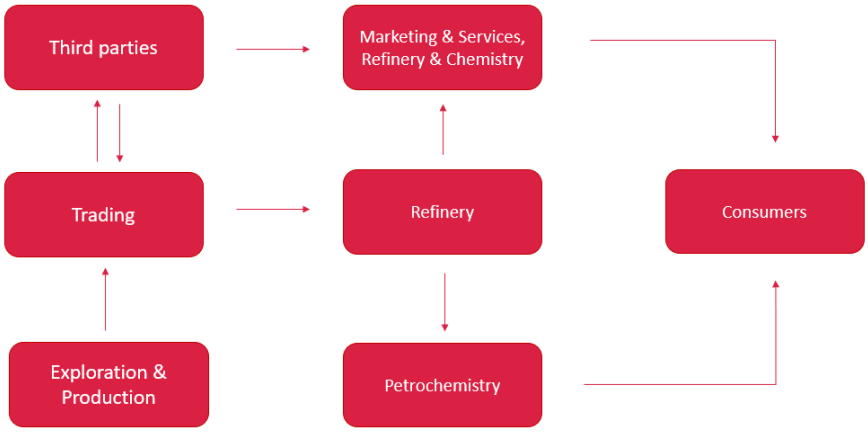


Figure 2.1: Supply chain of oil [6][5]

In the case of the company, one intermediate step between the division EP and the refinery is trading: a step that allows the company to maximize its profit [53].

The main oil activities of the company are the production and sales of crude oil, refined products and petrochemical products. In order to avoid double-counting, the emissions considered are mostly based on sales data. In some cases, it was necessary to consider production data in order to verify the total quantities sold: even in these cases, no double-counting is realized. Another main sector considered is the distribution of these products. In the case where the data provided is not sufficient, assumptions have been made and will be specified.

Crude oil

In 2021, the company produced 1274 kb/d[1] of crude oil in the division EP [5]. As shown in Figure 2.2, 1241 kb/d is sold via trading. Since there is no information about the remaining 33 kb/d, it has been assumed that they were sold to third parties and will be considered as such in the carbon footprint assessment.

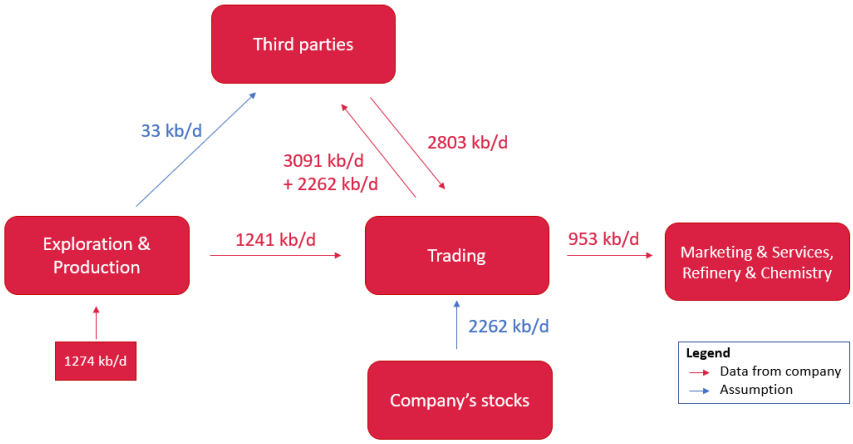


Figure 2.2: Crude oil activity of the company (kb/d) [5]

In Table 2.1, the different purchases and sales of petroleum products realized via trading are detailed. According to the GHG protocol, *considering emissions from fuel purchased for resale to non-end users (e.g. traded) is optional* [49]. Since no information is given about the identity of third parties, it has been assumed that they were non-end users. Therefore, only the trading including the production of the company is considered. However, since trading contributes significantly to the company's revenue, its total emissions are discussed in chapter 6.

Purchases and sales	**Amount of petroleum products (kb/d)**
Purchase from EP	1241
Purchase from 3rd parties	2803
Total purchases	**4044**
Sales to *Refinery & Chemistry* and *Marketing & Services sectors*	953
Sales to 3rd parties	3091
Total sales	**4044**
Sales of petroleum products through trading	2262

Table 2.1: Purchases and sales via trading (kb/d) [5]

Table 2.1 shows that the purchase from the sector EP, which represents part of the company's production, is sold via trading. In order to avoid double-counting and to make sure that all the quantities produced are considered, since 953 kb/d were sold to the sectors Refinery and chemistry (RC) and MS, they will be considered in the following

[1] kb/d = kilobaril per day. 1 baril is equal to 159 L.

section *Refined oil and products*. The remaining 288 kb/d (1241-953=288) are assumed to be sold to 3rd parties and will be considered in the total emissions in this section(since they are part of the company's production).

The company's report also indicates that 2262 kb/d of petroleum products were sold via trading, from which 1696 kd/d are refined products [5] (it has been considered that the remaining 566 kb/d are crude oil). Since no information is given about these quantities, the assumption has been made that it comes from the company's stock. The total amount of crude oil sold by trading is therefore 854 kb/d. The resulting emissions for crude oil can be found in Table 2.2.

Sales crude oils	**Quantity (kb/y)**	**Emission factors ($kgCO_2e/l$)**		**Total emissions (tCO_2e)**
		Upstream	**Combustion**	
Trading sales produced by company	311 710.00	0.24	2.79	150 107 943.59
Sales from E&P to 3rd parties	12 045.00	0.24	2.79	5 800 424.05
				155 908 367.64

Table 2.2: Generated emissions from sales of crude oil produced by the company (tCO_2e) [5]

The upstream emission factor corresponds to the extraction and production as well as the transport from the extraction site to the refinery site. The distribution between the company's site and the clients will be computed in Section 2.1.1.

Refined oil and products

Refined products are grouped into three categories by the company. The distribution is given in Table 2.3.

Refined products sales excluding trading and bulk sales	1503
Trading sales of company's products	1696
Bulk sales	383

Table 2.3: Sales of refined products sold by the company (kb/d)

As shown in Table 2.4, the company provides information about its refined products production and its sales via MS [17]. However, one can notice that there is a difference between the two columns. Due to a lack of information, it has been assumed that the difference has been bought from third parties. According to the company, the category of other products refers to refining base, petcoke, naphta, propylene and other petrochemical bases. The part of other products not sold via MS is considered to be a base for petrochemical products produced by the company (see Table 2.6).

Refined products (kb/d)	Production (kb/d)	Sales (kb/d)	Difference (kb/d)
Motor gasoline	228	353	125
Avgas, kerosene and jet fuel	67	135	68
LPG	35	55	20
Diesel fuel and heating oils	524	790	266
Fuel oils	44	55	11
Bitumen	19	36	17
Solvents	0	18	18
Lubricants	6	37	31
Other products	205	23	-182
Renewable diesel and Ethyl Tert-Butyl Ether (ETBE)	9	0	-9

Table 2.4: Production and sales of refined products (kb/d)

The different types of refined products are detailed by the company only for the refined products sales excluding trading and bulk sales. Therefore, it has been assumed that the trading and bulk sales were following the same distribution as the latter.

The total quantity of refined products considered in this section is the sum of the MS sales, the difference between MS sales and production, the trading sales and the bulk sales. The resulting emissions can be found in Table 2.5.

The upstream emission factor corresponds to the extraction and production, the transport from the extraction site to the refinery site and the refining process. The distribution between the company's site and the clients is not included in the emission factor and is computed in Section 2.1.1. In order to avoid double-counting and since it has been considered that the other products not sold to MS are used as a base for petrochemical products produced by the company, the emissions generated by the latter are considered in Section 2.1.1.

Renewable diesel and ETBE, which will be referred to as biofuels in the next chapters, are considered in the section *Refined oil and products* in this chapter because the quantity produced in 2021 (and its associated emissions) is negligible compared to the other products. Since no other decarbonized molecule is produced in 2021, it seemed appropriate to regroup biofuels with refined products. However, in the following chapter concerning the simulation of the company's transition plan, biofuels will be considered as decarbonized molecules.

Renewable diesel is produced by hydrotreating vegetable oils or feedstocks from circular economy [5] and ETBE is an oxygenate gasoline additive that is used blended in petrol because it improves its combustion characteristics [54]. Nowadays, it is rather difficult to estimate the emission factors since they can significantly vary depending on the feedstock distribution and the direct or indirect land use change. To give an order of magnitude, for an optimistic scenario in terms of land use change and by using a standard feedstock distribution, the emission factor for renewable diesel is 0.433 $kgCO_2e/l$ which is 6 times smaller than the emission factor of gasoline [55]. For a pessimistic scenario, the emission factor is 7.17 $kgCO_2e/l$, which is 2.7 times higher than the emission factor of gasoline [55]. Since the company gives only a total amount for renewable diesel and ETBE, it has been assumed that half of the amount given was renewable diesel and half

was the ETBE. Since no information is given about the sales of renewable diesel and ETBE, it has been assumed that it was sold to third parties.

Due to a lack of information, the emission factor considered does not take into account land-use change [40]. However, one has to keep in mind that land use change does occur, which means that the following hypotheses underestimate the actual emissions. In order to show the impact of land-use change, a sensitivity study is realized in section 3.4. Based on the European distribution of feedstock used for biodiesel in 2020, 36% of the feedstock used is composed of rapeseed oil, 30% of palm oil, 7% of soy oil, 3% of sunflower oil, 10% of animal fat and 10% of used cooking oil [56], giving a total emission factor of 0.79 $kgCO_2e/l$ (including upstream and combustion). By considering that the category renewable diesel and ETBE is composed of half of biodiesel and half of bioethanol without land-use change [55], the total emission factor is 0.82 $kgCO_2e/l$[2].

Refined products	**Total quantity (kb/y)**	**Emission factors ($kgCO_2e/l$)**		**Total emissions (tCO_2e)**
		Upstream	**Combustion**	
Motor gasoline	352 811.38	0.43	2.22	129 309 227.69
Avgas, kerosene and jet fuel	142 299.21	0.53	2.48	56 154 877.06
LPG	55 161.90	0.23	1.60	13 951 921.05
Diesel fuel and heating oils	784 560.94	0.55	2.68	352 734 779.64
Fuel oils	51 876.90	0.41	2.80	24 460 928.29
Bitumen	37 532.79	0.40	-	1 973 574.96
Solvents	22 233.89	2.56	-	6 370 105.65
Lubricants	43 513.01	2.61	-	13 350 557.44
Other products	54.84	0.22	-	705 626.64
Renewable diesel and ETBE	3 285.00	-	0.82	428 342.70
				599 439 941.11

Table 2.5: Emissions of company's sales of refined products (tCO_2e)

Petrochemical products

The only information about the petrochemical products produced by the company is the quantities of monomers, polymers, recycled plastic and bioplastics produced. Since the company produces mostly polyethylene, polystyrene and polypropylene, the emission factor chosen is the mean of their three emission factors. The same reasoning has been followed for the monomers, which are considered as an equally distributed mix of ethylene, styrene and propylene.

The emission factors consider raw materials used in production, energy consumption during manufacturing and emissions associated with transportation and distribution.

[2]The emission factor is located under **Combustion** but it actually also takes into account the upstream part

Since the raw materials are considered in the emission factor, the quantity of other products considered as a base for petrochemical products (see Table 2.5) are not taken into account separately in order to avoid double-counting.

Since no distinction is given between recycled and bioplastic, it has been assumed that 30 kt was recycled plastic and 30 kt was bioplastic.

The resulting emissions can be found in Table 2.6.

Petrochemical products	**Quantity (kt/y)**	**Emission factor (tCO_2e/kt)**	**Emissions (tCO_2e)**
Monomers	5 745	2 367	13 596 500
Polymers	4 908	2 813	13 807 840
Recycled/bioplastic	60	2251	153 060
Total	10 713	-	**27 557 400**

Table 2.6: Emissions from sold petrochemical products (tCO_2e)

Distribution

Since no information is given about the distribution (from the production site to the clients), several assumptions have been made. This section gives an idea of the order of magnitude of the emissions caused by distribution. However, one must remember that it is mostly based on hypotheses.

Refined products are considered to be transported in three ways: by pipeline, truck and oil tanker. According to the U.S. Energy Information Administration, 61% of crude oil and petroleum products are transported by oil tankers worldwide [57]. The same distribution has been used for the company. Therefore, the assumption that 61% of crude oil and petroleum products are transported by oil tanker has been used, and the remaining 39% are distributed almost equally between pipeline and truck transportation (20% by pipeline and 19% by truck). The emissions due to the transport by pipeline are not considered because they are negligible compared to the emissions of other transport types.

Vehicles used for road transportation are considered to be trucks of 40t Gross Vehicle Weight (GVW) which can transport 25 tons of products. While vehicles used for maritime transport are considered to be Aframax oil tankers with a capacity of 68500 to 200000 Deadweight tonnage (DWT), which is an oil tanker commonly used. Since very large vehicles have been considered, fewer vehicles are necessary and the computed emissions should be lower than the real emissions. The average distances realized by the vehicles are considered to be 400 km for oil trucks and 2 000 km for oil tankers [58]. The results of these hypotheses are given in Table 2.7.

Transport type	Type of vehicle	Quantity transported (t/y)	Average distance (km)	Emission factor ($kgCO_2e$/t-km)	Total emissions (tCO_2e)
Truck	40t PTAC (25t)	30 206 932.55	400	0.0485	586 014.49
Tanker	Aframax 68500-200000 DWT	96 980 151.87	2 000	0.00543	1 843 107.79
Pipeline	-	31 796 771.10	-	-	-
					2 429 122.28

Table 2.7: Emissions related to distribution of crude oil and refined products for energy-use (tCO_2e)

Similar hypotheses are made for petrochemical products. With a total quantity of 10 653 kt (see Table 2.6) and considering they are transported by trucks of 40t GVW over a mean distance of 400 km, the emissions generated by the transportation of petrochemical products is estimated to **207 832.20 tCO_2e**. Refined products not used as fuels (bitumen, solvents, lubricants and other products) are also considered to be transported by trucks of 40t GVW over a mean distance of 400 km and represent a total quantity of 13 484 967 t. The transport of this quantity is estimated to **716.74 tCO_2e**.

Summary of GHGs emissions

The total emissions generated by crude oil and petroleum products can be found in Table 2.8.

	Total emissions (tCO_2e)
Crude oil	155 908 368
Refined oil and products	599 439 941
Petrochemical products	27 557 400
Distribution	2 637 671
Total	785 543 380

Table 2.8: Summary of total oil emissions (tCO_2e)

The total amount of emissions generated by the oil sector is **785.543 $MtCO_2e$** with 96% of the emissions coming from crude oil and refined oil and 80% coming from the combustion of crude oil and refined oil.

2.1.2 Gas operations

Natural gas is often considered as a green fossil fuel. Indeed, to produce the same amount of energy, the combustion of natural gas emits less CO_2 than the combustion of other fossil fuels such as coal or petroleum products. However, emissions are not limited to the combustion of natural gas. First of all, the entire natural gas supply chain has to be taken into account, including the discovery of a reservoir, the extraction and processing of the gas, and finally the transportation of the gas to the end consumer. In addition, natural gas is composed mainly of methane which is at a Global Warming Potential

(GWP)[3] of 28 times higher than CO_2. Since methane leaks are present throughout the gas chain, they contribute significantly to GHG emissions.

In order to determine the emissions from the natural gas supply chain, it is important to understand each step of the chain. The supply chain can be separated into three distinct parts: upstream, midstream and downstream. The main steps are shown in Figure 2.3.

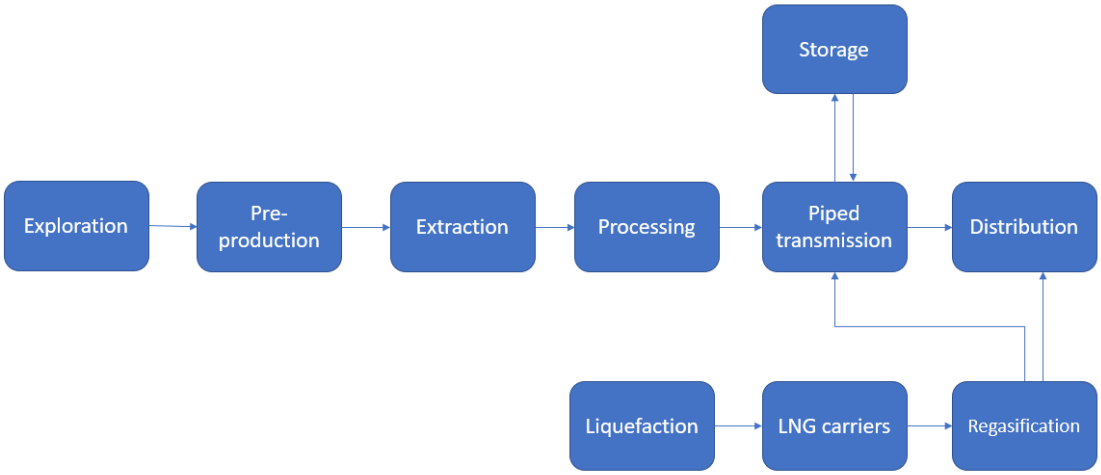


Figure 2.3: Natural gas supply chain

In order to calculate the emissions related to the gas sector, the company's production and sales data will be stated. Subsequently, the emissions generated by natural gas will be computed by going through the supply chain.

Throughout the calculation, key assumptions are made: gas extracted from wells is assumed to have an average concentration of 80%[4] methane, the GWP of methane is 28 over 100 years and the energy density of methane is 55.5 MJ/kg.

Production and sales data

The gas production of the company was 7 203 Mcf[5] per day in 2021, with less than half coming from Europe. Therefore, the annual production amounts to **66.25 Mtoe** [17].

The total sales can be divided into 3 separate parts [17]:

[3]Global warming potential is a measure used to compare the relative contributions of different greenhouse gases to global warming. It quantifies the ability of a particular greenhouse gas to trap heat in the Earth's atmosphere over a specific time period (usually 100 years) compared to carbon dioxide CO_2. By definition, CO_2 has a GWP of 1.

[4]Natural gas is composed of 70-90% methane

[5]Million cubic feet

- LNG sales.
- The sale of natural gas by pipeline.
- The sale of natural gas in Business to Business (BtB) and Business to Consumer (BtC).

A summary of the company's gas sales and purchases can be found in Table 2.9. Note that the difference between sales and production is due to the purchase of 21.6 Mtoe of LNG from third parties.

	Sales (Mtoe)	Production (Mtoe)
LNG	52.17	-
Pipeline gas	33.62	-
BtB and BtC	8.7	-
Total	**94.47**	**66.25**

Table 2.9: Summary of the group's gas sales and purchases (Mtoe)

Upstream activities

Upstream activities consist of several stages: exploration, pre-production, extraction and processing.

The first step is exploration, which consists of a search for natural gas reserves. Once a potential natural gas reserve is found, exploration wells are drilled in order to check the presence of gas.

Pre-production activities involve site preparation, drilling and well completion to prepare a gas field for production.

Once the well is completed, gas production begins. Natural gas extraction is the process of extracting natural gas from underground. During this stage most emissions are due to leaks and vents in the equipment, the workovers (repairing leaks, re-drilling or cleaning the wellbore) and the offloading of liquids (removing fluids that accumulate at the bottom of the well to improve the gas flow).

After the natural gas has been extracted, it is transported to the processing facilities. Processing transforms the gas extracted from the ground into a product that can then be transported and used by the final consumer. Processing stripping out impurities and other hydrocarbons and fluids from the "raw" natural gas. Therefore, the concentration of methane varies before and after processing, rising to over 95%. In this phase, the main emissions source is the fugitive/vented natural gas and CO_2 emissions from fuel for equipment such as compressors.

As it is difficult to quantify the part of exploration/pre-production and as it represents a very small part of the overall emissions of the gas chain, these emissions have been neglected. Therefore, Table 2.10 represents emissions from natural gas production, including extraction and processing activities.

Types of sales	**Gas sales (toe)**	**Emission factor ($kgCO_2e$/toe)**	**Production emissions (tCO_2e)**
LNG	52 173 913	401	20 921 739.11
Pipeline gas	33 618 124	401	13 480 867.72
BtC and BtB	8 701 633	401	3 489 354.83
Total	94 493 670	-	**37 891 961.67**

Table 2.10: Emissions from gas sales (tCO_2e)

Midstream activities

The midstream activities refer to the transportation of gas, whether in its gaseous form (natural gas) or as a liquid (LNG).

As you can see on Figure 2.3, after the gas processing, there are 2 possible choices: either part of the natural gas is simply transported through pipelines (*Piped transmission*), or it is liquefied and then transported by LNG tankers (*LNG carriers*). Note that at this stage the gas is composed of 95% of methane due to the processing stage.

The first case is natural gas transport (Pipeline gas and BtB/BtC), gas is transported through transmission pipelines and travels an average distance of about 1000 km [20]. The gas inside the pipeline is at high pressure, which requires compressor stations every 80 to 160 km [20]. Typically, the compressor is powered by an engine fuelled by some of the natural gas extracted from the pipeline. Emissions come mainly from the combustion of gas-fired compressors and from pipeline leaks/venting.

During the transmission phase of natural gas, methane leaks and vents account for about 1.6% of the total methane produced and fuel consumption for compressors is between 0.5% and 8.6% of total gas production [20]. An average value of 4.55% gas consumption for the compressors has been assumed. The emissions associated with the transportation of natural gas are included in Table 2.11.

Transmission stage emissions	**Quantity of natural gas consume or lost (toe)**	**Emission factors ($kgCO_2e$/toe)**			**Total emissions (tCO_2e)**
		Production	**Methane leakage**	**Combustion**	
Compressors consumption	1 925 548.94	401	-	2 174	4 958 288.53
Methane leaks and vents	677 116.11	401	21 139	-	13 869 403.18
					18 827 691.71

Table 2.11: Emissions generated from pipeline gas transportation (tCO_2e)

The second case is LNG transport, where natural gas is liquefied in order to transport it over long distances. When LNG transport is preferred, it means that pipeline transport is not feasible or simply not economically viable because of the long distance involved.

The LNG midstream stages consist of liquefaction, transport by LNG tanker and once at the destination it is stored or regasified when there is a demand for gas.

After the liquefaction[6], the LNG is transported by LNG tankers, which are ships equipped which are thermally insulated to minimize evaporation (Boil-off rate (BOR)[7]) of the LNG and therefore any losses.

Several assumptions were made in order to calculate the emissions associated with the midstream stages of LNG:

- During liquefaction, natural gas is mainly used as fuel (diesel and electricity are also used but in very small quantities). The liquefaction energy demand is normally assumed to be 8–12% of the natural gas [20]. An average of 10% has been retained.
- For regasification, 1.5% of the natural gas is required to power the pumps, compressors and reboilers [20].
- The average journey in days for an LNG carrier is assumed to be 20 days [59] with an average distance of 17 000 km [60]. The transport emissions vary considerably depending on the size of the tanker. A large majority of ships carrying LNG have a capacity of more than 60 000 cbm [61], thus these are considered to be Very Large Gas Carriers (VLGC)[8]. The associated emission factor is 14.65 gCO_2e/tonne-km [55].
- The BOR during shipping is typically 0.15% per day[9] [61]. The recovery of BOR depends on the vessel's age. In order to prevent the pressure in the LNG storage tanks from increasing too much due to the accumulation of BOR, it is necessary to either vent the gas or burn it. To release the gas into the atmosphere as little as possible, the gas is therefore re-used to power the propulsion system. If there is more Boil-off gas (BOG) available than the power required for the propulsion, the excess BOG is sent to the Gas combustion unit (GCU). The boil-off recovery rate is estimated to be around 80% as used as fuel for the tankers or burned in a GCU [20].

The LNG midstream stages emissions associated with liquefaction, transportation and regasification are represented in Table 2.12.

[6]Liquefaction involves condensing natural gas by reducing its temperature to minus 162°C while remaining at atmospheric pressure.

[7]It is the rate at which LNG evaporates during transport in LNG carriers.

[8]VLGC is a class of ships that have a capacity between 60 000 and 200 000 cbm.

[9]In newly built ships the BOR is less than 0.1%, as there is no information on the age of the ships, BOR of an old LNG carrier is considered [61].

LNG stages		**Quantity of natural gas consume or lost (toe)**	**Emission factors ($kgCO_2e$/toe)**			**Total emissions (tCO_2e)**
			Production	**Methane leakage**	**Combustion**	
Liquefaction		5 217 391.3	401	-	2 174	13 434 782.6
Regazification		782 608.7	401	-	2 174	2 015 217.39
Transportation	Evaporation	1 565 217.39	401	21 139	-	6 914 206.95
		Quantity of LNG transported (tonne)		**Distance (km)**	**Emission factor (gCO_2e/tonne-km)**	
	Tankers consumption	42 000 000		17 000	14.65	10 460 314.2
						32 824 521.14

Table 2.12: Emissions generated by LNG transportation (tCO_2e)

Downstream activities

The final stage refers to the distribution and end-consumer combustion of natural gas. As the gas approaches urban areas, it is distributed through low-pressure gas distribution networks to get the gas to the final consumer. Emissions at the distribution level mainly come from pipe leaks/venting and leakage at metering stations and at regulating stations.

