TRANSITION-RISK AND OPPORTUNITY FOR CAPTURING AND STORING CO2

A qualitative assessment of transition risk and opportunity for CCS and BECCS in the EU, focussing on cases in the Netherlands and United Kingdom.

Master thesis

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Abbreviations

AER	Alco Energy Rotterdam
AtJ	Alcohol to Jet
BECCS	Bioenergy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Usage
CCUS	Carbon Capture Utilisation and Storage
CO_2	Carbon dioxide
CRC	Carbon Removal Certificates
CRD	Climate-related Disclosures
DACCS	Direct Air Carbon Capture and Storage
DOGF	Depleted Oil and Gas Fields
EBN	Energie Beheer Nederland
EC	European Commission
EU	European Union
ETS	Emissions Trading System
EU ETS	European Emission Trading System
FF55	Fit for 55
GHG	Greenhouse gas
HEFA	Hydro Processed Esters and Fatty-Acids
ILT	Inspectie Leefomgeving en Transport (Environment and Transport Inspection)
NEa	Nederlandse Emissie authoriteit – Dutch Emission Authority
PoR	Port of Rotterdam
RED	Renewable Energy Directive II (second version)
SA	Saline Aquifer
SAF	Sustainable Aviation Fuels
SSI	Semi-structured Interviews
TCFD	Taskforce for Climate-related Financial Disclosures
UCO	Used Cooking Oils
UK	United Kingdom
UK ETS	Unite Kingdom Emission Trading system
U.S.	United States

Abstract

For humanity to combat climate change, urgent decarbonization measures are required. The IPCC's AR6 report estimates with improved accuracy that a overshooting a limited carbon budget is likely if no urgent measures of emission reduction are taken. Fossil, as well as biogenic Carbon Capture and Storage technologies are deemed the most techno-economic and cost-efficient to ensure large-scale emissions reduction and even have potential for negative emissions. Adequate uptake of these technologies is lacking due to lack of risk assessment tools. The Taskforce for Climate-related Financial Disclosures made a framework for financial and non-financial companies describing 'transition risk' to provide a holistic understanding of all non-physical climate risks for the assessment of investment. Transition risk, as well as opportunity were researched in relation to CCS and BECCS to develop a supplemental assessment for the TCFD's framework (TCFD, 2017b). Literature research and expert interviews provided the foundation for this assessment, after which results were tested on case-studies concerning Drax, Porthos, Shell and Alco Energy. The final result describes a set of parameters specifically tailored to the technologies of CCS and BECCS focussed on investors and project developer in the EU. These parameter reflect that transition risk can be the cause of investments becoming stranded assets, but can also result in resilience against future transition risk. The EU ETS can stimulate the potential for a business case. This research adds to close the discrepancy of translating climate risk towards targets and metrics for companies and investors that consider CCS and BECCS.

1 Introduction

While climate-change is almost universally recognised as a global threat, action to combat it is not yet sufficient (IPCC, 2021). The Paris Accord of 2015 showed global understanding for climate change and stated that countries must abide to 2 degrees of global warming in comparison to 1990 to avoid irreversible effects from climate change (UNFCC, 2015). Later research lowered this ceiling to 1.5 degrees, implying that stricter emission reduction measures must be taken (IPPC, 2018). The IPCC's recent AR6 report shows with improved accuracy the different emission scenarios and inherent global warming. 1.5 degrees of 'safe' global warming can be interpreted through the 'carbon budget': the amount of carbon the world is allowed to emit while staying below 1.5 degrees of warming. The AR6 finds that with a 66% chance there can be 360 Gigatons of CO_2 emitted from 2021, a budget that is depleted in 2031 under current (2020) emission-rates. Climate reports have argued the role of potentially necessary 'negative emissions' in the scenario that the world will pass the carbon budget (Fuss et al., 2018). This implies a 'net-negative' effect of emissions that assumes overall 'Carbon Dioxide Removal' (CDR) from the atmosphere. Emission scenarios in the AR6-report expect a surpassing of the carbon budget and starting negative emissions from 2050 in order to return to safe levels of global warming.