Emissions related to distribution (leaks and vents) correspond to 0.1-1.9% of the methane produced [20]. Therefore, emissions from this stage correspond to an average loss of 1% of methane into the atmosphere. The emissions resulting from downstream activities are illustrated in Table 2.13.

Distribution of natural gas	**Quantity of natural gas lost (toe)**	**Quantity of methane lost (toe)**	**Emissions factors ($kgCO_2e$/toe)**		**Total emissions (tCO_2e)**
			Production	**Methane leakage**	
LNG	498 260.87	473 347.83	401	21 139	10 205 902.3
Pipeline gas	321 053.08	305 000.43	401	21 139	6 576 146.38
BtC and BtB	83 100.6	78 945.57	401	21 139	1 702 153.65
					18 484 202.32

Table 2.13: Emissions generated from natural gas distribution (tCO_2e)

Emissions from the combustion of the final product can be found in Table 2.14.

Types of sales	**Gas sales (toe)**	**Emission factor ($kgCO_2e$/toe)**	**Combustion emissions (tCO_2e)**
LNG	52 173 913	2 174	113 426 086.86
Pipeline gas	33 618 124	2 174	73 085 801.58
BtC and BtB	8 701 633	2 174	18 917 350.14
Total	94 493 670	-	**205 429 238.58**

Table 2.14: Emissions generated from combustion of gas sales (tCO_2e)

Summary of GHG emissions

Table 2.15 shows the GHG emissions associated with each stage of the gas supply chain.

Supply chain stages	Total emissions ($MtCO_2e$)
Production (including extraction and processing)	37.89
Transmission	51.65
Distribution	18.48
End consumer combustion	205.43

Table 2.15: Summary of total gas emissions (tCO_2e)

The total emissions generated by the gas activity is **313.46 $MtCO_2e$**, with 65% generated from the combustion of final consumers.

In Appendix D (section D.2), you can find the emissions that are classified according to the GHG Protocol guidelines.

2.1.3 Electricity production

The company is not only active in the oil and gas sector. It also has a power generation park with a total capacity of 16 GW, which is distributed as follows:

Total capacity installed	16 GW
Photovoltaic	8 GW
Wind turbine	2 GW
Biogas and hydroelectricity	0.2 GW
Gas plant	5.8 GW

Table 2.16: Production capacities of renewable sources and gas plants (GW)

The company's net production is 21.2 TWh, of which 6.8 TWh comes from renewable sources (solar, wind, biogas and hydro) and 14.4 TWh from combined cycle plants [17].

Since no information on the distribution of the electricity production generated by renewable energies is given, knowing that the installed capacity for biogas and hydroelectric represents a minor part, the emissions, as well as the production related to biogas and hydroelectricity, have been neglected. Moreover, the emission factor of hydroelectric is considered to be negligible since it is of the order of magnitude of 10^{-3} $kgCO_2e/kW$. In order to determine the net production of solar and wind, a capacity factor[10] of 14% for solar energy and 28% for wind energy was considered. One should that almost all the company's current wind turbines are onshore[11]. The capacity factor chosen is an average depending on the region where the energy is located [62]. The emissions resulting from the company's net electricity production can be found in Table 2.17.

[10]The capacity factor is a measure of the actual output of a generator relative to its maximum potential output over a given period of time.

[11]The gross capacity for onshore wind is 2030 MW, while for offshore wind it is 32 MW

Type of production		Capacity (GW)	Net production (TWh)	Emissions factors ($kgCO_2e/kWh$)	Total emissions (tCO_2e)
Renewables	Solar	8	4.53	0.0323	146 426.67
	Wind	2	2.27	0.0141	31 960
	Biogas and hydro	0.2	-	-	-
CCGT plants		5.8	14.4	0.418	6 019 200
					6 197 586.67

Table 2.17: Net production emissions from renewable sources (solar, wind, biogas and hydro) and from combined cycle plants (tCO_2e)

In 2021, the sale of electricity in BtB and BtC was 56.6 TWh [17]. The source of the electricity sold is not indicated. However, having the details of where the electricity is delivered, the GHG emissions have been calculated based on the emission factors of the electricity consumed in each country, as shown in Table 2.18.

Country	Delivered electricity (TWh)	Electricity generation factors (gCO_2e/kWh)	Total emissions (tCO_2e)
France	33.4	67	2 237 800
Belgium	4.5	154	693 000
United Kingdom	12.6	463	5 833 800
Netherlands	0.8	418	334 400
Spain	5.2	232	1 206 400
			10 305 400

Table 2.18: Emissions from electricity sales (BtB and BtC) (tCO_2e)

Note that a distinction between the company's production activity and distribution activity (BtB and BtC) is taken into account in the emission calculations. Indeed, electricity is traded between producers and suppliers. Then, the supplier distributes the electricity to individuals and businesses. In the distribution activity, in theory, the company could repurchase its own electricity produced on the market, given the significant quantity of electricity sold in the market, it is unlikely to occur in practice. It is therefore assumed that the electricity produced by the group is not included in BtB and BtC sales.

The total emissions generated by the electrical activity is **16.503 $MtCO_2e$** and are distributed according to the GHG Protocol in Appendix D (section D.3).

2.1.4 Discussion on uncertainty and chosen indicator

Emissions factors

In order to estimate the carbon footprint, emission factors have been used to calculate the GHG emissions associated with an activity. To define these factors, measurements have been made upstream (which can be found in databases such as ADEME [55]). Having variations in the sampling data, each factor is endowed with an uncertainty that

is associated with a confidence interval, which is in most cases 95%.

Note that only the uncertainty related to the emissions factor will be taken into account, but other sources of uncertainty may arise from the assumptions made during the carbon footprint calculation. Each of these assumptions introduces a level of uncertainty that can affect the accuracy of the carbon footprint result.

To determine the uncertainty of the carbon footprint related to the emissions factors, the following formula must be applied [63]:

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 + ... + (U_n * x_n)^2}}{x_1 + x_2 + ... + x_n}$$

where,

- U_{total} is the percentage uncertainty of the sum of the quantities
- x_i and U_i are the uncertain quantities and their respective uncertainty percentages

The ADEME database [55] gives the uncertainties of the emission factors it provides, for the coefficients not coming from ADEME or if the uncertainty is not provided, the grid provided in ADEME's methodological guide is being utilized [63]:

- 0% to 5% for data from direct measurement (bills or meters)
- 15% for unmeasured reliable data
- 30% for recalculated data (extrapolation)
- 50% for approximate data (statistical data)
- 80% for a known order of magnitude data

The Figure 2.4 shows the uncertainty for each activity and the overall uncertainty of the carbon footprint.

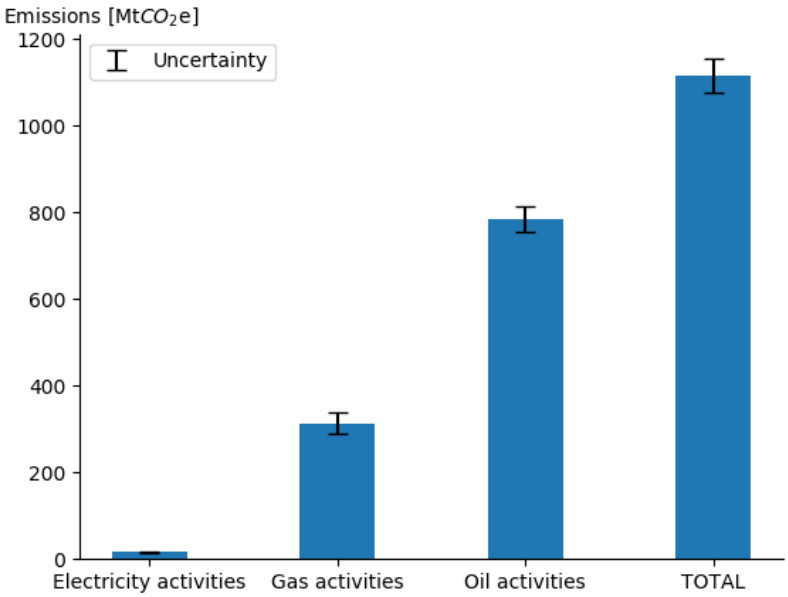


Figure 2.4: Uncertainty of the carbon footprint related to emission factors per activity ($MtCO_2e$)

More precisely, the uncertainty for electricity production is 10.06%, for gas activity it is 7.89% and finally oil activity it represents only 3.85%.

The uncertainty of the carbon footprint related to the emission factors is **3.51%**. In other words, the total emissions generated are 1115±39.1 $MtCO_2e$.

This result might be counter-intuitive. Indeed, the total uncertainty is lower compared to the uncertainty associated with the oil activity, which is the lowest. This can be explained by the fact that the largest source of emissions is oil combustion, which has an uncertainty of 5%. This means that it has a larger weight on the computation (see equation above). As the oil activity has a lower uncertainty than the other activities and represents a significant weight in the emissions, the uncertainty of the carbon balance is significantly reduced.

Climate indicator

The conventional indicator to quantify the effect of a GHG is the *Global warming potential* (GWP). It is defined as the measure of the radiative forcing due to a pulsed emission of a GHG compared to a pulsed emission of an equal mass of CO_2 over a specific time horizon. While this indicator is the most commonly used, it can be subject to criticism. Indeed, in the vast majority of emissions studies, the 100-year GWP is used, which means that short-term impacts are neglected and therefore this is equivalent to assuming a stable climate system. Some GHGs have a significant impact on short-term climate forcing, and these impacts may therefore be underestimated if one takes the GWP over 100 years, because only long-term effects are considered. One could also criticize this indica-

tor for the fact that the impact of GHGs is no longer considered after this 100-year period.

To show the importance of the GWP period chosen, Figure 2.5 represents the total emissions from gas activity over 20 (GWP20) and 100 years (GWP100).

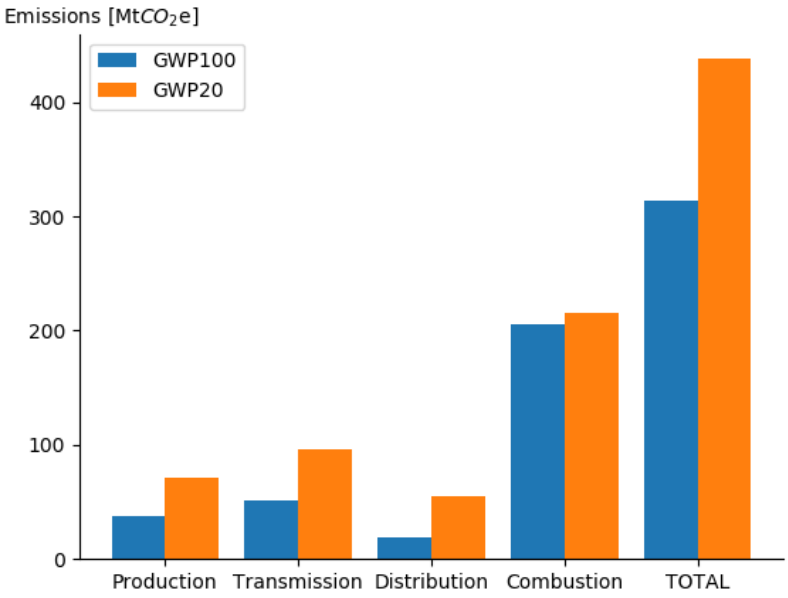


Figure 2.5: Impact of on natural gas supply chain emissions per supply chain step ($MtCO_2e$)

As explained in subsection 2.1.2, one of the major sources of emissions in the gas supply chain is associated with methane leaks and vents. Methane has a short lifetime in the atmosphere with an average lifetime of 12 years, after which it oxidizes into carbon dioxide. Therefore, the climate-forcing impact of methane emissions changes significantly depending on the period chosen. The GWP of methane is 28 on 100 years but 84 on 20 years, which means that reducing methane emissions can have a more immediate impact on reducing global warming. On the other hand, the N_2O which is also a GWP present in the gas supply chain has a fairly long lifetime (approximately 114 years) and thus the GWP of N_2O would not be strongly impacted by the change in the time frame.

The question that needs to be asked is whether global warming should be considered a short-term or long-term problem at this time. Using GWP over 100 years does not reflect the urgency of mitigating greenhouse gas emissions; in other words, the urgency to mitigate the impacts of climate change, which should already be critical before 100 years.

Given that a significant part of emissions from gas activities consists of methane, the difference in emissions calculated using GWP20 and GWP100 (Figure 2.5) is not negligible. The use of GWP100 may not be the most representative approach, particularly

for emissions associated with the gas activity. To ensure accuracy, it would be more appropriate to utilize GWP20 for methane-intensive activities. In order to obtain a more realistic assessment of a company's emissions, it is worth considering an open debate regarding the selection of emission indicators. Would it not be preferable to adapt the choice of indicators to the specific activities being evaluated, such as oil, gas, or electricity? This approach takes into account the emission profiles associated with each sector, therefore it provides a more accurate representation of the company's emissions impact.

2.2 Overview and comparison with company data

According to the calculations, the company would have generated a total of **1115.5MtCO$_2$e** (scope 1 and 3) over the year 2021, with a breakdown as follows :

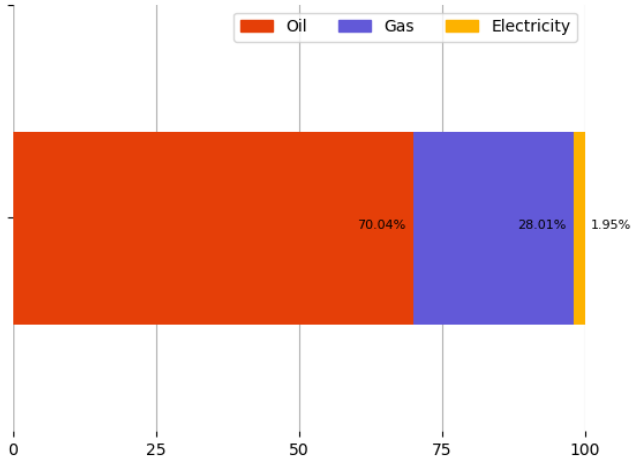


Figure 2.6: Emissions distribution related to each activity of the company (%)

The above graph clearly shows that if the company wants to reduce its emissions, it must first and foremost focus on its oil activities, which account for 70% of its total emissions.

Table 2.19 provides a global overview of emissions categorized by scope.

	Company's emissions (MtCO$_2$e)	Computed emissions (MtCO$_2$e)
Scope 1	82	122.81
Scope 2	7	-
Scope 3	370	992.69
Total	**459**	**1 115.15**

Table 2.19: Emissions reported by the company and emissions computed (MtCO$_2$e)

The company reported total emissions of **452 $MtCO_2e$** (scope 1 and 3), which is around 2.45 times less than the computed result. As a reminder, the emissions calculated in section 2.1 do not include scope 2 emissions as they represent a small proportion of total emissions. To give an order of magnitude, according to the company's estimates, scope 2 emissions would amount to approximately 7 $MtCO_2e$.

In order to understand the difference between the results obtained and those provided by the company, scope 1 and 3 should be analyzed more closely.

Total scope 1 emissions are **122.81 $MtCO_2e$** compared to **82 $MtCO_2e$** reported by the company. This difference can be explained by the fact that, depending on the sector of activity, certain sources of emissions are very difficult to quantify and can represent a significant part of the carbon balance. For the gas business, a major source assumed not to be fully included or underestimated in the carbon footprint provided by the group is gas leaks and vents. There are frequent throughout the supply chain but are very complicated to measure: the data on gas losses whether in process or transport varies considerably depending on the sources chosen.

The total emissions of scope 3 are **992.69$MtCO_2e$** against **370$MtCO_2e$** announced by the company. This difference may be due to the fact that the group only considers GHG emissions related to the use of energy products by customers (category 11 of the GHG protocol) and therefore does not take into account the other categories set out by the GHG protocol guidelines [36]. However, as shown in Table 2.20, keeping only the emissions from the combustion of the products (category 11), the result obtained is far from the one communicated by the company.

Activity	Company's emissions	Computed emissions
Oil	255	730
Gas	115	205

Table 2.20: Category 11 emissions from the company and computed data ($MtCO_2e$)

It seems like the group did not consider all the emissions for which it is responsible. The company may have excluded part of its sales volume. Indeed, the emissions computed in category 11 have been computed based on the production and sales data given in the DEU of the company. Moreover, the emission factors used come from ADEME, which means that no assumption has been made about the quantities considered. The category 11 computed represents 2.5 times the emissions reported by the company for the same category: this underlines a major incoherence in the company's way of computing its emissions.

The significant difference between the results obtained (see section 2.1) and those provided by the company is likely due to production or sales volumes not recorded by the company. The company is involved in oil, gas and electricity trading activities, which constitute an important part of its production and sales. The primary objective of trading for oil and gas companies is to buy and sell various energy products, such as crude oil, natural gas, and refined petroleum products, with the aim of generating profits. They have the flexibility to purchase oil and gas from producers and sell them to end-users or

other non-end-user entities, such as traders. Additionally, they can also choose to sell their own stock through trading activities. In general, trading activities help maximize their financial returns. According to the GHG Protocol [50], reporting *emissions from fuel purchased for resale to non-end users (e.g. through trading) is optional*, and it can be reported separately from scope 3 emissions as *optional information*. A discussion is conducted about the way trading is taken into account in chapter 6. Figure 2.7 illustrates the trading activities included in the calculated carbon footprint and those that are provided for informational purposes and are therefore optional.

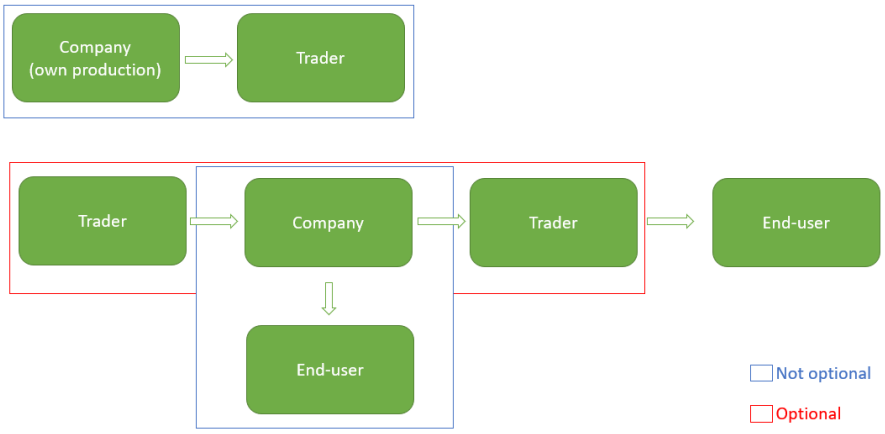


Figure 2.7: Optional and non-optional scope 3 emissions from trading activities

In the carbon footprint calculation, since no information regarding the quantity sold to end-users or non-end-user (e.g. traders) is given, and considering that the electricity and gas trading activities represent a negligible portion compared to oil trading, the volume of traded electricity and gas was not included in the carbon footprint assessment. However, in the case of oil products, the company's own production sold via trading, which may come from their stock in some cases (referred to as physical trading) is known and was taken into account. The significant difference in the emissions shown in Table 2.20 can therefore be explained by the fact that the company does not take into account the volume of trading sold and produced by the company. Without considering any trading, the computed category 11 emissions for the oil are **293.903 $MtCO_2e$**, which is much closer to the reported value of **255 $MtCO_2e$**. This confirms the hypothesis that the company does not consider its trading activity in its generated emissions.

Table 2.21 demonstrates that excluding trading, the computed total emissions (scope 1 and 3) generated are much closer to those reported by the company.

	Company's emissions	Computed emissions
With physical trading	-	1115
Without any trading	452	680

Table 2.21: Carbon footprint including physical trading only and without any trading for the year 2021 ($MtCO_2e$)

In both situations (the result obtained in section 2.1 and those provided by the company), scope 3 represents a majority of the total emissions, which is approximately 65-90%, depending on the sector of activity. Therefore, the latter is not to be neglected, the emissions made by the company but also those caused by it must be taken into account.

In conclusion, the emissions reported by the company are far from those calculated, which means that the company should review its carbon footprint assessment. Indeed, a detailed analysis of scopes 1 and 3 shows that the calculations undertaken by the company for its carbon footprint are not taking all the produced volumes into account and are not entirely transparent. Even by taking into account the uncertainty of the computed carbon footprint (see subsection 2.1.4), the result is still far from the emissions provided by the company. If the company wants to drastically reduce its emissions it must first tackle the oil sector which accounts for a major part of total emissions, as shown in Figure 2.6. Specifically, the company needs to act on the emissions generated by the combustion of its products, which would involve reducing the sale of fossil fuels and moving towards a more diverse energy mix. It is important to remember that the main objective of this assessment is to identify all the direct or indirect emission sources related to the company. This way, a company can adopt an adequate strategy in order to decrease its total carbon footprint. By not considering all of the emission sources related to its activity, the company cannot address them properly.

Based on the carbon footprint assessment developed in this chapter, a simulation of the company's targets from 2021 to 2050 is realized and is presented in the following chapter.

Key messages of chapter 2

1. Based on the data provided by the company and by making hypotheses when needed, the computed company's emissions (scope 1 and 3) in 2021 are **1115.15 $MtCO_2e$** with:
   - 122.81 $MtCO_2e$ in scope 1
   - 992.69 $MtCO_2e$ in scope 3
2. The uncertainty of the carbon footprint assessment related to the emission factors is 3.51%, which means that the total emissions generated are 1115.15 ± 39.1 $MtCO_2e$.
3. The company reported total emissions of **452 $MtCO_2e$** (scope 1 and 3), which is 2.45 less than the computed result. This could be explained by several elements:
   - Certain sources of emissions are very difficult to quantify and can represent a significant part of the carbon balance, they may not have been fully taken into account by the company (e.g. gas leaks and vents).
   - The company only considers the category 11 of the GHG protocol, which is related to the use of energy products (the 15 categories can be found in Appendix B).
   - The company may not consider its production volume sold via trading.
4. Even when considering the uncertainty related to the emission factors, the emissions computed by the company are much lower than the ones computed in this chapter.
5. The company should reassess its carbon footprint in order to take into account all of its emissions.

Chapter 3

Simulation of the company's transition plan

In order to project the emissions generated by the company by 2050, a simulation of the carbon balance was conducted for each year based on the work done in chapter 2 (computation of the carbon footprint in 2021).

In its annual report [5], the company has built its vision of achieving net zero on several treaties/scenarios. The company relies on global energy demand data from the World Energy Outlook published by the IEA. It also bases its ambitions on several treaties, such as the *Fit for 55* policy adopted by the European Union, which aims for a 55% decrease in emissions between 1990 and 2030 as well as the Glasgow Agreements which call for a reduction in methane emissions from 2020 levels of 50% by 2025 and 80% by 2030. This is why assumptions have been made based on these treaties and scenarios when there was a lack of information from the company.

> This section will provide an overview of the NZE scenario from the IEA, which is used as a long-term reference by the company. Furthermore, the methodology used to calculate the annual carbon footprint will be explained, including the analysis of each sector and projected sales until 2050. An analysis of other possible scenarios is also provided in order to complete the study. Ultimately, this section aims to demonstrate whether the company is on track to achieve net zero. The simulation tool created in order to realize the scenario was created on Excel (see link: Simulation Excel).

3.1 Net zero emissions scenario

To maintain the rise of global temperature below 1.5°C by 2050 and below 2°C by 2100, global emissions must be reduced by 45% by 2030 and by 100% by 2050.

The NZE by 2050 is a scenario created by the IEA that models how the energy demand and the energy mix should evolve for the world to reach net zero emissions by 2050 [9]. By providing detailed simulations and concrete guidelines, this scenario can be used as a reference for companies and governments. Indeed, this scenario gives sectoral

pathways to net zero emissions but also the wider implications of achieving it, such as the impacts on the economy, the energy industry and the affordability and security of energy. The scenario also considers the role that governments, companies, households and citizens should play in order to reach this goal. For example, the scenario states that achieving net zero will be very challenging for lower-income countries, which makes international cooperation essential. Another example is that equally behavioral changes are needed from companies and citizens but should be enabled mostly by the policies and investments made by governments and should be required, for some instances, by laws and regulations [9].

Even though the scenario gives the guidelines needed to reach net zero emissions, the commitments made by the various parties involved are far from sufficient, as illustrated in section 3.5. As shown by the Stated Policies Scenario (STEPS), which is a scenario that explores how the emissions would evolve without any change except the implementation of what is under development, the current measures and targets put in place by governments and companies are far from sufficient [9][64]. Even the Announced Pledged Scenario (APS), which assumes that all of the net zero targets announced by countries around the world to date are met in full [9], shows that even the ambitions pledges are not sufficient to reach this goal. Therefore, one has to keep in mind that the NZE scenario provides guidelines to follow but is not the most realistic scenario.

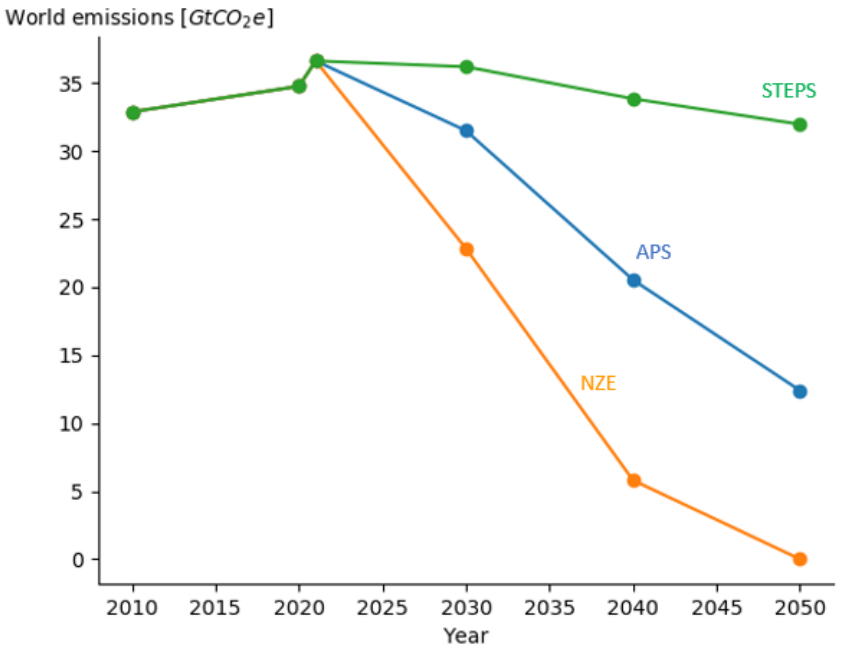


Figure 3.1: Worldwide emissions from 2010 to 2050 according to different scenarios ($GtCO_2e$)

Despite the fact that the company states that it uses the NZE scenario as a long-term reference, it does not respect some of its recommendations. Indeed, the company has increased its investments in exploration for new oil sites when the scenario states that

there should not be any new investments as they would lead to struggles to return the capital invested [14]. Another major risk of investing in exploration would be carbon lock-in[1].

In order to verify if the company will reach net zero by 2050 and since the company considers the NZE scenario as its long-term reference, the latter has been used when hypotheses needed to be made in the following sections.

3.2 Methodology

In order to check that the company's objectives in terms of production and sales are in line with its own ambitions and with the NZE scenario, a modelization based on the carbon footprint assessment of each year from 2021 to 2050 has been realized. As in chapter 2, the methodology was subdivided into the main activity sectors of the company: oil, gas, electricity and decarbonized molecules.

Modelization based on data given by the company and on the NZE scenario

The modelization was mostly based on the data given by the company, which will be detailed in the following sections. When the information provided by the company was insufficient, hypotheses have been made based on the NZE scenario. Since the company gives targets for the years 2030 and 2050 only, it has been assumed that the evolution between these years was linear.

Carbon footprint assessment

The carbon footprint assessment for each year was realized in the same way as the carbon footprint assessment of 2021 (see chapter 2 for more details). Due to some lack of information for certain years, a few simplifications have been made in some cases and will be detailed in the following section. Unless otherwise stated by the company, it has been supposed that the latter will produce the same products between 2021 and 2050.

In order to apply the same assessment for each year, a VBA[2] code combined with the adapted Excel sheet presented in chapter 2 has been realized. Its main function is explained in Figure 3.2.

[1] Carbon lock-in is a phenomenon that occurs when fossil-fuel systems are implemented and delays the transition to low-carbon systems [38]

[2] Excel VBA (Visual Basic Analysis) is Microsoft's programming language [65]

Figure 3.2: Functioning of VBA simulation

Hypotheses on the emission factors

Emission factors depend on several elements such as the energy source used to realize a process or the efficiency of a process. These elements are likely to evolve, which means that the emission factors will evolve as well. For each activity sector, the emission factors have been adapted according to the predictions of the NZE scenario and will be developed in the following sections.

3.3 Data and parameters estimations and computations

3.3.1 Oil sector

Modelization of the production and sales

To compute the annual emissions generated from 2021 to 2050, the first step is to estimate the sales for each year. Since the company's objective is to sell only its production from 2030 [5], estimating the sales is equivalent to estimating the production. To consider the largest scope possible, and since the company sells more than it produces before 2030, it has been decided to model the sales projected by the company instead of the production before 2030. The company claimed that it was following the NZE scenario [5], therefore this scenario has been used as a reference in many cases where hypotheses were needed.

The company claims that its objective is to reduce its sales until reaching an alignment with its production in 2030, which means that the company will sell all its petroleum stocks between 2021 and 2050. This is not taken into account in the following analysis but is important to remember: the emissions computed can be considered as a low estimate of the real emissions of the company.

The company expects a petroleum production peak during the decade and then a reduction of production in order to reach 1.4 Mb/d in 2030 and 0.3 Mb/d in 2050. Since

the company does not give an estimated year for the oil production peak, it has been assumed, based on the NZE scenario, that the production peak will coincide with the peak of the global oil demand, which should occur around 2024 according to the scenario.

Based on this hypothesis and by assuming that the company's production follows the global demand anticipated in the NZE scenario, the company should produce 2.64 Mb/d in 2024. The reference years considered in the simulation are 2021, 2024, 2030 and 2050. It has been considered that the production of the company evolved linearly between each reference year. The data used for the modelization of the company can be found in Table 3.1.

Year	2021	2024	2030	2050
Petroleum production (Mb/d)	4.41	4.53	1.4	0.3

Table 3.1: Petroleum products production per year (Mb/d)

Despite the fact that in 2050, part of the produced quantity will be used to produce 10 Mt/year of polymers and that the company will produce low-cost petroleum, no information is given about the type of products. Therefore, it has been considered that until 2050, the company will produce the same kind of products as in 2021 and that the distribution of production will follow the global oil demand in different sectors (such as road transport, power generation, buildings, etc.) [14]. The resulting distribution is given in Table 3.2. Since the distribution is given only for 2030 and 2050, it has been assumed that the distribution in the year 2024 is the same as in 2021.

Sectors	**Global demand 2030 (Mb/d)**	**Global demand 2050 (Mb/d)**	**Company production 2024 (kb/d)**	**Company production 2030 (kb/d)**	**Company production 2050 (kb/d)**
Road transport	27.50	1.30	1941.32	511.29	17.03
Shipping	5.00	1.00	237.27	92.96	13.10
Aviation	5.00	1.00	237.27	92.96	13.10
Petrochemical products	20.10	13.40	982.64	373.71	175.55
Buildings	5.40	0.29	378.68	100.40	3.73
Power generation	1.05	0.32	167.77	19.52	4.13
Other[3]	11.25	5.60	584.79	209.16	73.36

Table 3.2: Distribution of global demand and company production per sector for the years 2030 and 2050 (Mb/d or kb/d)

The distribution per sector given in Table 3.2 represents the company's petroleum production in each sector. It has to be separated per product and will be based on today's distribution of products per sector and on the following hypotheses, for each year considered (2024, 2030 and 2050). Only the use of petroleum products is considered in the latter hypotheses.

Due to a lack of information about the crude oil distribution per sector and since the base of each product is crude oil, it has been assumed that each sector consumes 10% of crude oil.

In the *Road transport* sector, the petroleum products used as fuels are mainly diesel, gasoline and a smaller amount of LPG. It has been assumed that 63% of the company's production in the road transport sector is made of Diesel, 24% of gasoline, and 3% of

[3]The sector *Other* includes coal-to-liquids, gas-to-liquids, additives and kerogen oil.

LPG [66].

In the *Shipping* sector, marine gasoil (which is considered to be equivalent to diesel except that it has a higher density) and heavy fuel oils are mostly used as fuels [67]. It has been assumed that 45% of the company's production is made of diesel and 45% of heavy fuel oils. As a reminder, the 10% remaining are considered as crude oil.

The company's production in the *Petrochemical products* sector has been assumed to be equally distributed between lubricants, solvents, bitumen and other products[4] which gives 22.5% of the petrochemical sector per products and 10% of crude oil as assumed earlier. The company specifies that part of its production will be used for the production of petrochemical products. In order to avoid double-counting, it is assumed that the other products[5], which are considered to be the base for the production of petrochemical products, will be used exclusively for the production of petrochemical products by the company. Their emissions will thus be considered in the total emissions of these end products. The petrochemical products that the company aims to produce are given in Table 3.3.

Petrochemical products	**Production 2021 (Mt/y)**	**Production 2030 (Mt/y)**	**Production 2050 (Mt/y)**
Monomers	5.75	0.00	0.00
Polymers	4.91	2.33	3.33
Bioplastic/recycled plastics	0.06	1	6.67
Total	10.71	3.33	10

Table 3.3: Planned petrochemical production of the company for the years 2030 and 2050 in (Mt/y) [5]

Since the company does not give information about the production of the monomers for the years 2030 and 2050, it has been considered that the company intends to produce polymers only.

The *Building* sector regroups different activities that are necessary to operate, maintain and manage buildings [68] such as plumbing, heating and providing electricity. In the case of petroleum products, it has been assumed that they are mainly used for heating and the other possible uses have been neglected. Since LPG and heating oil are the petroleum products that are mostly used in the *Building* sector, it has been considered that the company's production for the building sector is composed of 45% of LPG and 45% of heating oil [69][70].

Power generation with petroleum products mainly uses fuel oil and petroleum coke, it has therefore been assumed that the company's production for the *Power generation* sector is composed of 45% of fuel and 45% of petroleum coke (or other products, which

[4]According to the company, the category other products refers to refining base, petcoke, naphta, propylene and other petrochemical bases.

[5]As a reminder, part of the other products are supposed to be used for the sector *Power generation*, one should thus note that only the part used to produce petrochemical products is considered here

is the group of products containing petroleum coke by the company).

The sector *Other* is not described in detail (no precise distribution is given). Since the product with the lowest emission factor is crude oil, it has been considered that all the production of the company for the sector *Other* was made of crude oil.

The distribution of petroleum products is given in Table 3.4. As a reminder, the sales are considered to be equal to the production from 2030 onwards and the hypothesis has been made that it was also the case for the year 2024 in order to simplify the computations. As a reminder, it is assumed that there is a linear evolution between each reference year.

Refined products	**Sales in 2021 (kb/d)**	**Sales in 2024 (kb/d)**	**Sales in 2030 (kb/d)**	**Sales in 2050 (kb/d)**
Crude oil	887	979.29	328.25	96.03
Motor gasoline	841.61	465.92	122.71	4.09
Avgas, kerosene, jet fuel	321.86	213.55	83.67	11.79
LPG	131.13	228.64	60.52	2.19
Diesel fuel and heating oils	1883.48	1500.21	409.12	18.30
Fuel oils	131.13	182.27	50.62	7.75
Bitumen	85.83	221.09	84.08	39.50
Solvents	42.91	221.09	84.08	39.50
Lubricants	88.21	221.09	84.08	39.50
Other products	236.84	221.09	92.87	41.35
Total	4650.00	4529.75	1400.00	300.00

Table 3.4: Distribution of sales per type of refined product in 2021, 2024, 2030 and 2050 (kd/d)

Modelization of the emission factors

In order to assess the carbon footprint of each year, one should take into account the fact that the emission factors will be likely to evolve. To estimate these evolutions, several assumptions have been made, mostly based on the NZE scenario [14].

In the case of crude oil and refined products, the emissions are separated into two main emission factors as defined by ADEME [19]: the upstream and the combustion emission factor[6]. The upstream factor regroups different subactivities and each has its emission factor :

- **Extraction & process** which regroups the processes of searching and extracting the oil.
- **Transport** between the extraction site and the refinery site.

[6]One should note that the subdivision considered in this chapter is different than in chapter 2, where the upstream factor regroups the extraction and process and the transport.

- **Refinery** which consists of the transformation from crude oil to refined products. This part does not apply to crude oil.
- **Distribution** which represents the transport between the refinery site and the clients.

For all the petroleum products used as fuels, the most important emission factor is the one related to combustion and is therefore considered constant. The emission factors of the Extraction & Process and refinery should not vary in a significant way either.

As a reminder, several hypotheses have been made to assess the emissions generated by the distribution (see Section 2.1.1 for more details). Since the distribution account for only 0.4% of the total emissions in 2021, it has been considered that it remained constant[7].

However, the emission factor for transport is likely to change. The NZE scenario gives the following distribution for transport evolution [14]:

- In 2030, the shares in transport should be 75% for oil, 10% for electricity, and 10% for biofuels, and it has been considered that the remaining 5 % were equally distributed between hydrogen and natural gas
- In 2050, the shares in transport should be 10% for oil, 50% for electricity, 15% for biofuels, 30% for hydrogen and 5 % of natural gas

In order to model the distribution (or at least to have an order of magnitude), it has been assumed that from 2030, the transport of petroleum products used as fuel and bitumen[8] is realized by trucks of 40t on an average distance of 400 km. The upstream emission factors for petroleum products computed can be found in Table 3.5 (more details about the computation can be found in Appendix E).

Refined products	**Upstream emission factors 2030 ($kgCO_2e/l$)**	**Upstream emission factors 2050 ($kgCO_2e/l$)**
Crude oil	0.107	0.087
Motor gasoline	0.141	0.123
Avgas, kerosene, jet fuel	0.156	0.136
LPG	0.068	0.054
Diesel fuel and heating oils	0.155	0.134
Fuel oils	0.123	0.101
Bitumen	0.086	0.052
Other products	0.026	0.013

Table 3.5: Upstream emission factors for 2030 and 2050 ($kgCO_2e/l$)

As shown in Table 3.5, the upstream emission factor decreases slightly because of the evolution of the transport distribution between 2030 and 2050.

[7] By considering this hypothesis, the distribution represented only 0.7% of the total emissions in 2050

[8] Since the details of the upstream emission factor are not given for to petroleum products not used as fuel (solvents and lubricants), it is impossible to change the transport emission factor, therefore the emission factors of these products have been considered as constant

The emission factors of monomers and polymers have been considered constant. However, the amount of recycled/bioplastic increases, which impacts the emissions. As stated earlier, the emission factor of biofuel is difficult to estimate since it depends on land-use change, which is very complicated to model. In order to take into account this parameter, a sensitivity study is realized in section 3.4.

3.3.2 Gas sector

Modelisation of sales

Natural gas sales are broken down into LNG sales, pipeline gas and power sales (BtB and BtC).

The sale of LNG announced in the annual report can be found in Table 3.6.

Year	2021	2025	2030
LNG sales (Mt)	42	50	68.6

Table 3.6: Company's LNG sales from 2021 to 2030 (Mt)

From 2050 onwards, the company expects to produce between 25 to 30 Mt/year (an average of 27.5 has been chosen) of LNG. Furthermore, for 2050, it is assumed that its production is equal to its sales. Indeed, according to the NZE scenario provided by the IEA [9], the demand for natural gas between 2030 and 2050 decreases by about 65%. This means that in 2050, with the assumption made, production will always be higher than demand, therefore, the company will have no incentive to sell more.

For pipeline gas and power sales, the company has provided data for the year 2021, which includes pipeline gas sales of 3655 Mcf/d and power sales (both BtB and BtC) of 101.2 TWh. Table 3.7 illustrates the variation in natural gas demand according to the NZE scenario. It is assumed that the company would follow a similar trend. Therefore, by referring to Table 3.7, the gas sales from 2021 to 2050 can be determined.

2020-2030	-13.43%
2020-2040	-40.30%
2020-2050	-70.15%

Table 3.7: Fluctuation in natural gas demand according to the NZE scenario (%)

Note that the variation starts in 2020, hence the value of the year 2020 has been taken into account, with sales of 3562 Mcf/d for the pipeline gas and 95.8 TWh in BtB and BtC [5].

Improvement of the gas supply chain

Due to the constant improvement of the gas supply chain, including enhancements in installations and transportation, certain emission sources are expected to decrease over

time.

- Methane emissions (leaks and vents)

  The company has made a pledge to reduce methane emissions from their operational facilities by 50% by the year 2025 and by 80% by the year 2030 compared to 2020 [5].

  On the other hand, the IEA did a study to determine the extent to which methane emissions in the oil and gas sector could be reduced using existing technologies [71]. It estimates that a 75% reduction in methane emissions between 2020 and 2030 can be achieved with leak detection programs, repair of existing leaks and equipment upgrades.

  In addition, the IEA estimate that based on average natural gas prices between 2017 and 2021, approximately 40% of methane emissions could be reduced at a negative cost for the company[9]

  As can be seen, the methane reduction targets for 2030 set by the company are quite similar to those of the IEA. However, since the gas production is not equal to the sales[10], the affiliated companies are not bound by the objectives set by the company. It is why to have a more generalized case, the reduction target of approximatively 75% in methane emissions by 2030 (compared to 2021) in the gas sector, as determined by the IEA will be assumed.

  The methane emissions reduction target is taken into account in the emissions from the production (extraction and processing), transmission and distribution (see section E.2 for more details).

- BOR[11]

  The BOR of modern LNG carriers during laden conditions are generally less than 0.1% per day (usually around 0.07-0.08% per day) of the total volume per day, while older LNG carriers have an average BOR of around 0.15% of the total volume per day [61].

  Currently, the company's LNG transportation activities are carried out using a fleet of 20 LNG carriers, out of which 19 are leased from shipowners and 1 is co-owned [5]. However, as some of the contracts for these LNG carriers are set to expire in 2022 and 2023 and to support the increasing demand, an additional 8 new LNG carriers will be added to the fleet by 2022 and 2024 [5]. Therefore, by the end of 2024, the company's fleet will consist of 23 ships.

  According to the information provided by the company, the new LNG carriers (8 new ships) have a BOR of 0.085%/day [72], while the remaining 15 ships of the previous generation have a BOR of 0.15%/day [73]. Therefore, starting from 2025, it can be estimated that the fleet will have a BOR of 0.127%/day.

[9] This is because the value of the natural gas that would have been lost due to leaks is higher in the market than the cost needed for leak detection and repair equipment.

[10] It means that the company buys gas from external suppliers.

[11] It is the rate at which LNG evaporates during transport in LNG carriers.

As there is no information available on the expiry of contracts for the older fleet (which typically have 10-year contract durations that can be extended thereafter), it is known that a vessel is generally operated for 35 to 40 years before being decommissioned [61]. Therefore, from 2040 onwards, knowing that more than half of the world fleet in 2021 is over 10 years old [61], it can be assumed that all 15 of the company's previous generation ships will need to be replaced. The resulting BOR would be comparable to that of recently-built LNG carriers which is 0.085%/day.

- Recovery rate of BOG[12]

  To be consistent with the assumption made for the BOR, in 2040, the company's fleet is considered to consist of new and recently-built vessels, with a BOG recovery rate of almost 95%. Indeed, some of the recent[13] vessels are also equipped with a reliquification plant, which recovers the BOG and liquefies it to put it back into the tank. This added system allows to reach a recovery rate of almost 100%.

- LNG transport

  The company's fleet consists of over 20 gas carriers with capacities ranging from 138 000 to 180 000 cubic meters [73]. Based on the vessel capacity, an emission factor of 14.65 gCO_2e/tonne-km, which corresponds to a VLGC [55], has been considered. Additionally, the company has stated that its new vessels, which represent 8 of a total fleet of 23 by 2024, emit on average 40% less CO_2 than older ships [5]. Considering that the new fleet of 2024 consists of 35% of vessels emitting 40% less, the transport-related factor is reduced to 12.6 gCO_2e/tonne-km. In 2040, the fleet consists solely of new-generation vessels, therefore, the transport is expected to emit 8.79 gCO_2e/tonne-km.

- Fuel compressors, liquefaction and regasification energy

  The company states that it is working to improve the performance of its liquefaction plant through energy efficiency projects and the electrification of the liquefaction plant with renewable solar and wind energy. However, no information is provided regarding the fuel compressors and the regasification plant.

  Until 2050, according to the NZE scenario, global electricity production will continue to increase steadily. It is why, starting from 2050, a complete electrification of the LNG chain will be assumed.

  For instance, by 2050, electric compressors will be widely used (along the pipeline). Indeed, they come with numerous advantages [74]: no gas losses from leaks and vents, less maintenance, etc.

  Concerning liquefaction plants, they are usually powered by gas turbines. However, due to factors such as emissions reduction, effectiveness and improved performance, the liquefaction trains[14] should be fully electric.

[12] Refers to the gas that is released from a stored liquid due to temperature increase.
[13] Which are less than 5 years old.
[14] Included all processes used to liquefy natural gas

It is important to mention that emissions resulting from the production of electricity used by the facilities have already been taken into account since it is assumed that a portion of the company's net production will be used for this purpose. However, it should be noted that these emissions are expected to be minimal by 2050, as renewable energy sources are anticipated to provide a greater share of electricity production.

To summarize, methane emissions along the gas supply chain are reduced by 75% between 2021 and 2030, with no further reductions applied from 2030 to 2050.

Regarding LNG transportation, the factors related to LNG transport are as follows:

Year	2021	2025	2040	2050
BOR [%/day]	0.15	0.127	0.085	0.085
Recovery rate of BOG [%]	80	80	95	95
LNG carriers emissions factor [gCO_2e/tonne-km]	14.65	12.6	8.79	8.79

Table 3.8: Variation of LNG transport parameters

It is also assumed that the LNG chain will be fully electrified starting in 2050, resulting in no more consumption and losses of gas during liquefaction, regasification, and compression processes. The reduction in consumption and losses between 2021 and 2050 follows a linear trend.

3.3.3 Electricity sector

Modelisation of the production and sales

The company's electricity production can be divided into two distinct categories: renewable generation and Combined Cycle Gas Turbine (CCGT) generation. The data provided by the company (from the DEU [5]) are as follows:

	2021	2025	2030	2050
Net production (TWh)	**21.2**	**50**	**120**	**500**
Renewable	6.8	30	-	500
CCGT plants	14.4	20	-	0
Renewable capacity (GW)	**10**	**35**	**100**	**400**

Table 3.9: Summary of net production data provided by the DEU

The breakdown of production for 2030 can be calculated on the basis of 2025. Knowing that for an installed capacity of 35 GW, the associated renewable energy production is 30 TWh, for a capacity of 100 GW the production is assumed to reach 85.71 TWh. The Figure 3.3 shows the company's electricity production up to 2050.

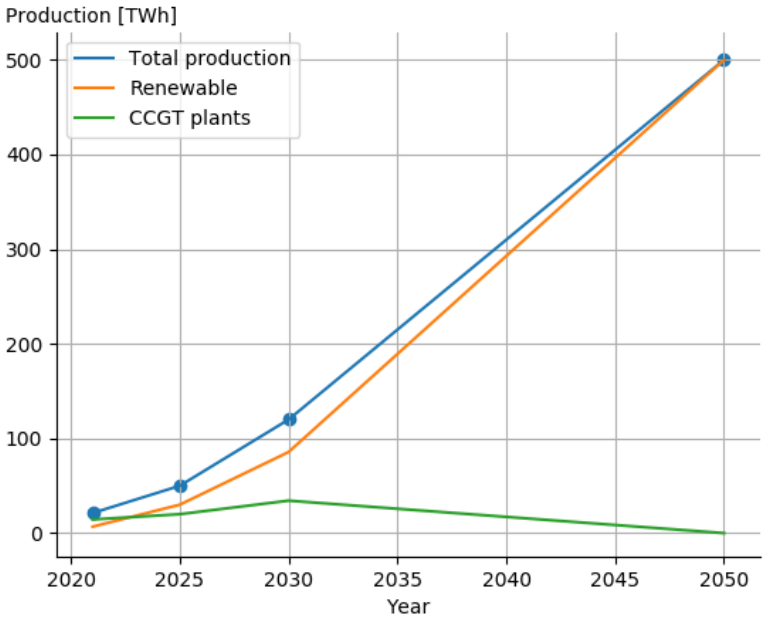


Figure 3.3: Net electricity production from 2021 to 2050 according to the company's targets (TWh)

It should be noted that from 2050 onwards, 500 TWh of electricity will be produced solely from renewable sources.

Regarding electricity sales, which include both BtB and BtC sales, they are presented in Table 3.10.

Year	2021	2025	2030	2050
Sales power (TWh)	56.6	80	138	-

Table 3.10: Sales power (BtB and BtC) data provided by the DEU (TWh) [5]

As shown in Table 3.10, there is still one data point missing. Based on the energy demand in the NZE scenario [9], the scenario projects a 64.01% increase in electricity demand between 2030 and 2050. Assuming that sales follow demand, sales in 2050 are 226.43 TWh.

Evolution of the energy production model

In the simulation, some parameters will change over time. They will take into account the evolution of the energy production model as well as technological advances in each production method.