The current pace of global warming exposes the world to increased climate risks. The TCFD divides climate risk in two categories: physical risk and transitional risk (TCFD, 2017). Physical risk stems from magnified climate-related events like tropical storms or increased periods drought. Transitional risk, as defined by the TCFD, is risk related to change of policy; technology; market and reputation as a result of climate change (TCFD, 2017). Physical risk is lacking publicly available methodologies and climate-data and hence is hard to assess (Bruin et al., 2019). Examples of transition risk include the taxing of carbon-intensive services like flights, or the increase in use of electric vehicles. It also accounts for emerging opportunities related to a low-carbon future, like subsidies for renewables or low-carbon technologies. Transition risk is useful to a fitting strategy for building resilience and understanding investment opportunity (Herbstein et al., 2019). Transition risk and opportunity will be defined in depth in the theory section, including examples related to this research.

Transition risk thus translates to direct financial consequences and applies to a wide set of actors in both the public and private sector. Financial risk with regard to climate change focusses on asset-exposure, integration of transition risks, potential future losses and ultimately stranded assets (Bouchet et al., 2020; Harnett, 2017). A fossil energy company could for example face possible tariffs for import of carbon-intensive resources, increasing costs. Decreased consumer demand for fossil energy may curb revenues, eventually having to cease operations resulting in pre-mature closing of a project. Transition risk is an essential element in informed investment decision-making and of correct market pricing of the risks and opportunities related to climate change for institutional investors (Andersson et al., 2016; Krueger et al., 2020). To mitigate this induced risk of climate-change to negative financial outcomes, the Financial Stability Board established the Task-force for Climate-related Financial Disclosures (TCFD) in 2015. Its mission is to "help identify the information needed by investors, lenders and insurance underwriters to appropriately assess and price climate-related risks and opportunities", and applies to financial (institutional investors) and non-financial companies (services and commodity companies) (TCFD, 2017 p. iii). It aims to do so by providing guidance for financial disclosures with regard to climate-risk, also known as climate-related financial disclosures (CRDs). The task-force has constructed a set of disclosure recommendations that have been adopted by a multitude of financial institutions and international bodies (Herbstein et al., 2019; European Commission, 2020). These recommendations can be used accordingly to the type of user and contain general recommendations. General recommendations are divided in governance, strategy, risk management and metrics and targets on climate-risk, accompanied by more specific financial disclosure recommendations that involve scenario building, risk management, GHG emissions (Scope 1-3) (TCFD, 2017). Scenario building involves the modelling of future business performance considering emissions, different climate scenarios. The enhanced reporting of GHGs are necessary to asses current internal performance, as well as in the future. CRDs are a necessary tool for providing more transparency on climate-risk, but also on possible opportunity because it generates shareholder engagement and investor trust (TCFD, 2017). These recommendations are the status quo in current climate-risk financial reporting frameworks and are considered to be invaluable and indispensable in future financial reporting (European Commission, 2020; Herbstein et al., 2019). Applying these recommendations are and will be very important to business in order to cope with climate change and create resilience. Some countries are pioneering in developing law for mandatory CRD such as France and the UK, topped by New-Zealand already putting a mandatory CRD system into work (Law, 2020; Beehive.Govt.Nz, 2020). As of now, 15 countries of the G20 have some sort of scheme related to CRDs, but differ widely in quality and content of information (Herbstein et al., 2019). Financial disclosures are generally known to be used as investment criteria (Roychowdhury et al., 2019) and although CRDs are still under development, they may already provide a useful angle towards investment in low-carbon technologies to reduce financial risk from climate risk.