- Breakdown of renewable energy capacities

  As mentioned earlier in chapter 2, the company produces renewable energy from various sources, including photovoltaic panels, offshore and onshore wind turbines,

as well as hydroelectric power plants. However, the company mainly focuses on generating energy from photovoltaic panels and wind turbines. Therefore, it can be assumed that the company's renewable electricity production exclusively originates from photovoltaic panels and wind turbines.

In Table 3.11, the values presented in black represent the distribution of installed renewable energy provided by the company. While the values highlighted in red are related to the NZE scenario [9], which provides the distribution of electrical capacity in 2030 and 2050.

Year	Photovoltaic panels [%]	Wind turbines [%]
2021	80	20
2025	75	25
2030	61.5	38.5
2050	63.6	36.4

Table 3.11: Breakdown of renewable energy capacities (%)

Figure 3.4 shows an overview of the company's installed renewable capacity from 2021 to 2050, based on the breakdown provided in Table 3.11.

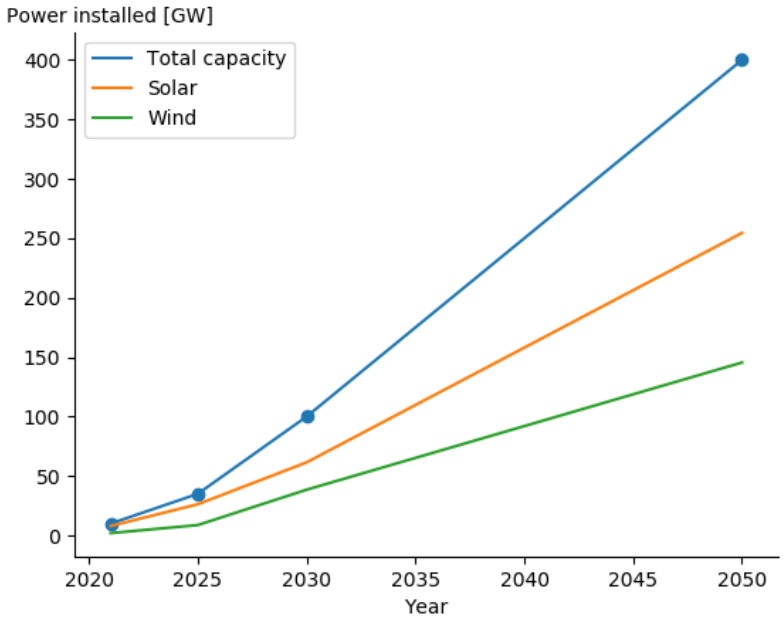


Figure 3.4: Company's installed renewable power from 2021 to 2050 (GW)

- Emission factor for wind turbines

  The emission factor varies depending on whether the wind turbine is onshore or offshore, therefore it is important to determine which type of wind turbine will be predominant in the coming years.

As of 2021, more than 99% of the company's operational wind turbines are onshore, and globally 93% are onshore. Therefore, the emission factor of an onshore wind turbine has been considered.

Figure 3.5 shows the evolution of the Levelized cost of energy (LCOE)[15] (averaged across different regions) in the NZE scenario for both onshore and offshore wind turbines. Since the LCOE gap between onshore and offshore wind turbines remains high until 2030, wind turbines are considered to be predominantly onshore. Starting from 2030 until 2050, the offshore wind turbine LCOE decreases at a faster rate than the onshore LCOE. This is why a progressive increase in offshore wind turbines is expected until they become the majority by 2050, where the LCOE is lower for offshore than onshore. It should be noted that by 2030, in Europe, the LCOE is already at 40$/MWh for offshore and 45$/MWh for onshore, which makes massive offshore construction in the coming years feasible.

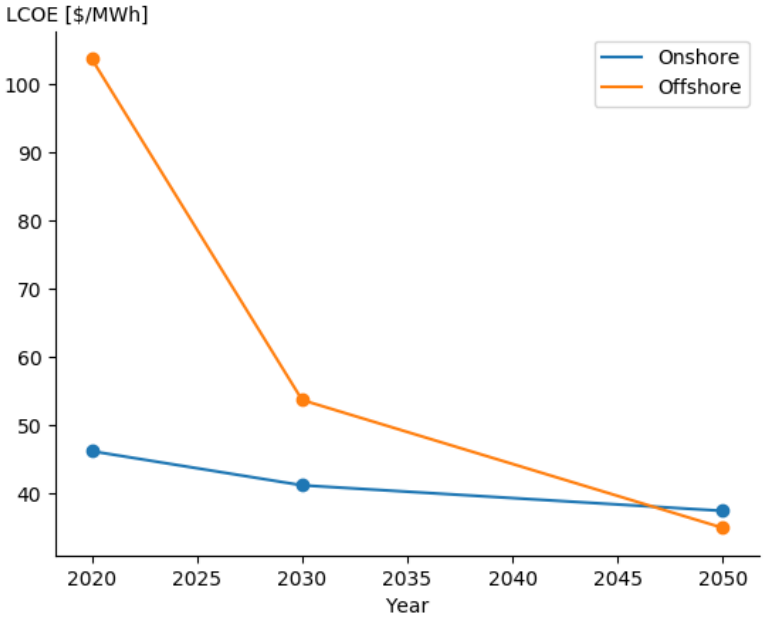


Figure 3.5: Electricity generation technology costs from 2021 to 2050 according to the NZE scenario ($/MWh)

It is worth noting that by 2050, the wind energy sector is expected to comprise both onshore and offshore wind farms, but the offshore ones might be predominant. As they are greater in size and length of their blades, offshore wind turbines have a significantly higher nominal power (capacity) of 8-12MW compared to onshore turbines, which typically have a capacity of 3-4MW [75]. Therefore, onshore turbines will only account for a small fraction of the energy production compared to offshore turbines. Moreover, wind turbines generally have a lifespan of around

[15]Refers to the average cost of producing one unit of electricity from a generator over the lifetime of the project.

20 years. Hence, wind farms built before 2030 will have to be decommissioned by 2050.

- Capacity factors[16]

  Due to technological advances, it is assumed that the capacity factor increases over time. Table 3.12 displays the capacity factor (average for each region) for upcoming years.

Year	Photovoltaic panels [%]	Wind turbines [%]
2021	17.75	30.75[17]
2030	18.75	32[17]
2050	19.25	47[18]

Table 3.12: Capacity factor for wind turbines and photovoltaic panels per year (%)

  The capacity factor of an offshore wind turbine was taken into account for the year 2050 due to a significant shift in the wind farm composition towards offshore turbines.

- Electricity generation emission factors

  In 2021, the company sold electricity only in Europe and it is assumed that this will be the case until 2030. The amount sold and the destination countries were known, which allowed the use of the corresponding generation factors for each country. To have a more general case (without knowing where electricity is produced and delivered), in 2021, the emission intensity of electricity generation was considered at the European level [76], which is equal to 275 gCO_2e/kWh.

  The evolution of the generation factors is determined based on the projected share of electricity generation for 2030 and 2050 under the NZE scenario, as depicted in Table 3.13.

[16]The capacity factor is a measure of the actual output of a generator relative to its maximum potential output over a given period of time.

[17]Onshore majority

[18]Offshore majority

	Share [%]	
	2030	2050
Renewables	**61**	**88**
Solar PV	19	33
Wind	21	35
Hydro	16	12
Bioenergy	4	5
CSP	1	2
Geothermal	1	1
Marine	0	0
Nuclear	**10**	**8**
Hydrogen-based	**2**	**2**
Fossil fuels with CCUS	**1**	**2**
Coal	1	1
Natural gas	0	1
Unabated fossil fuels	**25**	**0**
Coal	8	0
Natural gas	17	0
Oil	1	0

Table 3.13: Share of electricity generation for the years 2030 and 2050 (%) [9]

Considering the energy production distribution in 2030 and 2050 under the NZE scenario, as well as the associated emission factors for each type of energy production (see Appendix C), the generation factor can be determined. The generation factor for 2030 is calculated as 189.82 gCO_2e/kWh, while for 2050 it reaches 29.78 gCO_2e/kWh.

Note that the *Bioenergy* category in Table 3.13 represents the electricity generated with biomass, which was neglected in the calculation, given the imprecision of the generation factor and its relatively small share of electricity generation.

3.3.4 Decarbonized molecules sector

An emerging sector within the company is the production of decarbonized molecules, which will take a significant part of its activities by 2050. Indeed, by 2050, approximately 25% of the energy produced by the company is expected to come from decarbonized molecules, which would be equivalent to 50 Mt/year [5]. These molecules are in the form of biogas, hydrogen, or synthetic liquid fuels. However, there is no information provided by the company regarding the distribution and the exact quantity of current or future production for these decarbonized molecules.

One should note that the company does not consider biofuels as decarbonized molecules, which means that the ambitions for biofuels are given separately. However, it seemed more appropriate to include biofuels in this section when simulating the emissions from 2021 to 2050. A detailed description of the biofuels considered and their related

emission factor (which is equal to 0.82 $kgCO_2e/l$) can be found in chapter 2. The emission factor is assumed to be constant in this case but is discussed in chapter 6.

The company's disclosure gives the following information about biofuels:

- Biofuels production was 450t in 2021.
- The company's target is to produce 5 Mt of biofuel in 2030.

Since no information is given about the company's biofuel production in 2050, it has been considered that the production remained constant between 2030 and 2050. Even though biofuels emissions are usually lower than fossil fuels emissions, one should remember that biofuels use can present a lot of inconveniences such as the reduction of the overall health of natural resources, deforestation, an increase in food prices, etc. (see section section 1.3 for more information). These inconveniences can have an important impact on their emission factors: this part is developed in a sensitivity study in section 3.4.

The information available indicates that the company's objectives are to produce at least 2 TWh/year of biomethane by 2025 and more than 5 TWh/year by 2030 [5]. It appears, from the DEU [5], that the company is more focused on the production of biomethane[19] rather than biogas, which is why all biogas is considered to be transformed into biomethane. As for hydrogen production, the company intends to produce blue and green hydrogen, with negligible production in 2021. For synthetic liquid fuels, the company has not produced any in 2021.

Figure 3.6 shows the distribution and evolution of the production of decarbonized molecules. The assumptions made to obtain this figure were based on the energy demand of the IEA's NZE scenario (see section E.3 for more information).

[19]The conversion of biogas into biomethane involves the removal of impurities

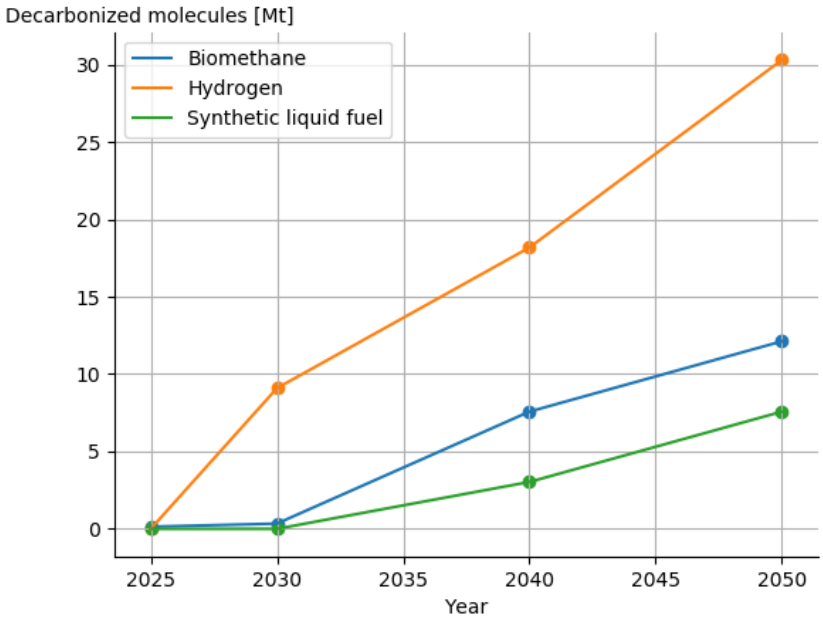


Figure 3.6: Production of decarbonized molecules from 2025 to 2050 based on hypotheses (Mt)

A detailed analysis of the production of decarbonized molecules and the corresponding emissions sources can be found in the Appendix F. The emission factors considered are described below.

Biogas

The company appears to be interested in producing biogas for road transport, including trucks and even the shipping sector, or for distribution in the gas network [5]. By purifying the biogas, biomethane can be obtained, which has similar properties to natural gas and can be injected into the distribution network or used as an alternative fuel for transportation, called bio-CNG.

Therefore, the emissions factor that has been selected is for bio-CNG, which is compressed biomethane used for road transport, and it is 0.0475 $kgCO_2e/kWh$ [55].

Hydrogen

The company aims to increase its production of hydrogen, specifically focusing on low-carbon or clean hydrogen, which includes both blue and green hydrogen. The production process of both types of hydrogen is shown in Figure 3.7.

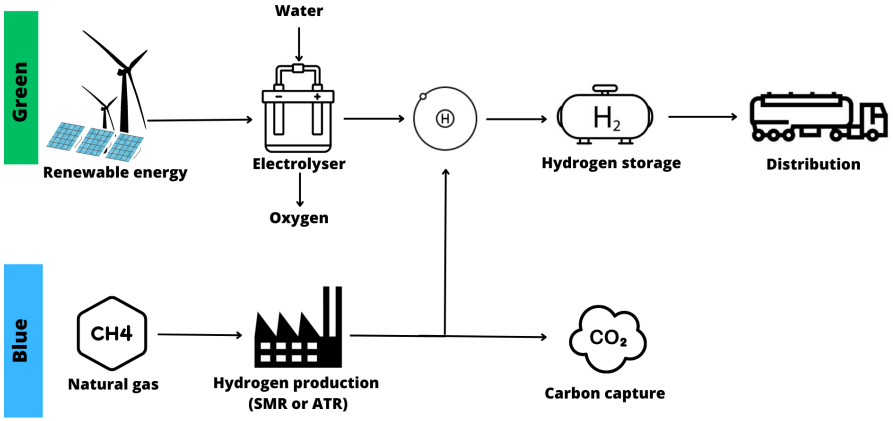


Figure 3.7: Green and blue hydrogen production

For blue hydrogen, the emission factor of an Steam methane reforming (SMR) with a carbon capture rate of 90% is considered: 3.2 $kgCO_2/kgH_2$ [77].

While green hydrogen, which is produced from renewable electricity through the process of electrolysis of water, has a lower carbon intensity than blue hydrogen but depends on the source of the renewable energy electricity. The three sources considered are hydro, wind, and solar with emissions factors of 0.45, 0.7, and 2.58 $kgCO_2/kgH_2$, respectively [55].

The distribution of the energy sources used to produce hydrogen is assumed to follow the NZE scenario electricity generation model[20], as shown in Table 3.13.

To determine the distribution of the quantities of blue and green hydrogen produced, the total low-emissions hydrogen production given in the *World Energy Outlook 2022* [14] under the NZE scenario was used.

	2030	2050
Total low-emissions hydrogen production (Mt)	**90**	**451**
Water electrolysis (Mt)	58	329
Fossil fuels with CCUS (Mt)	31	122

Table 3.14: Supply and demand of low-emissions hydrogen (Mt) [14]

Liquid e-fuels

Due to the fact that it is a fairly recent technology and still in the experimental stage, data on the emissions generated during the production of liquid e-fuels are very imprecise. Based on the resources required for liquid e-fuel production, the emission factor can be determined. For 1 liter of liquid e-fuel, it requires 3.7–4.5 liters of water, 82-99 MJ of renewable electricity, and 2.9-3.6 kg of CO_2 [78]. Knowing the energy required for

[20]IEA NZE scenario [9] Table A.3: Electricity - p.198

production as well as the means of production (renewable in our case), first, the emissions generated for the generation of electricity must be determined.

The production of e-fuels by the company is set to begin in 2030. By considering only renewable sources like solar PV, wind, and hydro (as indicated in Table 3.13) for electricity generation, an average emission factor of 19.5 gCO_2e/kWh is projected for the period between 2030 and 2050.

The average energy required to produce 1 liter of e-fuel is 90.5 MJ, which is equivalent to 25.14 kWh. Based on the previously calculated emission factor, it can be determined that the energy needed to produce **1 liter of e-fuel emits 0.49 $kgCO_2e$**.

To clarify, the e-fuel produced from the Fischer-Tropsch[21] reaction is assumed to be an equal mixture of diesel, kerosene, and gasoline with an average density of 0.798 kg/L.

3.3.5 Compensation mechanisms

To offset the emissions, natural carbon sinks and carbon storage will be put in place.

For 2030, the company aims to create carbon storage of more than 10 $MtCO_2$/year and to reach between 50 and 100 $MtCO_2$/year by 2050. An average of 75 $MtCO_2$/year for 2050 will be retained.

The company has also set a target to establish natural carbon sinks and plans to accumulate a stock of 100 $MtCO_2$ between 2020 and 2030. Furthermore, it aims to expand its annual production capacity by 5 to 10 $MtCO_2$/year by 2030.

The Figure 3.8 shows the storage capacity to reduce residual emissions to achieve the net emissions objective.

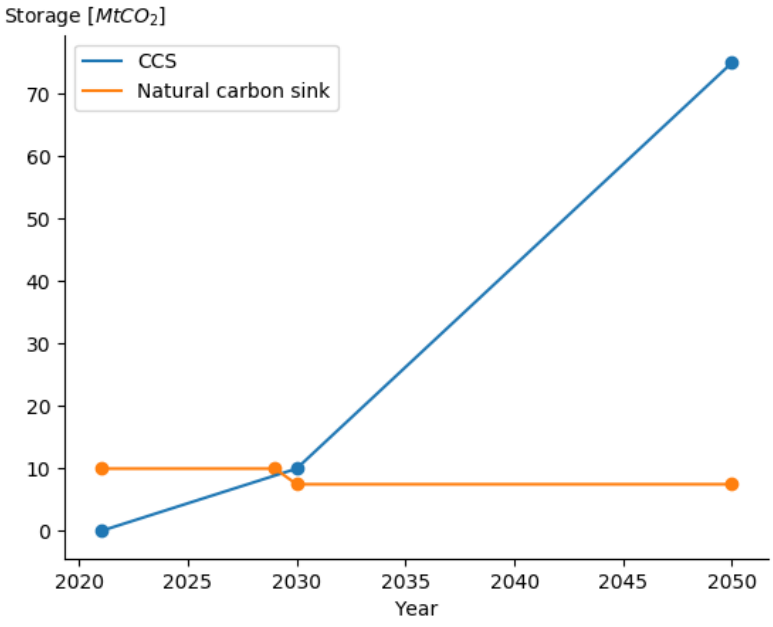


Figure 3.8: Natural carbon sink and CCS capacities targeted by the company ($MtCO_2$)

[21] It the process used to convert hydrogen and carbon monoxide into liquid hydrocarbons.

Although the values announced by the company were used in the simulation, it should be noted that these values are considered highly unlikely as explained in section 1.3. This is mainly due to the disproportionate nature of the emission-offsetting targets set by the company.

3.4 Results of the footprint projections

Based on the methodology detailed in the previous section, the total emissions with and without compensation for each year have been computed and are shown in Figure 3.9.

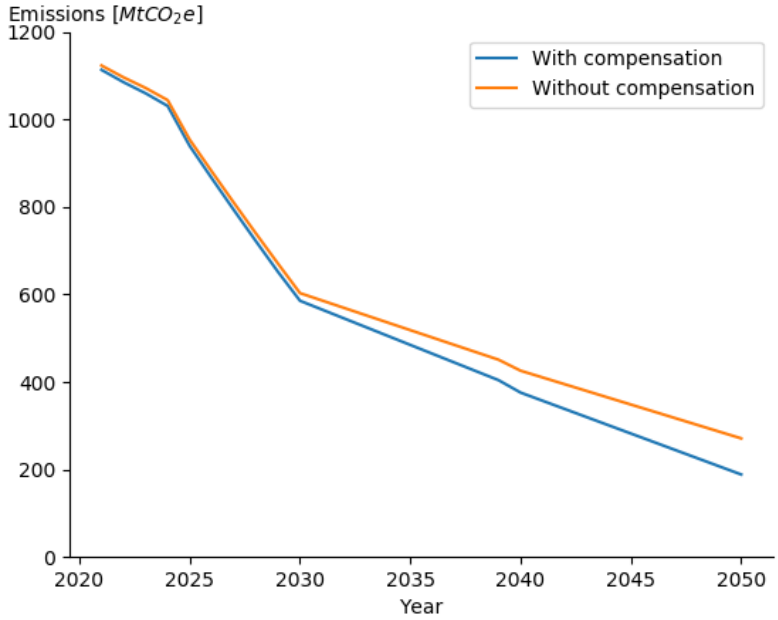


Figure 3.9: Projected simulation of the company's emissions from 2021 to 2050 with and without compensation ($MtCO_2e$)

As presented in Figure 3.9, a significant reduction in emissions is expected between 2021 and 2030, resulting in a nearly 50% decrease compared to 2021 in just 9 years. However, starting from 2030, the reduction targets are not sufficient despite the significant expansion of carbon storage.

The company does not reach net zero emissions in 2050: even by considering the compensation mechanisms, **188.48 $MtCO_2e$** are emitted in 2050. This first observation shows that even if the company respects its targets, it will not be sufficient to reach net zero.

An overview of emissions by sector for each year between 2021 and 2050 is given in Figure 3.10. The electricity sector remains much smaller than the other sectors in terms of emissions, even though the capacity of production of electricity pass from 21.2 TWh in 2021 to 500 TWh in 2050. This shows that transitioning to a more electrified world is

an option that can definitely help reach the net-zero emission target.

The emissions generated by the oil sector decrease slowly before 2024 because of the oil peak in 2024. One can note that they are highly reduced between 2030 and 2050, which shows that the company's targets in this period are rather strong. However, they are not sufficient to reach net zero in 2050.

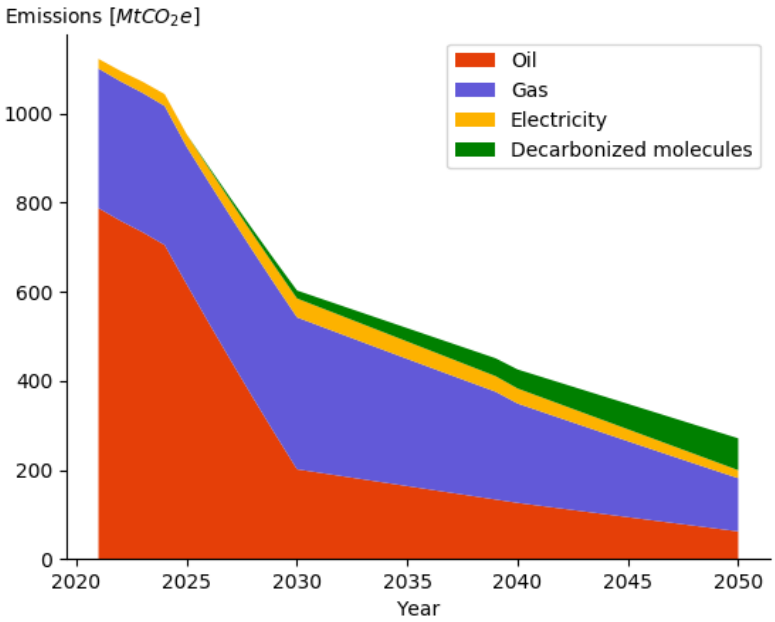


Figure 3.10: Projected emissions of the company per activity sector without compensation ($MtCO_2e$)

As shown in Figure 3.11, the most emitting sector in 2050 is the gas sector followed by the decarbonized molecules. This illustrates that these energy sources considered as pillars for the energy transition by the company are still generating emissions. In 2050 and without considering compensation, the gas sector accounts for 119 $MtCO_2e$ (44 % of the total emissions) and decarbonized molecules account for 72 $MtCO_2e$ (26 % of the total emissions). These results show that decarbonized molecules can be a short-term solution but needs to be reduced in order to reach net zero.

The emissions related to oil remain important, mostly because of the petrochemical sector which represents 62 % of the total oil emissions.