The limited carbon budget in combination with current emission-rates, indicate an urgent need for investment in technologies to decarbonize the world's economy. Apart from renewables and decreased power consumption, emission reductions and CDR can be achieved through the capture of carbon (from atmosphere or point-sources like incineration plants), and include the planting of trees in previously unforested area (afforestation); the active capturing of CO_2 from the air with a mechanical system and subsequent storage (Direct Air Carbon Capture and Storage, or DACCS); advanced weathering (carbonization of rocks and salts); among other technologies (Strengers et al., 2018). When operational, these technologies can potentially generate ‘negative emissions’, hence the classification as Negative Emissions Technologies (NETs). However, uncertainty exists considering the development and the cost per sequestered unit of CO_2 of such technologies (Strengers et al., 2018). BECCS (Bio-Energy with Carbon Capture and Storage) is one of the carbon capture technologies that has most upside in technical potential and has a favourable energy requirement per sequestered unit of CO_2, compared to alternative technologies. Moreover, BECCS has potential to consume net-negative energy, meaning it will generate power (Ng et al., 2020). For carbon capture technologies to become economically viable, investment is needed which can be enabled through carbon taxes and subsidies (Fridahl & Lehtveer, 2018). Important to understand is that for negative emissions only biogenic CO_2 (CO_2 from non-fossil, biosphere sources) is considered, meaning that CO_2 sequestration from fossil sources is only net-neutral at best (Harris et al., 2018; Bioenergy, 2020).

BECCS has a prominent role in many emission scenarios (IPCC, 2021). In contrast to CO_2 from fossil fuels, biomass stores carbon dioxide from the atmosphere. In theory, when this biomass is converted into fuel, heat or electricity, the emitted carbon can be net-neutral. The carbon can subsequently be stored in saline aquifers and depleted gas and oil fields (CCS), creating a net-negative effect. CCS can also be applied with any other point-source of CO_2 emissions, making it suitable for energy and fuel production from fossil energy sources as well to achieve emission reductions, approaching emission net-neutrality. Alternatively, the carbon emitted from combustion can be used in products, for example: chemicals, biofuels, cement, food products and is called Carbon Capture and Usage (CCU) (Strengers et al., 2018). CO_2 can even be used for extraction of oil, called enhanced oil recovery (EOR), which applies CCS (Bui et al., 2018). Combining bioenergy with CCS generates a net-negative flow of carbon, although EOR does not necessarily fit that definition. BECCS projects are planned but are not yet operational. Drax in the UK is currently piloting coal firing with CCS, and will apply biomass firing in order to achieve BECCS (Drax, 2021). Another CCS projects include Porthos (Porthos, 2021) in the Netherlands, that will become operational in 2024.

Although fossil CCS and BECCS have prominent roles in combatting climate change, there are a variety of risks ingrained. General CCS is (lightly) exposed to CO_2-leakage from transport and storage infrastructure, creating potential hazardous situations for human health (Bui et al., 2018). A prominent risk to BECCS is the sourcing of feedstock: biomass often needs to be sourced from over-seas, decreasing its net-negative potential. Other risks (but also opportunities) related to CCS and BECCS are diverse and resemble transition risk and opportunity. Markusson et al. (2011) identify uncertainties to CCS that emphasize the need for safety, public acceptance, economic viability and policy and regulatory uncertainty. Reputational and legal risk are linked to the resistance BECCS due to use of biomass and land, availability of sustainable biomass and bad public perception (Bui et al., 2018; Fridahl et al., 2020). Public health concerns due to leakage, action of opposed non-governmental organizations (NGOs), danger of seismic activity, concerns of property value and perceived procedural unfairness were leading factors some case-studies for the termination of CCS project (Ilinova et al., 2018). The market and policy category are tied to the development and use of financial incentives from taxes, subsidies and emissions allowances (EEA, 2021a; Fridahl & Lehtveer, 2018). Technology risk and opportunity relates to development of other NETs and the increased cost-efficiency of DACCS and CCS technology: BECCS is considered one of the most cost-efficient technologically ready NET technologies (Ng, 2020). Further elaboration on related risks and opportunities can be found in the theory.