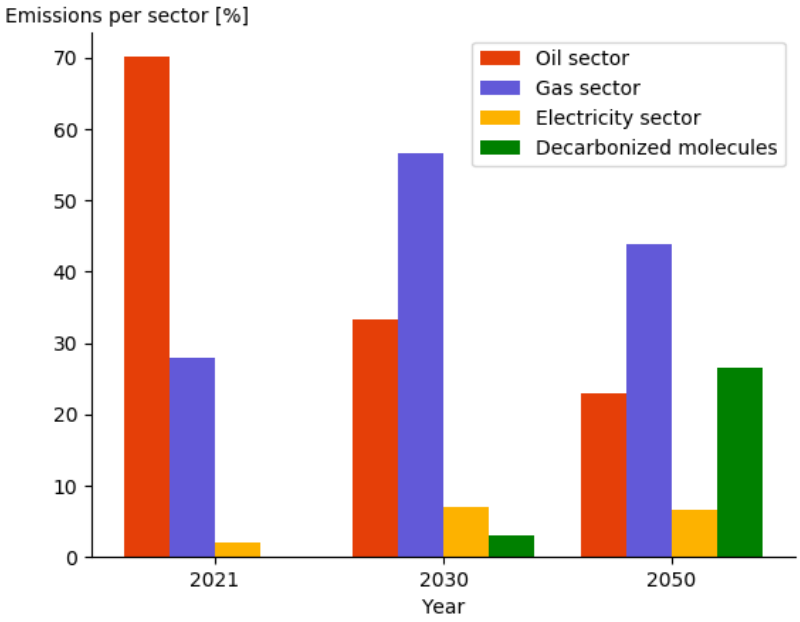


Figure 3.11: Company's emissions distribution per activity sector (%)

It is important to remind two elements:

- The goal of the NZE scenario is to provide guidelines in order to reach net zero, but this scenario is far from being the most realistic one, which means that the company is likely to emit much more GHG emissions in 2050. This shows that the company needs to take more drastic and ambitious measures in order to reach the net zero target.
- The simulation realized is mostly based on assumptions since it is a projection in the future. Therefore, the main elements to remember are the orders of magnitude and the general trends of the evolution of the company's evolution.

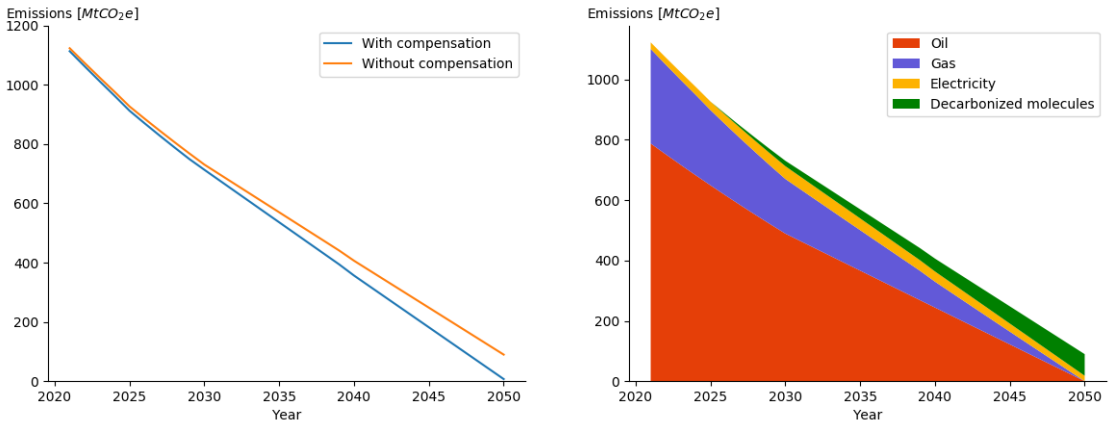
3.5 Analysis of different scenarios

Fossil fuel free model by 2050

The following scenario shows the evolution of the emissions produced by the company if it no longer sells fossil fuels, which are generating an important part of the total emissions by 2050. In other words, this scenario represents the evolution of the company's emissions in the case of a transition from oil and industry to renewable energies and decarbonized molecules. To achieve this, the assumption is made that starting in 2021, the company gradually divest from its oil and gas activities, and instead, focus solely on the decarbonized molecules sector and electricity.

As shown in Figure 3.12, even if the company reduces its sales of gas and petroleum products in a linear pattern to achieve a fossil fuel-free model by 2050, emissions in

2050 with compensation amount to 7.09 $MtCO_2e$, which falls short of reaching net zero. Without compensation the total emissions are 89.59 $MtCO_2e$ in 2050, the production of decarbonized molecules alone accounts for 71.56 $MtCO_2e$, with the remaining emissions originating from electricity generation.



(a) (b)

Figure 3.12: Projected emissions without fossil fuels from 2021 to 2050 ($MtCO_2e$)

In order to achieve net zero emissions by 2050, one solution could be to decrease or phase out the production of decarbonized molecules in favor of electricity generation, which, as can be seen in Figure 3.12b, represents a minimal share of emissions. Another approach could involve increasing the capacity for CCS and NBS. However, as discussed in section 1.3, since the reduction capacities targeted by the company already seem too ambitious, increasing them is not an interesting option.

In the case where the company would not only stop the production of fossil fuels but also any production and sale of decarbonized molecules, achieving net zero becomes feasible. As shown in Figure 3.13, considering the capacities targeted by the company in terms of CCS and NBS, the net emissions reach zero by 2048.

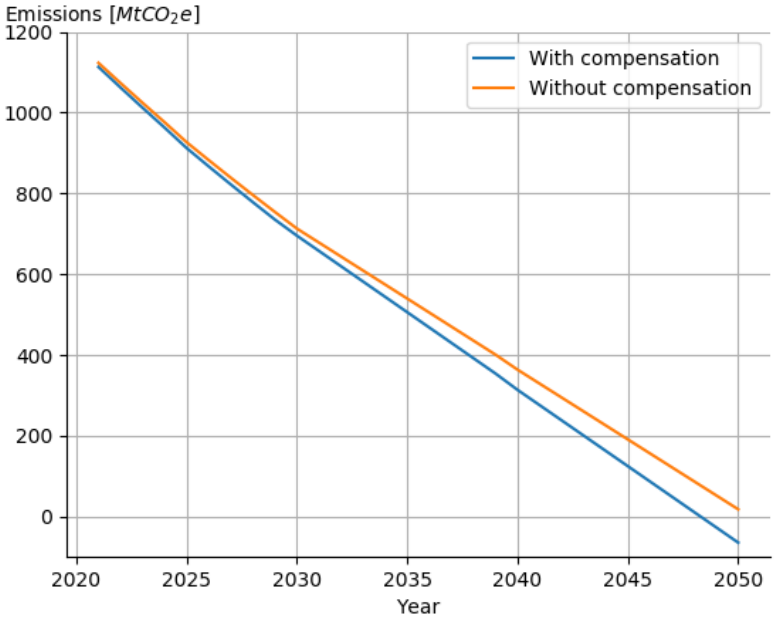


Figure 3.13: Projected emissions without fossil fuels and decarbonized molecules from 2021 to 2050 ($MtCO_2e$)

To achieve net zero by 2050 (instead of 2048), the company can sell up to 3319.78 TWh, which represents **7.07% of the total electricity demand** (mainly used by industry, transport, and buildings) in the NZE scenario in 2050.

These scenarios highlight the fact that the company must inevitably disengage from its fossil fuel-related activities in order to be able to reach net zero by 2050, even though this decision alone is not sufficient to reach this goal. One of the possible solutions, as presented in Figure 3.13, to reach net zero by 2050 would be to exit the production of decarbonized molecules altogether. This would mean that the company would shift towards a company that only generates electricity.

However, it is worth exploring other possibilities. According to the IPCC, decarbonized molecules are needed to replace fossil fuels in some sectors such as aviation, shipping and heavy-duty land transport [79]. In order to reduce its emissions without abandoning decarbonized molecules, the company could therefore focus on low-emission decarbonized molecules, for example by reducing the production of blue hydrogen in favor of green hydrogen. This possibility is developed in further detail in chapter 6.

Focus on biofuels

The scenario realized in section 3.1 is mainly based on the company's disclosure and on the NZE scenario. However, as previously stated, the NZE scenario does not give the most realistic view of the energy system evolution in terms of emissions and is usually considered as a set of guidelines to follow in order to reach net zero in 2050. This

is especially the case for recent energy sources such as e-fuels, hydrogen and biofuels since predicting their evolution involves a lot of uncertainties. This section focuses on the uncertainties related to biofuels by analyzing more closely the hypotheses made in the NZE scenario and comparing them with a more realistic point of view. Particular attention will be paid to land use, which is a significant source of uncertainty.

As briefly mentioned in section 1.3, biofuel emissions can considerably vary depending on the feedstock distribution and land use change. Nowadays, the most important feedstocks are conventional biofuels, which means that they are produced from crops such as sugarcane, corn or oil [35].

However, the NZE scenario considers a shift towards a more sustainable supply of bioenergy[22], including certified agricultural products and wood, and does not include land-use change [80]. By 2050, according to the scenario, bioenergies will be produced with advanced conversion technologies coupled with CCS when needed and mostly with advanced bioenergy[23] feedstocks. For this same year, the feedstock distribution is described and estimated as follows [80]:

- Organic waste streams from agriculture and industry (45 EJ[24])
- Short-rotation woody crops[25] (25 EJ)
- Sustainably managed forestry fuelwood and plantations and tree planting (10 EJ)
- Forest and wood residues from wood processing and forest harvesting (20 EJ)
- Conventional bioenergy crops (3 EJ)

In the NZE scenario, the total land use for bioenergy in 2050 is estimated to be 410 Mha and remains below the estimated ranges of land available for sustainable[26] bioenergy production.

However, it is important to note that a significant saving on land use is realized by the increase of woody crops (as a reminder, it will produce 25 EJ), which produce twice as much bioenergy per hectare as conventional bioenergy crops (which will produce 3 EJ) [80]. According to the STEPS scenario[27] and the APS scenario[28], which are more realistic than the NZE scenario, conventional bioenergy crops will represent half of the

[22]Bioenergy refers to biogases, liquid biofuels and traditional use of biomass. One should note that the NZE scenario shifts away from the traditional use of biomass between 2020 and 2030 [80]. It has been assumed that biofuels followed the same evolution as bioenergy.

[23]Advanced bioenergy is produced from lignocellulosic feedstocks such as agricultural and forestry residues, non-food crops such as grass or algae, or industrial waste and residue streams. The interest of this bioenergy is that it has a low impact on land use change, which reduces its overall CO_2 emissions[81].

[24]1 Exajoule $= 10^{18}$ Joules

[25]Short-rotation woody crops (SRC) refer to energy crops made of fast-growing deciduous trees. They are usually composed of willow or poplar trees [82]

[26]In this case, the term sustainability includes the need to protect biodiversity and the respect of the UN Sustainable Development Goal 15 on biodiversity and land use [80]

[27]As a reminder, the STEPS scenario explores how the emissions would evolve without any change except the implementation of what is under development [80]

[28]The APS assumes that all of the net zero targets announced by countries around the world to date are met in full [15]

total feedstock for bioenergy in 2050. This means that land use change will be much higher than in the NZE scenario and may exceed the estimated ranges of land available for sustainable bioenergy production.

The NZE scenario itself states that the estimated ranges of available land include a high degree of uncertainty, particularly when considering the conversion of new lands to bioenergy crops. This means that even if the total land use for bioenergy estimated by the NZE is below the estimated ranges, it may be larger than the actually available lands in 2050. According to the NZE scenario, limiting land use to 330 Mha (which corresponds to land use in 2020) would reduce the available energy supply by more than 10 EJ. This production reduction, still according to the scenario, could be compensated by the increase in hydrogen or synthetic methane production. If this production was realized through electrolysis, it would generate an increase in electricity demand. This element shows that, in order to ensure the projected supply while reaching net zero in 2050 and to produce energy in a sustainable way, it is safer for the company to focus on electricity than on biofuels. This analysis confirms the conclusions of the scenario *Fossil fuel free model by 2050* previously developed, which is that the company should increase its electricity generation target in order to reach net zero by 2050.

Another element that should be considered is that in order to reach the 45 EJ produced from organic waste streams expected by the NZE scenario, important investments in waste collection and sorting are needed [80] and cannot be guaranteed, which increase the uncertainty of reaching the bioenergy production planned.

Finally, the emission factor related to biofuels is strongly related to land use change and feedstock distribution and can therefore significantly increase in some cases. In order to analyze the variation of that parameter, different scenarios have been considered:

- The scenario called "CAS maximal" is the most pessimistic scenario: it corresponds to the replacement of one hectare of primary tropical rainforest by one hectare of sugarcane or palm trees [19].
- The scenario called "CAS optimist" considers the case where the coproduct of the biofuel is replaced by products that can be used for animal feeding [19].
- A scenario without land-use change

It is important to distinguish between direct land-use change (LUC) and indirect land-use change (ILUC). Direct land-use change is used when the land was initially used for food or energy crops and is then converted to another type of crop, whereas indirect land-use change refers to a case where the purpose of the land is changed: for example, when a forest is cleared for the cultivation of energy crops [83]. The emissions generated are much more important in the case of indirect land-use change but are also rather taken into account.

Since the scenario realized in section 3.1 is based on the NZE scenario, land-use change was not taken into account. However, as shown in Figure 3.14, the latter can

have a very important impact. In the case of the worst scenario, the emissions would increase by 21%. In the best-case scenario, emissions still remain higher than in the case of no land-use change.

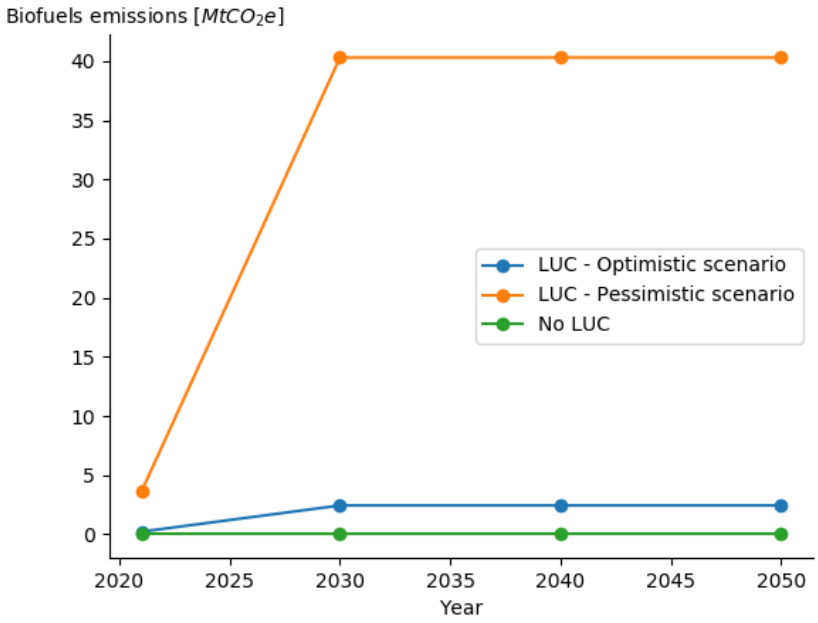


Figure 3.14: Emissions generated by the company from biofuel according to different scenarios and to the company's production targets ($MtCO_2e$)

In conclusion, biofuel evolution is surrounded by a lot of uncertainties, which may jeopardize the net zero emission objective. The main uncertainty remains the land-use change needed to produce the predicted biofuel quantities. Even though it was not stated in the NZE scenario, another risk that land-use change may encounter is droughts and floods caused by climate change that will likely decrease the fertility of lands intended for energy crops. Moreover, another uncertainty is the fact that an important part of biofuel production relies on investments in waste collection and sorting. Finally, since the emission factor related to biofuel can highly increase if the land-use change is not realized in a sustainable way, resorting to biofuels might increase emissions instead of decreasing them. This analysis shows that the company should be careful when relying on biofuels and should pay particular attention to the way feedstocks are produced.

This study could be generalized to all decarbonized molecules (e-fuels, hydrogen and especially biogas since it also requires land-use change) whose development and evolution bring a lot of uncertainties. The company should therefore carefully consider these energy sources and should mostly rely on electricity in order to ensure a sustainable and resilient energy transition.

3.6 Overview and conclusions

Based on the simulation results, the company's targets do not seem sufficient to reach net zero emission by 2050, even by taking into account the CCS and NBS targets. However, it is important to remind that the simulation realized is partly based on hypotheses which means that the results obtained present uncertainties. A general discussion about the uncertainties of the model used is presented in chapter 6.

However, an additional scenario shows that by moving away from fossil fuels and decarbonized molecules, it is possible to reach net zero. Therefore, one possibility for the company to reach this objective would be to shift toward electricity generation.

A second additional study shows that biofuel production is surrounded by a lot of uncertainties such as land-use needed to produce the predicted biofuel quantities, which makes its evolution hard to predict. If biofuel is not produced in a sustainable way, its production may lead to an increase of emissions.

Key messages of chapter 3

1. Based on the company's disclosure, on the NZE scenario and on several assumptions, it can be stated that the company **does not reach net zero emission in 2050**. Even when considering the emission compensation realized with CCS and NBS, the company should emit **188.48 $MtCO_2e$** in 2050.

2. According to the simulation realized, the main emissions sources in 2050 are the gas sector (44 % of total emissions) followed by the decarbonized molecules sector (26 % of total emissions). This illustrates that these energy sources considered as pillars for the energy transition by the company are still generating emissions.

3. The emissions related to oil remain important (23 % of the total emissions), mostly because of the petrochemical sector which represents 62 % of the total oil emissions.

4. The electricity sector is by far the lowest emitter and represents 7% of the total emissions.

5. As illustrated by the *Fossil fuel free model by 2050*, a possible way for the company to reach net zero by 2050 would be to:

    - Gradually divest from oil and gas activities in order to stop its production and sales by 2050.
    - Abandon the use of decarbonized molecules in favor of electricity generation or prioritize the production of low-emission decarbonized molecules, such as green hydrogen.

6. Other possibilities to reach net zero by 2050 are possible and will be discussed in chapter 6.

7. Biofuel evolution is surrounded by a lot of uncertainties and by relying on them, the company may increase its emissions instead of decreasing them. This can be explained by several elements:

    - It is very difficult to predict the actual surface of land-use change that will be available by 2050.
    - An important part of biofuel production relies on investments in waste collection and sorting, which are not guaranteed.
    - The emission factors related to biofuel can highly increase when the land-use change is not realized in a sustainable way.

Chapter 4

Computation of the company's carbon budget and cumulated emissions

One way of assessing the climate credibility of a company's transition plan is to estimate its carbon budget and verify if the anticipated emissions generated by the company exceed this budget. The carbon budget of a company can be described as the cumulative amount of CO_2e emissions that a company is allowed to emit over a period of time to keep the global temperature under a certain threshold [84]. By estimating it, one can verify if a company is aligned with a given scenario in a specific timeframe. When a company exceeds its carbon budget, several alignment indicators can be used to characterize this misalignment such as the overshoot, the overshoot year, and the carbon intensity excess. These indicators will be described in more detail below.

The NGO Reclaim Finance developed a methodology that allows verifying if the decarbonization targets of a company related to a certain sector are in accordance with a carbon budget that would be aligned with the 1.5°C scenario[1][7].

> This section details the methodology for computing the company's carbon budget and comparing it with its cumulative emissions. The parameters and data, as well as assumptions used in this study will be explained. An analysis will then be conducted to assess the company's alignment with its allocated carbon budget through alignment indicators.

4.1 Methodology

The general methodology provided by the NGO Reclaim Finance is illustrated in Figure 4.1 and can be subdivided into three main steps [7]:

- Computing the carbon budget allocated to the company until 2050 in the case of a 1.5°C scenario and by using the Transition Pathway Initiative (TPI)'s methodology.

[1]As a reminder, the 1.5°C scenario is also called the NZE scenario

- Computing the cumulated projected volumes of GHG emissions generated on a given time period by the company considered based on the company's decarbonization targets and the IEA projections.
- Comparing the allocated carbon budget to the cumulated emissions of the company and analyzing alignment indicators.

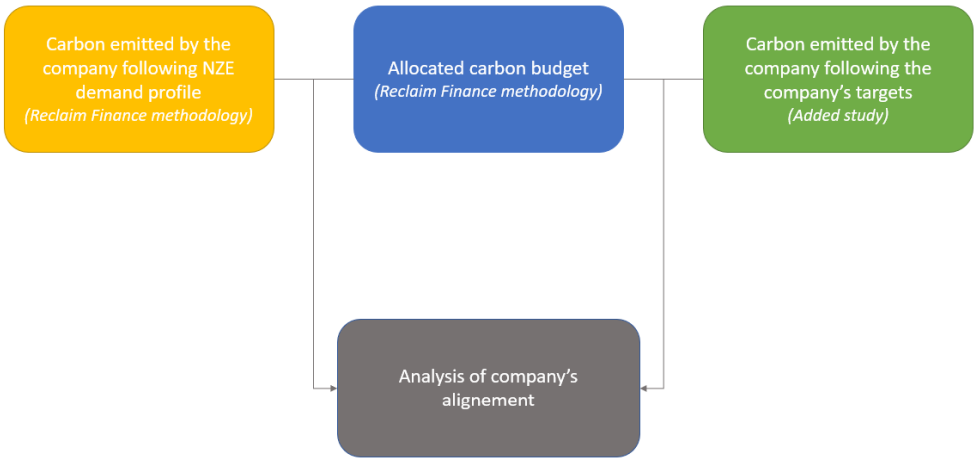


Figure 4.1: Schematic representation of carbon budget analysis from 2019 to 2050 for the 1.5°C scenario [7]

The cumulated projected volumes of GHG emissions generated by the company are expressed in terms of absolute emissions ($MtCO_2e$) and are computed by summing the absolute emissions of each year over a certain time period. In this case, the time period considered is between 2019 and 2050. When a company expresses its emissions in terms of emission intensity (which is the case of the company considered), the absolute emissions can be computed as follows [7]:

$$\text{Absolute emissions} = \text{Emission intensity} \times \text{Production}$$

Since the company expresses its targets in terms of energy sales, it has been assumed that the company's sales are equal to its production[2]. This means that the sales data of the company will be used to compute the absolute emissions.

The emission intensity (or carbon intensity) is defined as the absolute emissions generated by energy unit. One should note that companies often express their emissions in terms of carbon intensity instead of absolute emissions and it is the case for the company considered. The sales evolution is assumed to follow the 1.5°C reference scenario as described by the IEA. Therefore, this computation, which results in absolute emissions, only provides a low estimate of the cumulated emissions of the company. Indeed, it

[2]One should note that the company actually aims to equalize its oil products sales to its oil products production by 2030.

assumed that the company's sales will follow the 1.5°C reference scenario when it is actually quite unlikely. However, this low-estimate computation gives a first overview of the company's pathway.

In order to complete the analysis, the emissions generated by the company according to its own sales targets have also been computed (see Figure 4.1). This will allow to verify if the company's sales are too high compared to the net zero target and will be developed in further detail in the section *Alignment indicators*.

In order to compute the cumulated emissions generated by the company, several hypotheses are made [7]:

- The reports provided by the company cover all significant emission sources.
- The company will meet its decarbonization targets.
- The company will keep the same market share over the different energy activities, which means that its share of the global carbon budget will not vary.

One should note that the first two hypotheses are to the company's advantage. Indeed, as shown in chapter 2, the company does not seem to be covering all its signification emission sources and nothing ensures that it will meet all its decarbonization targets. The last hypothesis is quite large but is necessary in order to estimate the company's emissions.

4.1.1 Carbon budget allocated to the company

The TPI's methodology used is described in Figure 4.2. Its objective is to compute a carbon intensity pathway for the oil and gas sector, which will then allow to compute the carbon budget allocated to the company.

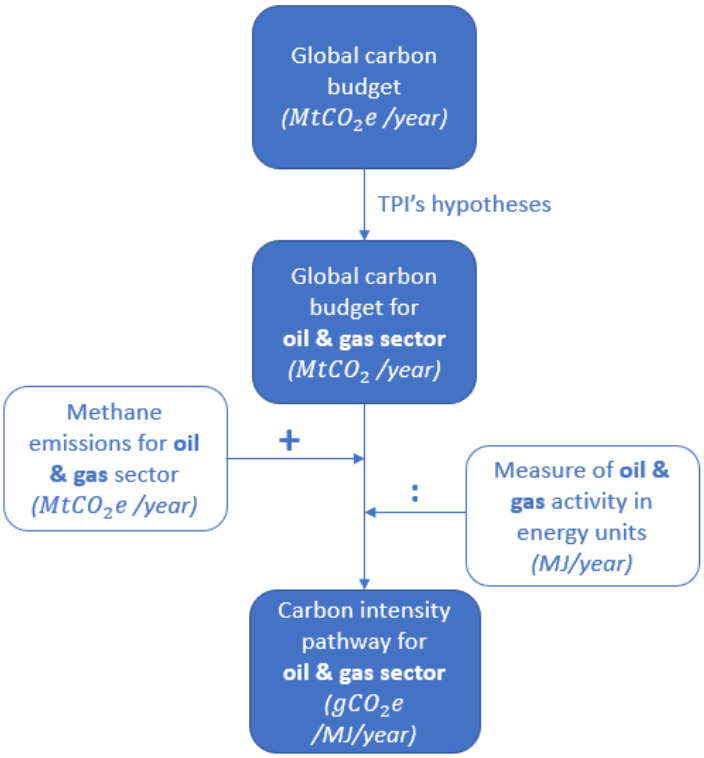


Figure 4.2: Computations of the carbon intensity pathway for oil and gas sector [8]

The TPI's methodology is based on the Sectoral Decarbonization Approach (SDA), which translates emission targets on an international level into benchmarks per sector, against which the emissions of the companies related to the given sector (oil and gas sector in this case) can be compared [85]. The SDA can be broken down into three main steps:

- Establishing a global carbon budget based on international emissions targets. In this case, the reference emission targets are derived from the 1.5°C scenario given by the IEA.
- Allocating the global carbon budget across time to different sectors and regions.
- Normalizing the sectoral emissions by dividing them by a relevant measure of the sectoral activity (often in terms of energy unit), which results in an emission intensity pathway.

As shown in Figure 4.2, in order to obtain the carbon intensity pathway for the oil and gas sector, it is needed to define a relevant measure of the oil and gas activity in energy units. According to the TPI, the total supply of primary energy is an appropriate measure of the oil and gas activity, since oil and gas companies are primarily engaged in energy supply [8]. One should note that the global energy supply is defined as *the total net calorific energy supply from all energy sources, which includes hydrocarbons, biomass and waste used for energy generation, and energy supplied as electricity generated from fossil fuels, nuclear or renewables* [85]. Therefore, the sectoral emissions considered include all

the emissions of the total supply of energy products, defined by the TPI as the *Energy products sold externally* [8].

The global budget allocated to the oil and gas sector computed based on the SDA methodology is shown in Figure 4.3.

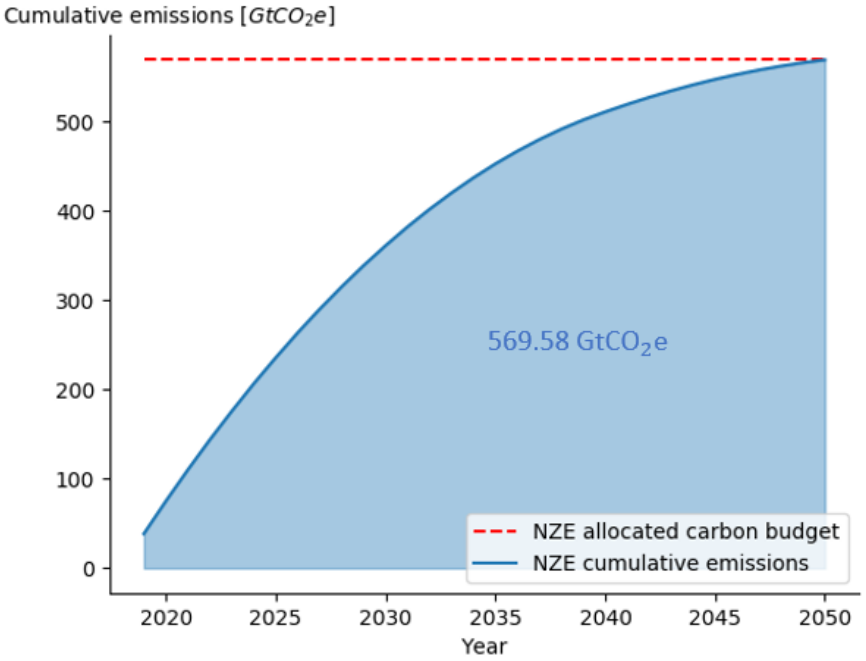


Figure 4.3: Carbon budget allocated to the oil and gas sector ($GtCO_2e$) [8]

The emissions provided by the IEA only consider CO_2 emissions: it does not consider other greenhouse gases such as methane, whose emissions are quite significant. In order to complete its study, the TPI considered the methane emissions computed by the Emissions Database for Global Atmospheric Research (EDGAR) in 2010 and applied IPCC's pathways in order to project the methane emissions from 2010 to 2050[3] [8]. This step is illustrated in Figure 4.2.

Dividing the sectoral global carbon budget by the sectoral activities gives the **global carbon intensity pathway for the oil and gas sector** and is shown in Figure 4.4 for each scenario defined by the IEA. The Sustainable Development scenario aims to limit global warming to 1.65°C with a 50 % probability [8] and the STEPS explores how the emissions would evolve without any change except the implementation of what is under development [64]. As stated above, the reference scenario used in order to assess the company's alignment is the 1.5°C scenario (which corresponds to the NZE scenario).

[3]The other GHG such as SO_2 and HFCs are considered as negligible[8]

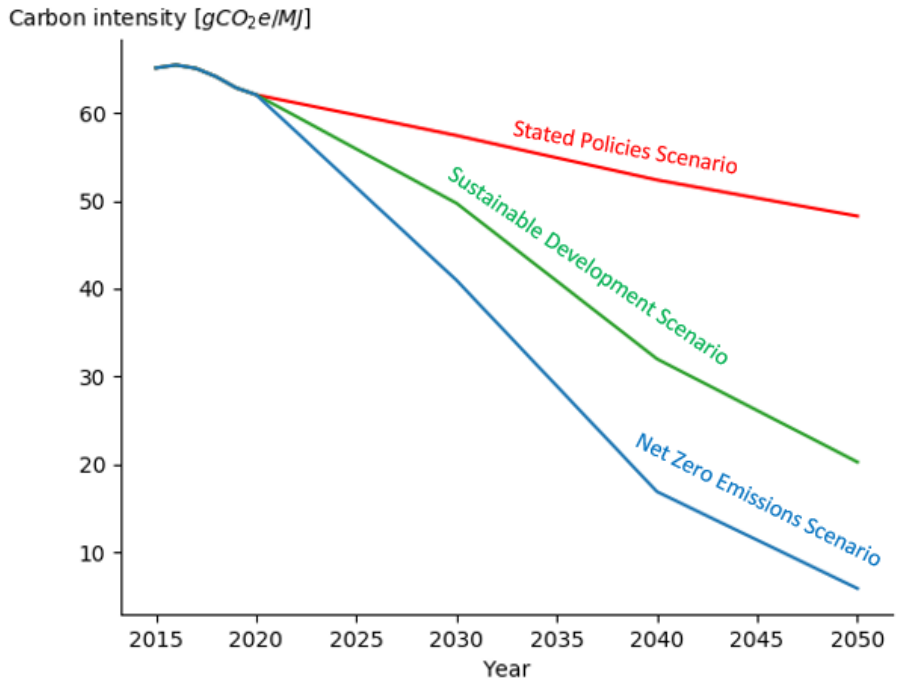


Figure 4.4: Global intensity paths for the oil and gas sector per scenario from 2021 to 2050 (gCO_2e/MJ) [9]

By considering that the carbon budget allocated to the company is computed from 2019 to 2050, it can be defined as:

$$\text{Carbon budget} = \sum_{i=2019}^{2050} (\text{Carbon intensity O\&G})_i \times (\text{Company's sales following NZE})_i$$

4.1.2 Cumulated emissions based on IEA projections

The cumulated emissions of the company based on the IEA's projections can be computed as follows:

$$\text{Cumulated emissions}_{IEA} = \sum_{i=2019}^{2050} (\text{Emission intensity comp.})_i \times (\text{Company's sales follow. NZE})_i$$

The emission intensity can be found in the company's annual reports [5][10][11]. The company's sales are assumed to follow the variation of the energy supply defined in the NZE scenario and can be found in Table 4.1.

Year	Total energy supply (EJ)
2019	613.0
2020	589.1
2030	547.1
2040	534.5
2050	543.0

Table 4.1: Total energy supply according to the NZE scenario [15]

4.1.3 Cumulated emissions based on company's reduction targets

The cumulated projected company's emissions based on the company's reduction targets can be computed as follows:

$$\text{Cumulated emissions}_{Comp} = \sum_{i=2019}^{2050} (\text{Emission intensity comp.})_i \times (\text{Company's sales})_i$$

4.1.4 Alignment indicators

Once the carbon intensity pathways and the company's sales are estimated, the analysis of the company's alignment on the allocated carbon budget can be realized. A company is considered as aligned on a scenario on a specific timeframe when its total cumulated absolute emissions are kept within the carbon budget allocated by that scenario [7].

Misalignment occurs when [7]:

- The company's carbon intensity is too large. This highlights a GHG emission per unit of produced energy that is too high. This could be translated into a production reduction strategy without transitioning towards clean energy generation.
- The company's sales are too large. In this case, even if the carbon intensity is aligned, the cumulated emissions are exceeding the carbon budget because the sales are too high. This could be the case of a company diversifying its energy mix without sufficiently decreasing its fossil production.

The first possibility can be assessed by comparing the total cumulated emissions of the company for which the production follows the NZE scenario demand profile (yellow element in Figure 4.1) to the total allocated carbon budget (blue element) when the second possibility is assessed by comparing the total cumulated emissions of the company for which the production follows the company's targets (green element in Figure 4.1) to that same allocated carbon budget (blue element).

Two other alignment indicators are defined by the Reclaim Finance methodology in order to characterize a misalignment [7]:

- **Overshoot and overshoot year.** The overshoot corresponds to the excess of a company's total cumulated emissions compared to its carbon budget [7]. The overshoot year is the minimum year for which the company's total cumulated emissions are higher than the allocated carbon budget.
- **Share of allocated carbon budget consumed by 2030** which is defined as the ratio between the total cumulated emissions consumed by 2030 and the total carbon budget. This indicator highlights the carbon budget share consumed by 2030.

4.2 Parameters computations and estimations

Based on the oil share of the energy mix of the company in 2019 (see Table 4.4), the total company's sales can be computed for 2019. By following the variation of energy supply of the NZE scenario given in Table 4.1, one can obtain the sales given in Table 4.2.

Year	Total energy sales (PJ)
2019	9689.72
2020	9311.93
2030	8648.04
2040	8448.87
2050	8583.23

Table 4.2: Company's total energy sales computed based on the NZE scenario (PJ) [15]

The company's carbon intensity pathway can be computed based on the data provided by the company. It is disclosed from 2015 to 2019 and can be deduced from its targets for the following years: from 2015, the company aims to reduce its carbon intensity by 15 % by 2030, by 40 % by 2040 and by 60 % by 2050 [10][5][86]. The resulting carbon intensities can be found in Table 4.3.

Year	Carbon intensity (gCO_2e/MJ)
2015	71.10
2016	70.15
2017	69.20
2018	67.31
2019	66.36
2030	60.43
2040	42.66
2050	28.44

Table 4.3: Company's carbon intensities from 2015 to 2050 based on the company's disclosures (gCO_2e/MJ)

The company's sales in energy units can be approximated from the company's disclosure: the latter gives both the oil sales in Mb/d and the oil share in the energy mix [5][11]. Based on this information, the total sales in energy units can be estimated [16]. Since no sales information is given in 2050, it has been assumed that the production is equal to the sales.

The data disclosed by the company and the total estimated energy are given in Table 4.4.

Year	Oil sales (Mb/d)	Oil share in energy mix (%)	Total energy (PJ)
2015	2.4	65	8243.4
2019	2.3	53	9689.7
2020	1.8	47	8550.3
2021	1.8	44	9133.3
2022	1.7	41	9258.5
2030	1.4	30	10426.8
2050	0.3	7.5	8954.7

Table 4.4: Oil sales data and total energy sales of the company [5][11][16]

4.3 Analysis of the company's alignment

By applying the methodology described and based on the previously estimated elements, one can obtain the assessment of the company's alignment which is represented in Figure 4.5.

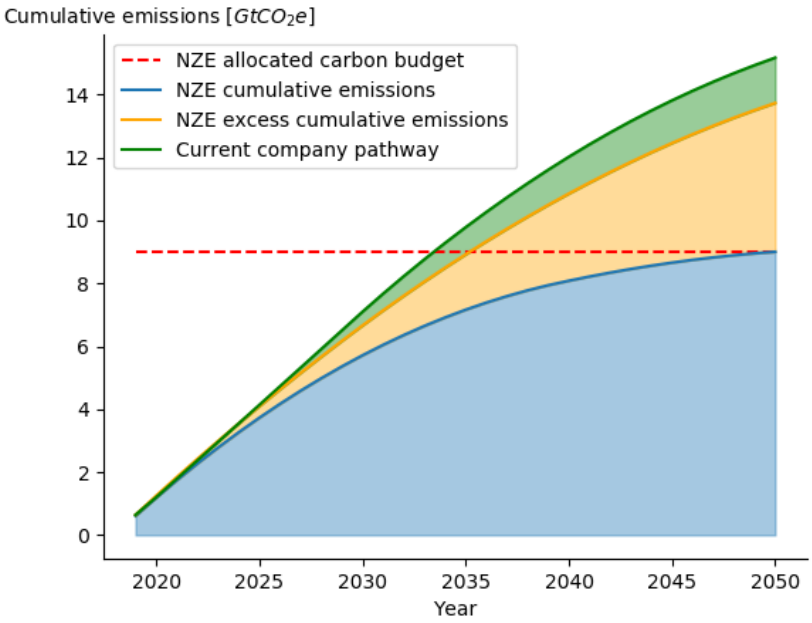


Figure 4.5: Simulation of the carbon budget, the cumulative emissions according to the NZE scenario and the cumulative emissions according to the company's sales ($GtCO_2e$)

The total carbon budget allocated to the company is **9003.4 $MtCO_2e$** and represents less than 2 % of the whole oil and gas sector[4]. As shown in Figure 4.5, the company's absolute emissions are exceeding this budget, both in the case when the company's sales are assumed to follow the NZE profile demand and in the case when the company's targets in terms of sales are considered.

In the first case, which is a low estimation, the company's overshoot is **4723 $MtCO_2e$** and represents a surplus of 53 % of its allocated carbon budget. The overshoot year would be 2035 and 74 % of the total carbon budget would be consumed before 2030. Since this first case considers that the company's sales are aligned with the energy demand profile of the 1.5°C reference scenario, it shows that the company has an energy production that is too carbon intensive. In other words, the diversification of its energy mix is not sufficient to align its carbon intensity with the NZE scenario.

The fact that the company's carbon intensity is too high is illustrated in Figure 4.6. Indeed, the company's carbon intensity is much higher than the one recommended by the 1.5°C reference scenario. The Sustainable Development scenario aims to limit global warming to 1.65°C with a 50 % probability [8]. As shown in Figure 4.6, the company's carbon intensity is not aligned with this scenario. However, the carbon intensity considered by the company seems to be more ambitious than the STEPS[5], which is far from being aligned with the two previous scenarios that aims to limit global warming.

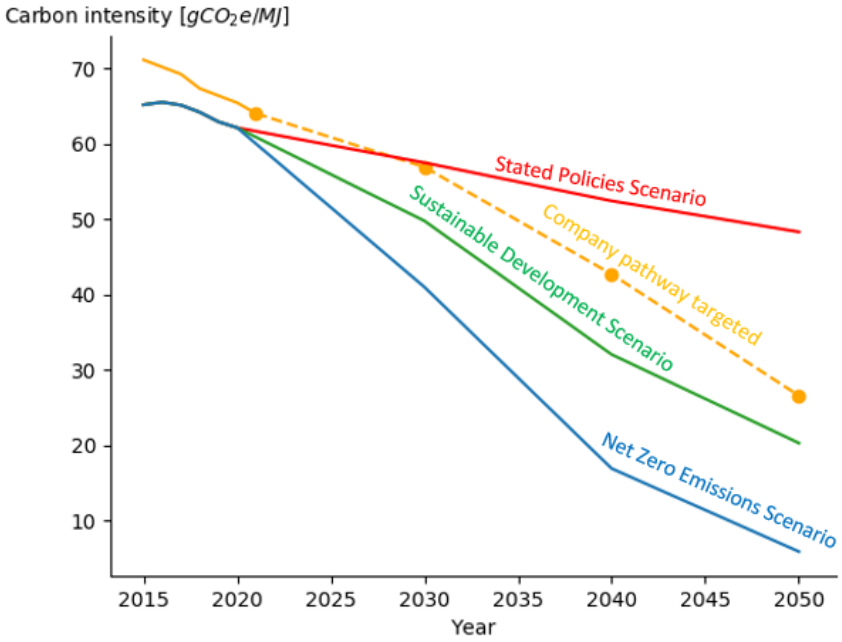


Figure 4.6: Global intensity paths for the oil and gas sector per scenario from 2021 to 2050 (gCO_2e/MJ) [9]

[4]As a reminder, the total carbon budget of this sector is 569.58 $GtCO_2e$ and is given in Figure 4.3

[5]As a reminder, this scenario explores how the emissions would evolve without any change except the implementation of what is under development [64]

In the second case, which is more realistic but remains ambitious since it considers that the company will meet its targets, the company's overshoot is **6205 $MtCO_2e$**. This represents 79 % of the actual carbon budget and the overshoot year is 2033. This second case highlights the fact that the company has a fossil production that is too high, which shows that the company needs to reduce its production [7].

In conclusion, the company's carbon emissions go far beyond its carbon budget because neither its carbon intensity targets nor its production targets are aligned with the 1.5°C scenario. Its carbon intensity targets are not even aligned with the Sustainable Development scenario (see Figure 4.6), which corresponds to a scenario that would keep the rise of global temperature below 2°C scenario. This analysis shows that the company needs to drastically review its ambitions and strictly stick to them in order to reach net zero in 2050.

Key messages of chapter 4

1. Based on the TPI's methodology and on the company's disclosure, the carbon budget allocated to the company is **9003.4 $MtCO_2e$** and represents 2 % of the carbon budget of the oil and gas sector.

2. The carbon intensity of the company is not aligned with the NZE scenario and even exceeds the Sustainable Development Scenario, which aims to limit global warming to 1.65°C with a 50 % probability [8].

3. A first low estimate of the company's emissions based on the assumption that the company's sales follow the NZE scenario profile demand shows that the company exceeds its carbon budget by **4723 $MtCO_2e$**. This shows that **the diversification of the energy mix of the company is not sufficient**. In this case, the overshoot year is 2035.

4. A second estimate of the company's emissions based on its own production and sales targets shows that the company may exceed its carbon budget by **6205 $MtCO_2e$**. This shows that **the fossil production of the company is too high**. In this case, the overshoot year in 2033.

Chapter 5

Economical feasibility and company's financial health

In order to achieve its goal of net zero emissions by 2050, it is essential, as shown in the previous chapters, that the company progressively moves from an oil and gas company to one that is primarily made up of renewable energy sources. While it may not be necessary to abandon all fossil fuel activities abruptly, given the limited timeframe of less than 30 years for this transition, it is crucial for the company to begin a significant diversification of its investments. Beginning this process early will mitigate costs and ease the transition, increasing the likelihood of achieving the desired goal.

The only thing that can potentially hinder or prevent the company from switching to renewable energy is cash flow, i.e. whether the company can afford to switch to renewable energy. For this reason, the company should be analyzed from a number of different angles, using performance indicators to assess its overall financial health, which can help determine its ability to switch to renewable energy sources.

> In this section, the company's financial health will be analyzed through financial indicators. This will be followed by a review of the company's investments in oil and gas as well as renewable energy sources. Finally, the case of a former oil and gas company that has successfully embarked on the energy transition by divesting from polluting activities and focusing on renewable energy will be introduced.

5.1 Financial indicators

To transition from an oil and gas company to a multi-energy company, it is vital for the company to maintain strong financial health as it requires a lot of investment. Therefore, it is important to analyze the financial health of the company using different performance indicators.

One of the most important indicators is the **net income** of the company, which is the amount of money remaining after deducting all expenses from the total revenue earned during the year. The revenue has been continuously increasing and reached a profit of 16 billion dollars in 2021, as shown on Table 5.1. Since 2021, the company has even

been referred to as having super profits, which is attributed to the rise in hydrocarbon prices, especially gas, from which the company has fully benefited [87]. This indicates the company's profitability and overall excellent financial health. It is worth noting that in 2020, the net income was negative, which was the case for a large majority of companies due to the impact of the Covid-19 pandemic on the global economy.

Another indicator of business health is the **growth rate**[1] which is used to measure the expansion rate of a business. It should be noted that there is no such thing as a good growth rate. What is needed is a sustained[2] growth rate over the long term, not just short-term fluctuations, which is more indicative of a healthy and successful business. The indicator for the year 2020 is not meaningful because of the negative net result. As mentioned before, it is due to the Covid-19 effect.

	2021	**2020**	**2019**	**2018**	**2017**
Net income [M$]	**16 302**	**-7 242**	**11 267**	**11 446**	**8 631**
ROE[3] [%]	16.9	3.7	10.4	12.2	10.1
Retention ratio[4] [%]	47.9	195	40	57	67.7
Growth rate [%]	**8.1**	**7.21**	**4.16**	**6.86**	**6.84**

Table 5.1: Financial indicators resulting from the DEU [5][10]

According to Table 5.1, the company demonstrates profitability and ongoing growth, supported by a consistent increase in net income and a favorable growth rate. However, it is important to analyze the cash flow from operating activities, which measures the amount of cash generated by a company's operational activities (such as those in the oil, gas, or renewable sectors). This is because net income also takes into account financial investment results. Therefore, a company could generate a lot of profit from these investments but very little from its core activities.

On average, from 2017 to 2021, the operating cash flow from activities directly related to oil and gas accounted for more than 92.5% of the company's total operating cash flow [5][10]. This highlights the fact that for oil companies, the transition to a multi-energy company cannot happen quickly, as the majority of the company's cash flow is directly linked to oil and gas activities. Therefore, it will require a reduction in sales of oil & gas and a massive reinvestment in renewable energy sources.

5.2 Investments

The company's investments are segregated into 5 parts: Integrated Gas & Renewables & Power, Exploration & Production, Marketing & Services and Corporate. Figure 5.1 shows the net investments[5] allocated each year associated with each part. The majority of investment is in exploration and production as well as in gas, renewable and other

[1] Growth rate = Return on equity (ROE) × Retention ratio

[2] Sustained means which fluctuates little in the short-term but increases in the long-term

[3] ROE equals to the net income divided by the shareholder equity

[4] It indicates how much of a company's earnings are reinvested back into the business, rather than distributed to shareholders as dividends

[5] Net investment = gross investment – capital depreciation

power plant projects (i.e. in the segments Integrated Gas & Renewables & Power and Exploration & Production). From 2016 to 2020, investments in oil projects have only decreased in favor of other energies (natural gas, renewable energies and power plants). Despite this positive trend, the company has not continued its efforts since 2020. Indeed, the company increased its investments in exploration, without drastically decreasing them until now.

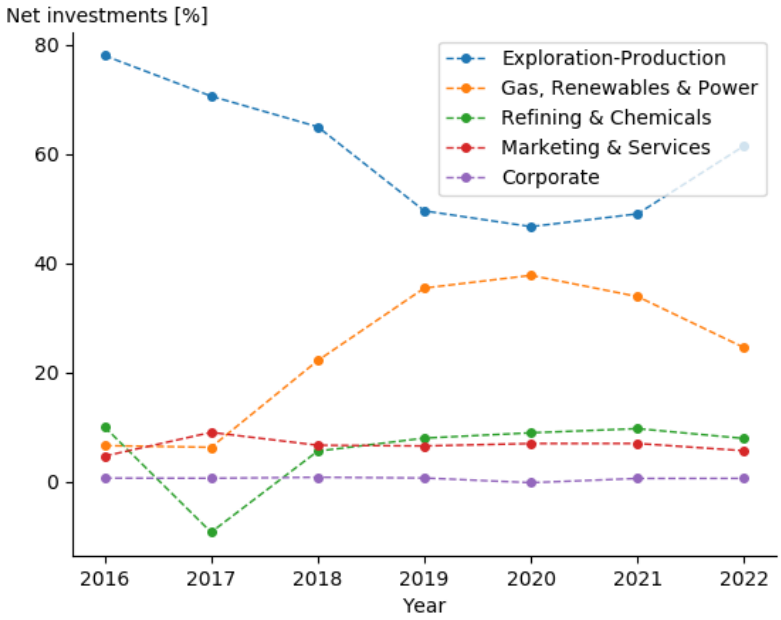


Figure 5.1: Net investment percentage compared to each sector (%) [5][10][11]

Moreover, the segment Integrated Gas & Renewables & Power does not only represent renewable energy. In reality, the investment allocated to green energy is much lower. The share of investment in renewable energy was 15% in 2020 compared to 25% in 2021 (data for the renewable part for other years is not provided).

Note that the net investment is a more representative indicator (compared to gross investment) to determine how much the company has actually spent to acquire new assets in the oil, gas, or renewable sector, as it takes into account asset depreciation. For instance, at the beginning of the year, the company owned 5 wind turbines. It purchased an additional 10 wind turbines, while only 4 wind turbines were in operation. The gross investment represents the purchase of 10 new wind turbines. However, by the end of the year, only 14 wind turbines (5 + 10 - 1) were in operation. Therefore, the net investment, because of the depreciation, corresponds to the acquisition of 9 wind turbines (this represents the actual added value).