Europe is set to have 30 CCS, BECCS and CCU plants that will capture around 60 Mega tonnes[1] per year by 2030 (IOGP, 2019), but fitting risk-assessment methodology for CCS projects varies per case (Li et al., 2016). Currently, the International Organisation for Standardization (ISO) and the World Resource Initiative (WRI) have designed production and safety guidelines on CCS, but these only partially encompass the risk of aforementioned transition risks (World Resources Institute, 2020*; ISO,* 2020; Li et al., 2018). Besides lack of financial incentive and available information are other reasons for the current low uptake of BECCS and CCS projects (Hepburn et al., 2019).

The increased adoption of CRDs in combination with the development of NETs like BECCS and CCS are researched to a small extent and assessment methodology on risk is lacking. Additionally, CCS and BECCS technologies are not thoroughly described in TCFD literature, although the role of these technologies will be crucial to adhere to climate targets in the coming decades. By incorporating the parameters found in transition risk categories with existing CCS and BECCS projects, an assessment was made on transition risk and opportunity that is tuned to the disclosure recommendations of the TCFD, which are becoming increasingly mandatory in CRDs. Considering this, the following research question was composed:

'How can transition risk and opportunity be specified for CCS and BECCS in the EU?'

To answer this research question, the following sub-questions were assessed:

'Which parameters of transition risk and opportunity regarding CCS and BECCS in the EU can be identified for project developers and investors?'

As well as;

'How do these parameters inhibit or encourage project development and investment for CCS and BECCS?'

The spatial scope was defined as Europe but includes the U.K. for the sake of case-studies. The research focuses on cases of specific CCS and BECCS and includes the Porthos CCS project in the Netherlands

[1] This number demonstrates the capturable carbon from point-sources in the EU. This is does not represent full CCS and BECCS activity, but rather illustrates carbon capture potential.

with cases of Shell and Alco Energy Rotterdam, and the Drax BECCS project in the UK. The assessment includes current-day data and projections over 10 years. For some transition risk categories, no forecasted information is available, so the final product is a snap-shot representation of most relevant findings for transition risk and opportunity.

This research consisted of a qualitative multi-method approach applying literature research, expert interviews, and case-studies to answer the research questions. Providing more insight on stakeholder management, financial incentives, technological possibilities and local policy and regulation will support institutional investors and project developers to make well-informed decisions and increase successful deployment. The TCFD status report (Quarles, 2019) stresses the need for financial and non-financial companies to identify climate-risk and how to translate those risks into metrics and targets, but how exactly is not thoroughly elaborated. This is a discrepancy that demands additional research which this thesis aims to provide.

This research was conducted in combination with an internship with Platform Duurzame Biobrandstoffen (Platform Duurzame Biobrandstoffen, 2021) where research was conducted on the potential negative emissions from BECCS.

2 Theory

This section shall discuss the main concepts of this research, whereafter relevant research instruments shall be shortly discussed. An important distinction of the scope research is the omission of CCU technologies. CCU differs with CCS on the ultimate destination of CO_2. This is important when considering the permanency of storage and the possible incentivisation. CCU shall be considered a competitive technology in this research. Figure 1 presents the scope of technologies for this research within the dotted line.