Regarding its future net investments, between 2022 and 2025, the distribution is as follows:

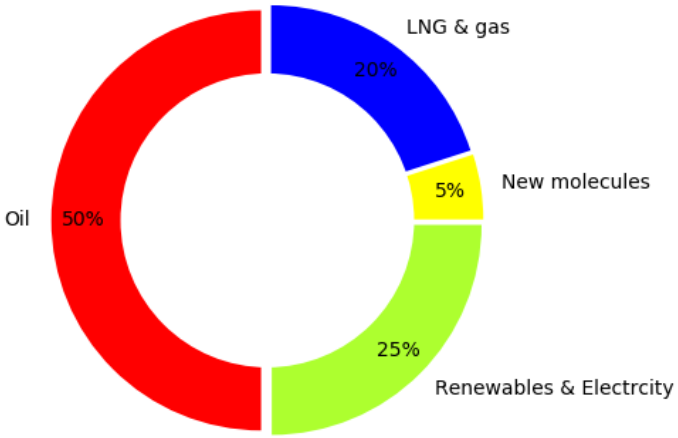


Figure 5.2: Investment breakdown between 2022-2025[5]

By 2030, the oil investment policy decreases slightly to 45% [11]. It should be noted that the company's investment is heavily based on a projection of demand, and it announces to adapt its sales of petroleum products to the evolution of demand.

If the company continues to invest in fossil fuels without decreasing them, in the near future, it may face significant financial issues, as will be explained below. Therefore, it is crucial to comprehend and define the various systems and concepts that could considerably affect the gas and oil industry.

Policy tools - Carbon tax and Emissions trading system (ETS)

There are two main systems that have been implemented in many countries around the world, especially in Europe: carbon tax and carbon markets (ETS). Both are political tools aimed at reducing GHG emissions by making the largest emitters pay. The systems mainly target industries such as refineries, aviation, electricity production, steel, cement, etc.

The carbon tax is based on a price set by the authorities and imposes a fee on each ton of CO_2 emissions released by an entity, while the carbon market works by setting a limit on the total amount of carbon emissions. This system operates in phases, each representing a specific period of time. For each phase[6], a certain number of emissions quotas are allocated to each company, currently phase 4 is underway, which runs from 2021 to 2030. If a company emits more than its allocated amount, it must obtain additional quotas on the market, and if it emits less than its allocation, it can sell its

[6]As we move forward in the phases, the system becomes more restrictive (less free allocated quotas, decreased quota supply, taking into account more GHGs, etc.).

surplus quotas and earn additional revenue. The aim is to encourage companies to reduce their emissions by making it more cost-effective to invest in emissions-reducing measures rather than buying additional allowances on the market [88].

The company has already announced that it plans to exceed its allocated quota for phase 4 by 30% [5], which shows that the company has every interest in reducing the sale of fossil fuels, given that the price of a carbon quota has continued to increase, reaching an all-time high in August 2022 of nearly 100 euros per tCO_2 on the European market [89].

Economical concepts - Carbon lock-in and carbon bubble

Some concepts can support the idea that a sudden transition may not be feasible. If a company continues to invest in fossil fuels, it may get trapped in a spiral known as carbon lock-in. The long lifespan of infrastructure (coal, gas power, etc.) can lock companies into a trajectory with high carbon intensity. Once expensive infrastructure has been built to exploit fossil energy, it is difficult for substitute technologies such as renewable energy sources to compete with their low short-term usage cost. Indeed, existing infrastructure has high fixed costs but relatively low marginal costs, therefore it is less expensive to continue using it than to build new infrastructure to replace it. This can lead to what is called socio-economic inertia, where companies continue to use existing carbon-based infrastructure instead of switching to cleaner alternatives because they are cheaper [90].

Another concept that has recently emerged, highlighted by The Carbon Tracker initiative, is the notion of a carbon bubble [91]. This term refers to the overvaluation and subsequent massive loss of value in fossil fuel investments due to increasing climate policy stringency aimed at limiting global warming. Indeed, to prevent exceeding a 2°C warming by 2050, the global carbon budget between 2010 and 2050 is 565 $GtCO_2$. However, the known fossil fuel reserves amount to approximately 2795 $GtCO_2$, with 65% from coal, 22% from oil, and 13% from gas. Of which the fossil fuel reserves of the top 100 listed coal, oil and gas companies amount to 745 $GtCO_2$. This means that the market is pricing in assets from reserves equivalent to five times the remaining carbon budget. This implies that 80% of known fossil fuel reserves would become unusable, assuming there are agreements and policy measures to prevent exceeding the carbon budget by 2050. This would create an unprecedented loss of value for oil and gas companies listed on the stock market because they have overvalued reserves that will not be extracted.

In summary, the carbon bubble encompasses the emissions generated by the combustion of current fossil fuel reserves, but a much smaller bubble represents the remaining carbon budget for 2050 to have a chance of staying below 2°C. From a financial point of view, this means that the remaining reserves are assets that are destined to lose all their value by becoming unusable, leading to a loss of reserves and an economic collapse.

5.3 Fossil fuel transition: Ørsted's example

To demonstrate that it is possible to transition away from fossil fuels, the Danish energy company[7], Ørsted, is the perfect example. Previously, the company was primarily a producer of fossil fuels, mainly coal and oil, but today, the majority of its production is based on renewable energy.

The company has set a very ambitious target to become a carbon-neutral company by 2025. To achieve this, since 2016, the company has ended its investments in the oil and gas sectors and shifted its focus to clean energy, primarily in offshore wind farms. In 2017, the company ended its activities in the oil and gas business, and by 2024, it will also exit the coal industry.

Compared to 2006, carbon emissions will be reduced by at least 98% by 2025, and the remaining emissions will be offset [12].

It is worth noting that their net profit during the 2006-2011 period, where fossil fuel energy accounts for over 70% of their production, was approximately 3.65 times lower than the one realized for the year 2022. Therefore, transitioning away from oil and gas can be profitable in the long term.

Figure 5.3 illustrates the distribution of energy production already achieved.

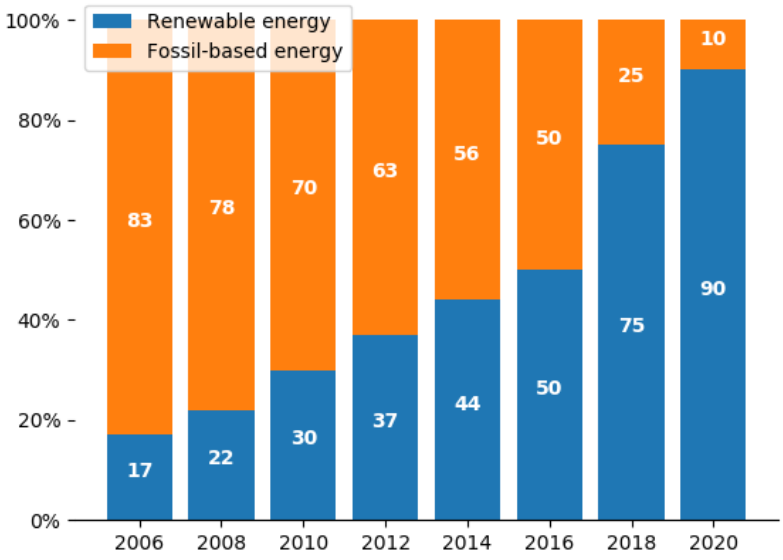


Figure 5.3: Share of energy generation per year (%) [12]

The Danish company is a prime example of how it is possible to shift from predominantly fossil fuel-based production to low-carbon energy sources without jeopardizing the

[7]It should be noted that the size of the company is negligible (with a market capitalization of only tens of millions) compared to the multinational corporations present in the industry.

company's financial situation. It is important to note that the Danish company operates on a smaller scale and is therefore not directly comparable to a multinational company. Therefore, further analysis would be required to determine whether the larger company could make a similar transition. Indeed, transitioning to low-carbon energy sources can be more complex for larger companies due to existing fossil fuel infrastructure, complex supply chains and greater pressure from investors.

Key messages of chapter 5

1. Based on the performance indicators, the company records strong profitability and continuous growth, making it well-positioned to embark on significant investments in renewable energies.
2. From 2016 to 2020, net investments in oil projects have decreased in favor of other energy sources such as natural gas, renewable energy and power plants. However, since 2019, this trend has reversed, with the company increasing its investments in the exploration and production sector.
3. Not stopping its oil production and investments (phasing out of the oil sector by 2050) could be financially detrimental to the company. This is due to policy tools such as carbon taxes and ETS. And also economic concepts such as carbon lock-in and the carbon bubble also come into play.
4. The Danish energy company, Ørsted, has demonstrated that it is possible for a company to transition from being primarily focused on fossil fuel production to a completely renewable energy-based operation without compromising its financial situation.

Chapter 6

Discussion

The objective of the study realized in this thesis is to analyze the credibility of the transition plan of the company considered with regard to the net zero emission target.

The first study realized in this master's thesis was the assessment of the carbon footprint of the company. This assessment was then used as a basis for simulating the transition plan of the company based on its own targets and on the NZE scenario as defined by the IEA. This simulation was followed by the estimation of the carbon budget of the company in order to provide an assessment of its cumulated emissions. Finally, a more economic point of view was brought to the analysis by analyzing the investments and the economic situation of the company through performance indicators.

> Some of the conclusions of the study presented in this master's thesis require closer attention and a broader perspective, they will therefore be addressed in this section. In order to complete the study, some additional discussions will be included.

The role of trading in the carbon footprint

As explained in section 2.2, the calculated emissions results for the 2021 carbon footprint are significantly different from those reported by the company. One of the main reasons for this discrepancy is that the emissions associated with the trading volumes of oil, gas, and electricity may have not been accounted for in the carbon footprint assessment realized by the company. The question may therefore arise: should emissions related to trading be taken into account?

In the carbon footprint assessment realized in chapter 2, only the trading including the production of the company has been considered. The reasoning behind this choice is that the company should at least be responsible for its own production. Moreover, there is no consensus about the consideration of purely virtual trading in carbon footprint assessments, it has been decided to neglect it.

However, as shown in Table 6.1, the company's trading activity represents a significant part of the company's operations, which means that it also represents an important part

of its profits.

	Trading activity	Company's sale excluding trading
Oil (kb/d)	6 306	1 919
Natural gas (Gm^3)	75	49.5
LNG (Mt)	35.1	42
Electricity (TWh)	111	56

Table 6.1: Trading volume compared to the company's sales in 2021 [17]

According to the company itself, the objective of a carbon footprint assessment is to have a precise idea of the emissions generated by a company and in order to allow the elaboration of an action plan to reduce the impact of the company's activities on the environment [92]. In other words, the role of a carbon footprint assessment is to identify all the emission sources related to the company's activity in order to be able to decrease them.

Based on this definition, it seems rather important to include trading in the carbon footprint assessment. Indeed, trading is part of the company's activity and not including it would mean that it would not be considered in the action plan realized by the company when trading accounts for an important part of the company's benefits.

Taking into account trading activities in the assessment would significantly increase the carbon emissions considered, which would highlight the fact that the company needs to change its behavior in terms of trading.

However, trading involves buying and selling assets with the aim of making a profit, the same quantity could be counted several times. Therefore, accounting for all the transactions may not be the best option to take trading into account. An interesting question to explore would be to find a way to take trading into account without double-counting.

Energy sources to reach net zero by 2050

The simulation of the company's transition plan realized in chapter 3 shows that the company's targets are far from sufficient to reach net zero emission by 2050. Predictably, oil and gas are amongst the most emitting sectors, which shows that their production and sales should be drastically reduced immediately and stopped before 2050, as recommended by the IPCC.

Another important sector in terms of emissions is the production of decarbonized molecules, which is composed of biogas, biofuels[1], hydrogen and liquid e-fuels. Indeed, these energy sources generate a significant amount of emissions (see section 3.5 for more

[1]As mentioned in chapter 3, even though the company considers biofuels separately, it is also considered as a decarbonized molecule in this master's thesis.

detail). However, all decarbonized molecules are not equivalent in terms of emission generation (more detail about decarbonized molecules is given in Appendix F).

In the case of bioenergies[2], since their evolution strongly depends on the way land use change is realized and on investments in waste collection and sorting, the emissions related to their production may increase in the future. Therefore, in order to ensure net zero emissions by 2050, the company should remain cautious when setting bioenergy production and sales targets and should mostly focus on reliable energy sources in terms of emissions.

The emissions generated by hydrogen production depend on the way that it is produced. The company intends to produce two types of hydrogen:

- Blue hydrogen, which is produced from natural gas. Its production process is combined with carbon capture.
- Green hydrogen, which is produced from renewable electricity through the process of electrolysis of water.

Since fossil fuel production and sales should be drastically reduced and stopped before 2050, the company should focus on green hydrogen.

As mentioned in chapter 3, emissions related to liquid e-fuels are difficult to estimate due to the fact that it is a recent technology. However, since its production mainly relies on electricity, its related emissions should decrease with the rise of renewable energies. E-fuel production still requires an important of electricity, which means that its emission factor will not be negligible.

One should note that switching to decarbonized molecules remains necessary in order to replace fossil fuels. Indeed, alternative fuels will be needed for certain sectors such as shipping, aviation and heavy-duty land transport [79]. It should be included in the company's strategy, even though the company should carefully choose in which energies to focus on by taking into account the emissions generated.

Unsurprisingly, the least emitter revealed by the simulation is the electricity sector, which is exclusively composed of renewable energy sources. Indeed, by 2050, the electricity generated is 726 TWh, which represents 9 times the Belgian electricity consumption in 2021 [93], for only 18.03 $MtCO_2e$ emitted. This illustrates the importance of electrification[3] to reach net zero by 2050 and shows that the company's strategy can safely rely on this energy source in order to reduce its emissions. However, one should keep in mind that electrification may not represent an important cost in terms of emissions but will require the use of large quantities of materials and rare metals such as silicon for photovoltaic panels and neodymium for wind turbines [94]. These resources need to be extracted and may not be infinite. The spread of renewable energies will therefore always

[2]The term bioenergy refers to biogas and biofuels.

[3]As a reminder, electrification means shifting from fossil fuels to electric power as the primary energy source for diverse applications.

have a cost for the environment, although this will not always be quantifiable in terms of emissions. In order to increase the production of these energy sources in a sustainable way and to ensure long-term use, it is therefore important to invest not only in their development but also in the recycling process of their materials.

Finally, it is worth looking again at CCS and NBS and at the way that the company considers them. As developed in its annual report, the company relies on these technologies to compensate for the emissions generated by the use of its products. Therefore, the company considers CCS and NBS as compensating mechanisms that can allow it to keep generating emissions. Moreover, the company sets irrealistic targets for the development of these mechanisms (see section 1.3 for more detail). It is important to remind that CCS technologies are recommended by the IPCC as an option to reduce emissions in sectors that cannot be decarbonized such as the cement process or the production of chemicals. Therefore, the company should decarbonize its energy production before resorting to these mechanisms, instead of relying on them in order to generate more emissions.

The company's strategy should therefore focus on electricity generation and decarbonized molecules development, while cautiously choosing which decarbonized molecules to focus on based on the related generated emissions. One should note that this would require an important shift in the company's activities, which have always been centered around fossil fuels. Because of carbon lock-in[4], it is important that the company starts this shift as soon as possible. As shown in chapter 5, the company's financial health seems stable enough to go through this important activity change. However, it is worth exploring the possibility for a company as large as the one studied to realize it before 2050.

Responsible parties of Scope 3

As stated before, the objective of a carbon footprint assessment is to identify the main sources of emissions generated, in this case, by the activities of a company. However, it does not mean that the company considered is entirely responsible for all the emissions included in its carbon footprint assessment. For example, scope 3 regroups all the indirect emissions generated by the company's activities including the use of sold products by end-consumers, for which the consumers and the producers are equally responsible. In fact, according to the NZE scenario, another responsible party would be governments. Indeed, although behavioral changes needed to reach net zero by 2050 should come from people and companies, it is the responsibility of governments to facilitate these changes through policy regulations and messaging. By 2030, around 70% of the emissions saved by behavioral changes could be influenced directly by regulations put in place by policymakers [15].

This reasoning shows that decreasing emissions will require efforts not only from the oil and gas industries but also from other actors. Political measures need to be implemented, including stricter emission standards, promoting the adoption of renewable

[4]Carbon lock-in is explained in detail in chapter 5.

energy and other sustainable practices. Consumers, on their part, can contribute by reducing their demand for fossil fuel products and making lifestyle choices that align with environmental sustainability.

Lack of vision or bad faith?

The study realized shows that the company not only underestimated its emissions but also set targets that are not realistic or far from sufficient to reach net zero by 2050. In the context of climate urgency that is faced today, is it really possible that the company just lacked vision and precision? This section intends to bring answers to this question.

Despite the countless warnings of scientists and NGOs, the company keeps investing in fossil fuels and is even planning on launching a new pipeline project called EACOP. Even though 200 scientists publicly stood against this project by describing it as a climate bomb, the company is refusing to back down [95]. An impressive involvement of the citizen against this project has taken place since its announcement but the company's project remains unchanged.

Moreover, according to a study published in 2021 and based on the company's archives, the company would have been aware of the effects of fossil fuels on climate change since 1971 [96]. Indeed, in a special edition of the company's magazine about the environment, a research scientist warned the company about the rise of global temperature and other disastrous consequences of human activities. Instead of acting on it, the company would have financed counter-studies to sow doubt about the real effects of global warming. This strategy, initially used by tobacco industries, consists of casting doubt on scientific data that would go against a company's economic interests. Different means are used in this strategy such as financing scientific counter-studies or operating intense lobbying towards policymakers [96][97]. One should note that the company recognizes being aware of the effects of fossil fuels since 1971 and that several documents belonging to the company confirm these accusations.

In these circumstances, it is hard to believe that the company's lack of ambition was involuntary. It also seems quite unlikely that the company will deliberately take measures to reach net zero by 2050, especially if this objective compromises its ability to commercialize fossil fuels, its main source of profit. Moreover, it seems possible that the development of biofuels, which need land-use change in some cases, will not be realized in a sustainable way by the company if it goes against its economic interests.

Therefore, in order to ensure that the company takes its responsibilities in terms of emission reduction, it seems necessary to enforce political regulations around emissions generated by companies and put in place strict controls to verify that these measures are respected.

Key messages of chapter 6

1. Based on the definition of carbon footprint assessment, it would make sense to take all forms of trading into account in the carbon footprint assessment of the company.

2. According to the simulations realized, fossil fuels production should be stopped and the company should base its strategy on electricity generation and decarbonized molecules, while cautiously choosing which decarbonized molecules to focus on based on the related generated emissions. The company should start this shift as soon as possible to avoid carbon lock-in.

3. The company should prioritize decreasing its emissions before resorting to CCS and NBS, which are considered by the IPCC as means to reduce emissions in sectors that cannot be decarbonized, such as cement and chemicals industries.

4. Although the company is partly responsible for the emissions generated by its activity, consumers and governments also have a part of the responsibility. Decreasing emissions will require efforts from the three parties and strong political measures will be necessary in order to initiate behavioral change.

5. The company's behavior in the past shows that its lack of ambition in terms of emission reductions may be intentional and raises doubts about the company's intention to reach net zero by 2050. Therefore, in order to ensure that the company takes its responsibilities in terms of emission reduction, strong measures and strict controls need to be put in place by policymakers.

Conclusion

This master's thesis consists of an analysis of the credibility of the company's transition plan. First, based on the company's disclosure and on several hypotheses, a carbon footprint assessment of the company activities has been realized for the year 2021. Then, based on the company's targets and on the NZE scenario, the simulation of the company's targets has been realized. In order to study the emissions generated with a more cumulative approach, the carbon budget of the company has been estimated by using the TPI methodology in order to assess its cumulated emissions. Finally, a more economic point of view has been adopted with the study of the financial situation of the company through performance indicators and an analysis of the company's investments.

Several conclusions were drawn from these studies:

- The company does not consider all of the emission sources related to its activities: its computation excludes trading, even if the trading quantities are part of the company's production. Its carbon footprint assessment should therefore be reviewed.
- The company's targets in terms of emissions do not seem to be sufficient to reach net zero by 2050. Moving away from renewable energies will be a necessary step in order to reach this objective.
- The company exceeds its allocated carbon budget, which underlines the fact that its sales are too carbon-intensive and too high.
- According to financial indicators, the company seems to have strong financial health. This may mean that a shift towards renewable energies and decarbonized molecules is possible. However, this question needs to be explored.
- By observing the company's behavior in the past and today, it seems that the company will not take ambitious targets to reduce its emissions if it can jeopardize its financial interests.

To summarize, the company's transition plan needs to be deeply revised and more ambitious measures have to be taken. A shift towards renewable energies and decarbonized molecules seem necessary and need to be realized with caution, since some decarbonized molecules may still generate significant emissions depending on their development. Since this shift will be slowed down because of carbon lock-in, it needs to start as soon as possible in order to reach net zero by 2050. Based on a study of the company's financial health, the latter seems stable enough for the company to go through this important activity change. It is still worth exploring the possibility for a company as large as the

one studied to realize it before 2050.

However, the company's behavior suggests that the measures needed to reach net zero by 2050 will not be taken if they endanger the company's financial interests. In order to ensure that the company adopts a transition plan aligned with the net zero targets, strong regulations and control need to be put in place by policymakers.

Appendices

Appendix A

Objectives for 2030 and 2050

The emission reduction targets announced by the company are summarised in the following table:

Based year	Target year	Geographic zone	Net emissions	Reduction target	Emissions scope
2015	2025	Global level	No	-13%	Scope 1 & 2 of its operated facilities
2020	2025	Global level	No	-50%	Scope 1 & 2, methane emissions from operated facilities
2020	2030	Global level	No	-80%	Scope 1 & 2, methane emissions from operated facilities
2015	2030	Global level	Yes	-40%	Scope 1 & 2 for its operated activities
2015	2030	Global level	No	-2,5%	Scope 3 related to its customers' use of energy products
2015	2030	Global level	No	-30%	Scope 3 of the use of petroleum products sold worldwide
2015	2030	Global level	No	-20%	Scope 1 & 2 & 3, the average carbon intensity of energy products
2015	2030	Europe	No	-30%	Scope 1 & 2 & 3, emissions from energy products throughout the value chain
2015	2030	Europe	No	-30%	Scope 3 related to its customers' use of energy products
2015	2050	Global level	Yes	-100%	Scope 1 & 2 of its operated facilities
2015	2050	Global level	Yes	-100%	Scope 3 related to its customers' use of energy products
2015	2050	Europe	Yes	-100%	Scope 1 & 2 & 3, emissions from energy products throughout the value chain

Table A.1: Company emissions reduction targets

Note that if it is not specified, the emissions are by default in absolute terms. Absolute emission reductions refer to the amount of emissions that are reduced in total while reducing emissions intensity means reducing the amount of emissions per unit of output.

Appendix B

GHG protocol categories

The table below provides a description and categorization of all the scope 3 categories [36]:

Category	Description
1. Purchased goods and services	Extraction, production, and transportation of goods and services purchased
2. Capital goods	Extraction, production, and transportation of capital goods purchased
3. Fuel- and energy-related activities	Emissions generated from the extraction, production, and transportation of fuel and energy
4. Upstream transportation and distribution	Emissions generated from the transportation of purchased materials and products
5. Waste generated in operations	Disposal and treatment of waste generated
6. Business travel	Emissions generated from employee business travel
7. Employee commuting	Transportation of employees between their homes and their worksites
8. Upstream leased assets	Emissions generated from the production and transportation of leased assets
9. Downstream transportation and distribution	Emissions generated from the transportation and distribution of the company's products
10. Processing of sold products	Emissions generated from the processing of products sold by the company
11. Use of sold products	Emissions generated from the use of products sold by the company
12. End-of-life treatment of sold products	Emissions generated from the end-of-life treatment of products sold by the company
13. Downstream leased assets	Emissions generated from the production and transportation of leased downstream assets
14. Franchises	Operation of investments (including equity and debt investments and project finance)

Table B.1: Description and categorization of scope 3 categories

Appendix C

Emission factors

C.1 Oil sector

Most of the emission factors used for oil come from the database of ADEME [19], except for the one used for the lubricant [98].

Since some information could not be found in the database, a few assumptions have been made :

- Since the company does not make any distinction between AvGas, kerosene and jet fuel, the emission factor for combustion and LHV of this set of fuels are assumed to be the lowest values possible, which means the values of the AvGas
- Since there is no European estimation for the LPG emission factor, the French estimation has been considered
- Since the company does not make any distinction between diesel fuel and heating oils, it has been assumed that it was only heating oil, which has a lower emission factor for combustion than diesel
- Given the wide variety of solvents and in order to facilitate the computations, the solvent is assumed to be toluene only
- The other products considered by the company refers to refining base, petcoke, naphta, propylene and other petrochemical base. In order to simplify the computations, it has been assumed that all other products had the same emission factor as naphta.

The upstream emission factors take into account the extraction and process, the transport between the extraction location and the refinement station and the refinement (except for crude oil, which is not refined). The emissions resulting from the distribution of refined products are considered in Table 2.7.

Combustible	Upstream [kgCO_2e/GJ PCI]	Combustion [kgCO_2e/GJ PCI]
Crude oil	6.36	73.20
Motor gasoline	13.31	69.20
Avgas, kerosene, jet fuel	15.01	70.20
LPG	9.28	64.80
Diesel fuel and heating oils	15.01	73.80
Fuel oils	11.49	77.80
Bitumen	7.04	81.4
Solvents	73.3	-
Lubricants	73.3	-
Other products	10.51	73.8

Table C.1: Emission factor per fuel

C.2 Conversion elements used for oil sector

Combustible	Density [kg/m^3]	LHV [GJ/t]
Crude oil	900.0	42.3
Motor gasoline	747.0	43.0
Avgas, kerosene, jet fuel	800.0	44.1
LPG	538.00	46.00
Diesel fuel and heating oils	845.0	43.0
Fuel oils	900.0	40.0
Bitumen	1400.0	40.2
Solvents	868.0	40.2
Lubricants	885	40.2
Other products	525	40.2

Table C.2: Density and LHV

C.3 Gas sector

For this activity, the following factors have been defined: production, methane leakage and combustion.

The production factor takes into account processing and extraction (exploration is neglected) which are 234.838 and 166.032 kgCO_2/toe respectively. These factors have been calculated on the basis of the literature emissions estimates for each supply chain stage [20], and have been adapted for a methane GWP of 28.

For that of methane leakage, given the energy content of methane, assumed to be 55.5MJ/kg and used a GWP of 28, the emission factor is 21 139kgCO_2/toe.

The combustion factor is taken directly from the database of ADEME [55] and is 2 174kgCO_2/toe.

C.4 Electricity sector

The emission factors associated with the type of production (Table C.3) and the power plant (Table C.4) are found in the database of ADEME [55].

Type of production	Emissions factors ($kgCO_2e/kWh$)
Geothermal energy	0.045
Hydraulic	6e-3
Offshore wind turbine	0.0156
Wind turbine on land	0.0141
Photovoltaic - Made in Europe	0.0323

Table C.3: Emission factor by type of production

Power plant	Emissions factors ($kgCO_2e/kWh$)
Gas fired	0.0418
Nuclear	6e-3
Coal fired	1.06
Oil steam	0.73

Table C.4

Concerning electricity generation, the European Environment Agency provides the emission intensity of electricity generation by country in 2021 [76]. Table C.5 shows the emission intensity for the countries concerned.

Country	Emission intensity (gCO_2e/kWh)
France	67
Belgium	154
United Kingdom	463
Netherlands	418
Spain	432

Table C.5: Emission intensity of electricity generation by country in 2021 (except UK)

Appendix D

Summary of GHG emissions in accordance with the GHG protocol

The GHG Protocol is the benchmark for GHG emissions accounting and reporting. It provides requirements and guidance for companies to understand and methodically calculate the different emissions scopes (all scopes are included, i.e. scopes 1, 2 and 3).

Most companies in the energy sector rely more specifically on the IPIECA document [50], which is a global oil and gas industry association for environmental and social issues, in which it provides detailed guidance on GHG reporting for oil and gas companies.

It should be noted that not all scope 3 categories have been taken into account, due to the lack of information or their minimal impact, such as emissions linked to franchising, investments, business travel, etc.

D.1 Oil activity

In order to classify the emissions, the following assumptions has been made :

- The transport of crude oil between the EP site and the refineries is done by the company but the transport from the refineries to the clients is not
- The company is responsible for all its production (scope 1)

	GHG protocol categories	Total emissions (tCO2e)
Scope 1 (direct)	Combustion of energy	55 191 425
	Fugitive emissions (from equipment) and processes	-
	Land use change	-
		55 191 425
Scope 3 (indirect)	1 - Purchased goods and services	-
	2 - Capital goods	-
	3 - Fuel and energy	-
	4 - Upstream transportation and distribution	-
	5 - Waste generated in operations	-
	6 - Business travel	-
	7 - Employee commuting	-
	8 - Upstream leased assets	-
	9 - Downstream transportation and distribution	2 637 671
	10 - Processing of sold products	-
	11 - Use of sold products	727 714 283
	12 - End-of-life treatment of sold products	-
	13 - Downstream leased assets	-
	14 - Franchises	-
	15 - Investments	-
		730 351 955
	TOTAL	**785 543 380**

Table D.1: Summary of GHG emissions from oil activities

D.2 Gas activity

In order to determine the distribution of the production (as not mentioned in Table 2.9), hypotheses were made. As there is no information on the origin of the gas sold by pipeline and BtC/BtB, it has been considered that this share is also produced by the company. The production obtained with the assumptions made is 63.93 Mtoe, which is close to the value shared by the group of 66.25 Mtoe (3.5% deviation from provided data).

To categorize the emissions, the following assumptions were made:

- All natural gas, including BtB and BtC sales, is produced by the company but not transported by them.
- Of the 42 Mt of LNG produced by the company, 17.4 Mt is their own production (or 41.43% of LNG sales) and 35.1 Mt (or 87.75%) is transported by them [17].

	GHG protocol categories	Total emissions (tCO2e)
Scope 1 (direct)	Combustion of natural gas	21 653 249.57
	Fugitive emissions (from equipment) and processes	39 945 374.37
	Land use change	-
		61 598 623.94
Scope 3 (indirect)	1 - Purchased goods and services	19 323 761.17
	2 - Capital goods	-
	3 - Fuel and energy	-
	4 - Upstream transportation and distribution	-
	5 - Waste generated in operations	-
	6 - Business travel	-
	7 - Employee commuting	-
	8 - Upstream leased assets	-
	9 - Downstream transportation and distribution	27 105 991.73
	10 - Processing of sold products	-
	11 - Use of sold products	205 429 238.58
	12 - End-of-life treatment of sold products	-
	13 - Downstream leased assets	-
	14 - Franchises	-
	15 - Investments	-
		251 858 991.48
	TOTAL	**313 457 615.41**

Table D.2: Summary of GHG emissions from gas activities

To be clear, category 1 corresponds to emissions related to the production and distribution of gas sold but not produced by the company. While category 9 represents emissions related to company products but not distributed by them.

D.3 Electricity activity

In order to categorize the emissions, the following assumptions were made:

- The sale of electricity in BtB and BtC does not come from the company's production and is not transported by them.
- Emissions from the combustion of natural gas represent approximately 84% of the total emissions.

	GHG protocol categories	Total emissions (tCO2e)
Scope 1 (direct)	Combustion of natural gas	5 054 400
	Fugitive emissions and processes	964 800
	Land use change	-
		6 019 200
Scope 3 (indirect)	1 - Purchased goods and services	10 305 400
	2 - Capital goods	178 386.67
	3 - Fuel and energy	-
	4 - Upstream transportation and distribution	-
	5 - Waste generated in operations	-
	6 - Business travel	-
	7 - Employee commuting	-
	8 - Upstream leased assets	-
	9 - Downstream transportation and distribution	-
	10 - Processing of sold products	-
	11 - Use of sold products	-
	12 - End-of-life treatment of sold products	-
	13 - Downstream leased assets	-
	14 - Franchises	-
	15 - Investments	-
		10 483 786.67
	TOTAL	**16 502 986.67**

Table D.3: Summary of GHG emissions from electricity activities

Appendix E

Hypotheses and parameters computations

E.1 Oil sector - assumptions on emission factors for transport

According to the NZE scenario, the energy mix for transport will evolve as followed

- In 2030 : 75 % of oil, 10 % of electricity, 10 % of biofuels, 2.5 % of hydrogen, 2.5 % of natural gas
- In 2050 : 10 % of oil, 50 % of electricity, 15 % of biofuels, 30 % of hydrogen, 5 % of natural gas

These distributions can be taken into account by computing, for each refined product **i**, a total emission factor (in $kgCO_2e/l$) defined as follows

$$EF_{i,2030} = 0.75 \cdot EF_{i,oil} + 0.10 \cdot EF_{i,elec} + 0.10 \cdot EF_{i,biof} + 0.025 \cdot EF_{i,hydro} + 0.025 \cdot EF_{i,NG}$$

$$EF_{i,2050} = 0.10 \cdot EF_{i,oil} + 0.50 \cdot EF_{i,elec} + 0.15 \cdot EF_{i,biof} + 0.30 \cdot EF_{i,hydro} + 0.05 \cdot EF_{i,NG}$$

By assuming that trucks of 40t are used and that the mean distance traveled is 400 km, emission factors (EF) are given in Table E.1

Type of vehicle	**Emission factor ($kgCO_2e/t$)**
Diesel truck	56.4
Electrical truck	23.2
CNG truck	31.92
Hydrogen truck	9.84
Biodiesel truck	32.92

Table E.1: Emission factors for transport [18][19]

All the emission factors of Table E.1 have been found in ADEME except the emission factor of hydrogen [86], which was given as 443 g/km for an 18 GVW truck. Therefore,

the hypothesis has been made that a 40t truck emits the same amount of CO_2e as an 18 GVW truck per ton. It has also been assumed that trucks fueled by natural gas were using Compressed natural gas (CNG) exclusively.

By applying the distribution described above for 2030 and 2050 and by converting the emission factors in $kgCO_2e/l$[1], one can obtain the emission factor for transport for each oil product (see Table E.2.)

Refined products	**Emission factors upstream (without transport) ($kgCO_2e/l$)**	**Emission factors transport 2030 ($kgCO_2e/l$)**	**Emission factors transport 2050 ($kgCO_2e/l$)**
Crude oil	0.06	0.044	0.024
Motor gasoline	0.10	0.036	0.018
Avgas, kerosene, jet fuel	0.12	0.039	0.019
LPG	0.04	0.026	0.013
Diesel fuel and heating oils	0.11	0.041	0.020
Fuel oils	0.08	0.044	0.022
Bitumen	0.02	0.068	0.033
Other products	0.00	0.026	0.013

Table E.2: Upstream emission factors for 2030 and 2050

E.2 Gas sector

A reduction in methane emissions between 2021 and 2030 has been applied to the midstream and downstream activities to account for leaks and vents (primarily resulting from pipeline transportation), as shown in Table E.3.

	Total methane leaks and vents/Total natural gas (%)
Transmission	0,4
Distribution	0,24

Table E.3: Methane leaks and vents in 2030

The emission factor for natural gas production includes the percentage of methane emissions. Taking into account the reduction of 75% in methane emissions, the emission factor is expected to decrease from 401 to 225.92 $kgCO_2e$/toe by 2030, see Table E.4.

	Emission factor (gCO_2e/MJ)	% CH_4
Extraction	6.8	-
Normal operation	3.9	99.3
Liquids unloading	0.2	99.3
Workovers	0.1	97.4
Gathering	2.6	99.3
Processing	4.1	18.6

Table E.4: Emission factor for 2021 [20]

[1]This conversion has been realized by using the conversion elements given in Appendix C.

It should be noted that since a significant reduction in methane emissions is already expected between 2021 and 2030, no further reduction is considered between 2030 and 2050. While it is difficult to predict the evolution of technology, it is also challenging, if not impossible, to completely eliminate all leaks and vents, which will inevitably remain present.

E.3 Decarbonized molecules

Table E.5 shows that the total demand for decarbonized molecules produced by the company in 2050 is 33 EJ. Since the company's production in 2050 is 50 Mt, we know that a weight of 1 is equal to 1.515 Mt. The demand has been calculated for each year based on the NZE scenario, except for biomethane where the production for 2025 and 2030 were already provided. Knowing that the production of biomethane is 2 TWh/year by 2025 and more than 5 TWh/year (the lower value has been chosen) by 2030, using conversion Table E.6, the quantity of biomethane produced could be calculated.

	2025	2030	2040	2050
Synthetic oil	0	0	2	5
Biomethane	-	-	5	8
Hydrogen	0	6	12	20
				33

Table E.5: Energy demand (EJ) [9]

	Conversion
Mass density (kg/m^3)	0.75
Energy density (kWh/m^3)	11.06

Table E.6: Biomethane conversion [21]

Appendix F

Exploring the "decarbonized" aspect

This dedicated section has been included to examine the decarbonized molecules, highlighting that they are not entirely decarbonized and must be considered in the overall carbon balance.

Biogas

Biogas is composed of methane (55-70%), carbon dioxide (30-45%) and small amounts of other gases such as hydrogen sulphide and ammonia [21]. The latter can be formed from anaerobic bacterial decomposition in the absence of oxygen. The composition of methane in biogas depends on several factors, including the means of production and the feedstock used. Indeed, biogas can be made with crop residues, animal manure, municipal or industrial organic waste and wastewater sludge. Once the biogas is produced, biomethane can be produced from the biogas through a process called upgrading which is a process that removes impurities such as CO_2 and other gases to obtain natural gas (also called "renewable natural gas") [99].

Regarding emissions, the combustion of biogas is considered carbon-neutral because the released CO_2 is the same CO_2 that was assimilated during photosynthesis by plants in the biomass. Biogas also helps to reduce methane emissions that would have been otherwise released into the atmosphere due to the decomposition of organic waste. However, there are still emissions associated with the biogas process, such as methane leakage (e.g., from open slurry tanks) and emissions from the transportation of feedstocks. The emissions will also depend on whether the biogas production process is powered by renewable energy or fossil fuels.

Biogas has many applications and can be used to generate electricity or heat in co-generation facilities (CHP), which can then be used in the industrial and residential sectors for cooking and heating purposes. If biogas is upgraded to produce biomethane, which is rich in methane, it can replace natural gas and be used as fuel for vehicles or to be distributed in gas networks.

Hydrogen

Blue hydrogen is a type of hydrogen produced from natural gas using either an SMR or Auto-thermal reforming (ATR) process combined with carbon capture. The primary

technology used for blue hydrogen production is SMR, which involves heating steam using an external burner fueled by natural gas to separate hydrogen from natural gas and create a mixture of hydrogen and carbon monoxide[1]. This carbon monoxide is then converted to carbon dioxide through a water-gas shift reaction[2]. While the ATR converts methane into hydrogen using both steam and oxygen (which is directly added to the reactor). Combustion takes place directly in the reactor, thus there is no additional heat source required. The main difference between SMR and ATR is that SMR uses oxygen via air for combustion to create steam (as a heat source) while ATR directly combusts oxygen [100].

Whether it is SMR or ATR, both processes generate the same level of carbon emissions. The difference is in the output. In SMR, since the combustion reaction takes place in a separate part of the process, there is carbon in both the flue gas (approximately 40%) where it is less concentrated and in the process gas stream (around 60%). On the other hand, in ATR, all the carbon is contained within the process gas stream with a higher concentration. Therefore, in terms of cost, capture is cheaper with ATR because it has higher capture rates and requires less installation, as all the carbon is in the process gas [101].

It is important to consider the emissions associated with producing, processing, and transporting natural gas, as well as the leaks and methane emissions that occur throughout the entire gas supply chain.

Green hydrogen is produced using the process of water electrolysis, utilizing energy from renewable sources such as solar, wind, or hydro. The emission factor for producing green hydrogen is therefore significantly lower compared to blue hydrogen.

Liquid e-fuels

To produce synthetic liquid fuel, the process mainly relies on the production of hydrogen using renewable electricity through the process of electrolysis, which separates water (from seawater) into hydrogen and oxygen, called green hydrogen. Additionally, carbon dioxide is captured from the air or industries such as power plants or cement factories. Before the process that produces the synthetic fuel, there is a reaction called the water-gas shift, which is accelerated using a catalyst to react hydrogen and CO_2 and produce hydrogen and CO as an output. Finally, the hydrogen and CO are combined through the Fischer-Tropsch process to produce synthetic liquid fuel.

The main advantage of producing synthetic liquid fuels is that they can be used in existing internal combustion engines without the need to replace existing transport infrastructure, such as cars, trucks, etc. This allows for a smoother transition since the technologies used in transportation remain unchanged.

However, the use of synthetic liquid fuels also presents several disadvantages. The production process is complex and demands a significant amount of energy. As a result, the price of synthetic fuels is much higher than conventional fuels (approximately 50%

[1]Syngas is a commonly used term for the mixture of carbon monoxide and hydrogen.

[2]Chemical reaction in which CO and water vapor react to produce CO_2 and H_2 in order to increase the yield of hydrogen.

higher). Furthermore, given the amount of renewable energy required to produce them, it would be impossible to meet global demand. Additionally, synthetic fuels have a very low energy efficiency compared to electric vehicles. While electric vehicles have losses of about 10% during charging and 20% due to the motor, resulting in an efficiency of approximately 70%, vehicles powered by e-fuels lose 48% of the electricity used in the production process and up to 70% of the energy is lost upon combustion, resulting in an efficiency of only about 15% [102].

Therefore, using e-fuels for cars would be completely unreasonable. E-fuels are produced mainly to be used in the aviation and shipping sectors as a replacement for current fuels. However, even for this type of use, it is highly debatable. A study has shown that to power half of the aviation sector with e-fuel in Europe by 2050, 24% of the electricity currently generated in Europe would be required. And since this electricity must be renewable, 8 billion hectares of PV and wind turbines would be needed to meet this demand [103].

Appendix G

Simulation of the carbon footprint from 2021 to 2050 - Detailed results per sector

G.1 Oil sector

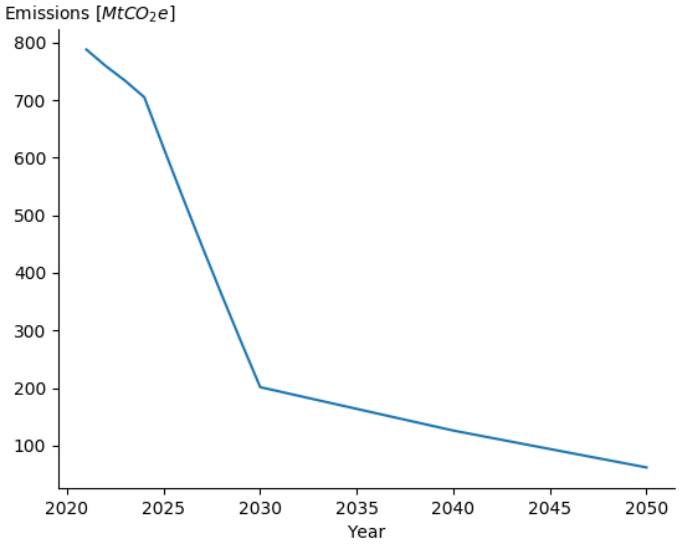


Figure G.1: Emissions generated by the oil sector from 2021 to 2050 ($MtCO_2e$)

G.2 Gas sector

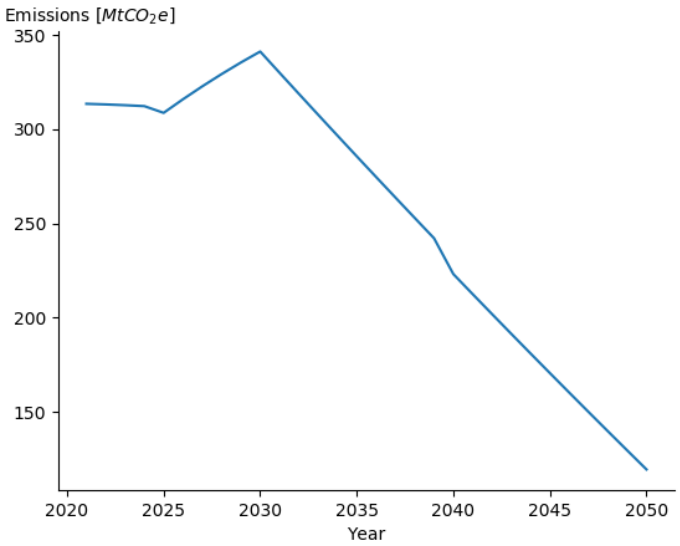


Figure G.2: Emissions generated by the gas sector from 2021 to 2050 ($MtCO_2e$)

G.3 Electricity sector

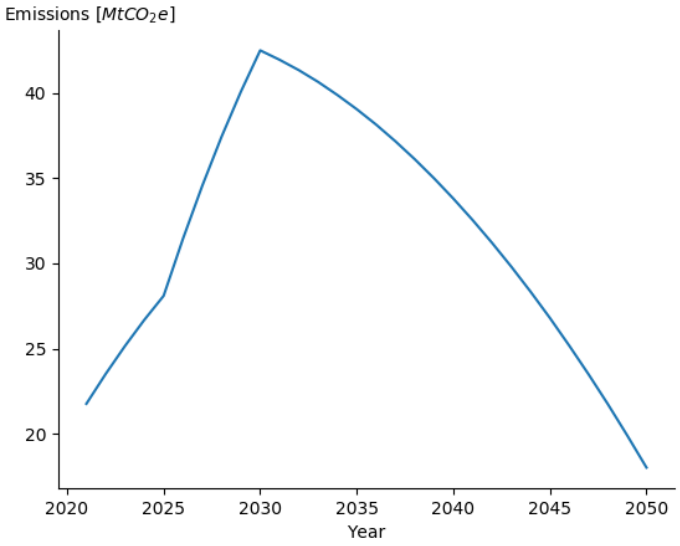


Figure G.3: Emissions generated by the electricity sector from 2021 to 2050 ($MtCO_2e$)

G.4 Decarbonized molecules

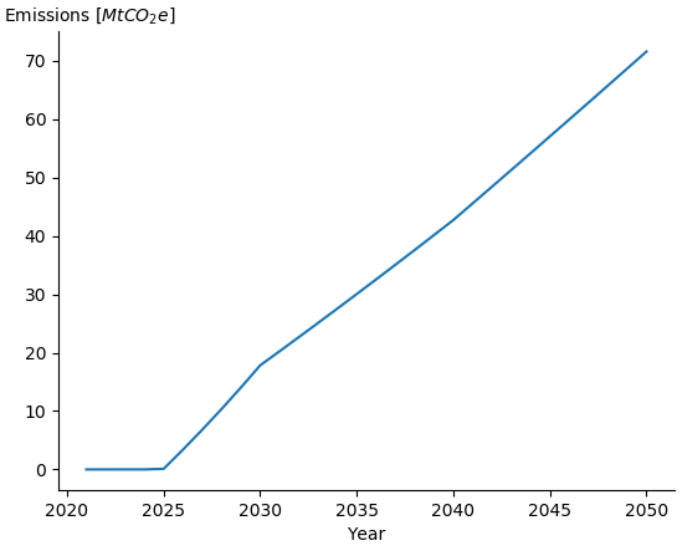


Figure G.4: Emissions generated by the decarbonized molecules from 2021 to 2050 ($MtCO_2e$)

Appendix H

Net zero scope 3

For oil and gas companies, scope 3 emissions constitute the majority of their total emissions. They account for approximately 75% or more of the overall emissions. In this case of the company considered, scope 3 emissions primarily consist of the GHG emissions generated from the combustion of oil and gas as fuel. What sets scope 3 apart from scopes 1 and 2 is that it encompasses indirect GHG emissions that are beyond the company's direct control.

To achieve NZE by 2050 within scope 3, the Wood's Mackenzie report identifies three emerging business models used by the oil and gas companies [13]:

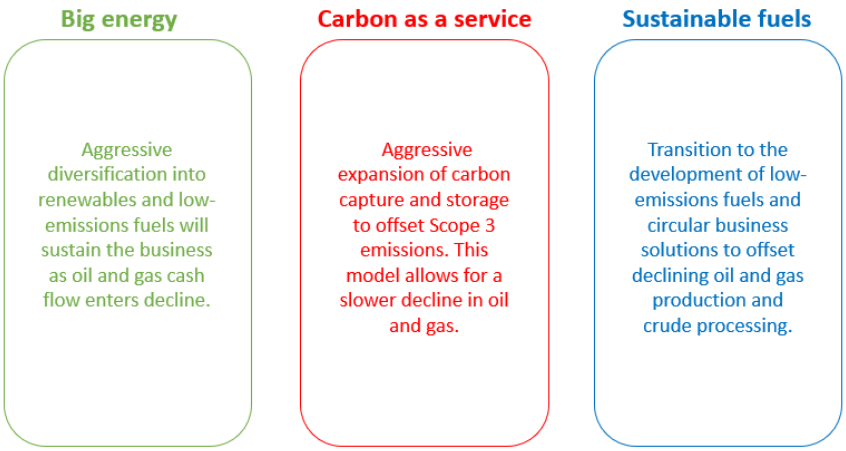


Figure H.1: Three main emerging strategies from the Wood's Mackenzie report [13]

Each model is interesting but may not necessarily be viable or properly implemented by companies. The first one, the "Big Energy" model, which involves transitioning towards an energy mix by heavily investing in renewable or low-carbon emission fuels while reducing fossil fuel production, can be a solution as demonstrated in chapter 5. The company analyzed partially applies this model by diversifying its sales (including more renewables, etc.) and focusing a part of its investments on renewable or decarbonized molecules. However, as shown in section 5.2, the company still invests a significant part in fossil fuels and does not significantly reduce its oil and gas production. For instance, recently, the company invest in an oil extraction mega-project in Uganda [5].

The second model, "Carbon as a Service," is also a promising initiative but requires a reduction in fossil fuel production. The goal of CCS is not to offset carbon emissions resulting from increased production but to offset existing emissions.

The last model, "Sustainable fuels", can be a transitional solution but may not be suitable for mass use or a complete replacement of traditional fuels, as they are not truly low-emission fuels. The company aims to venture into the production of "decarbonized molecules," but as shown in subsection 3.3.4, these molecules are not entirely decarbonized primarily due to energy-intensive processes.

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