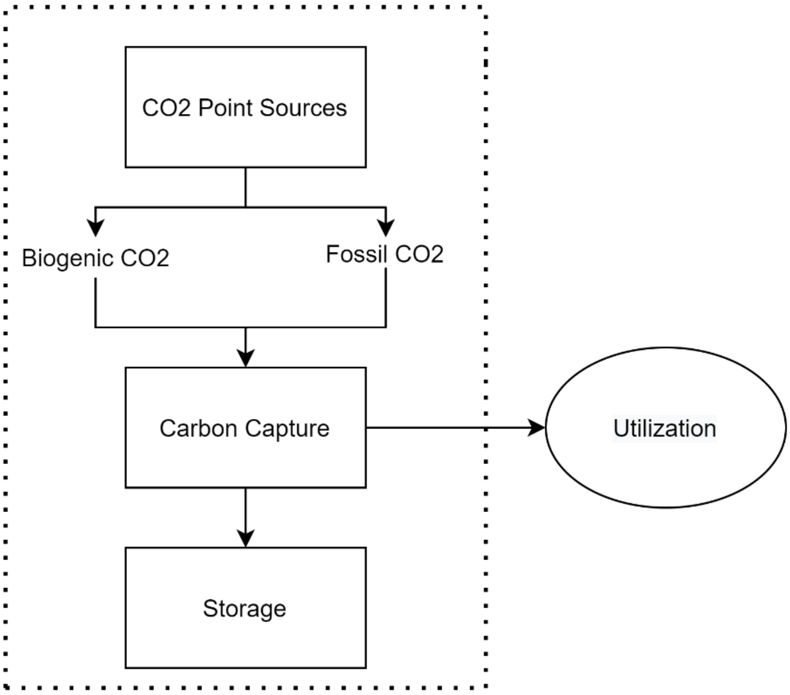


FIGURE 1: VISUALIZATION OF SCOPE OF TECHNOLOGY OF THIS RESEARCH.

2.1 CCS and BECCS

This research focusses on technologies Carbon Capture and Storage (CCS), classic Carbon Capture and Storage (CCS) from fossil fuels and bioenergy (BECCS). After a short introduction of the concepts of carbon cycles and negative emissions, the technical aspects of CCS and BECCS shall be discussed, as well as the potential role in emissions reductions, whereafter the known barriers will be displayed. Then, the current field of development of such projects shall be put in an overview, classified by capture of fossil emissions and biogenic emissions. Finally, the connection to Transition risk shall be emphasized regarding current day criteria. Figure 2 provides a conceptualization of the scope of the relevant technologies in context of emission reduction efforts and relevant industries.

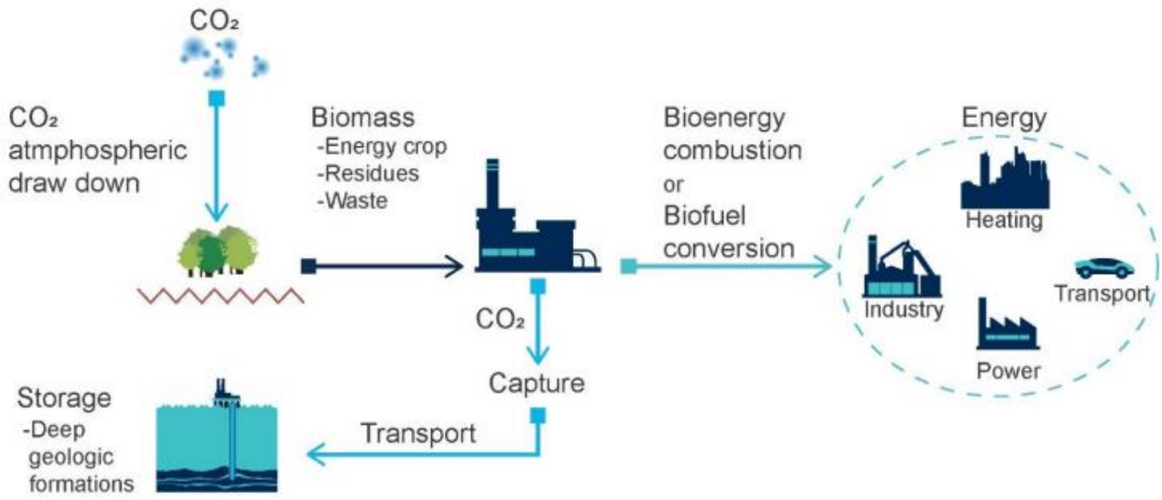


FIGURE 2: CONCEPTUALIZATION OF BECCS. RETRIEVED FROM THE GLOBAL CCS INSTITUTE (2019).

2.1.1 Carbon cycles

The term 'negative emissions' relies on the distinction between fossil and biogenic CO_2. Although both CO_2 molecules are the same, they differ in their cycles. Biogenic CO_2 relates to the short-term carbon cycle: the natural and cyclical process of organic matter production and natural (Shields, 2004). This cycle ranges between a few to 500 years (IEA Bioenergy, 2018). The long-term carbon cycle entails the formation of fossil fuels like oil and natural gas underground, which can take millions of years to

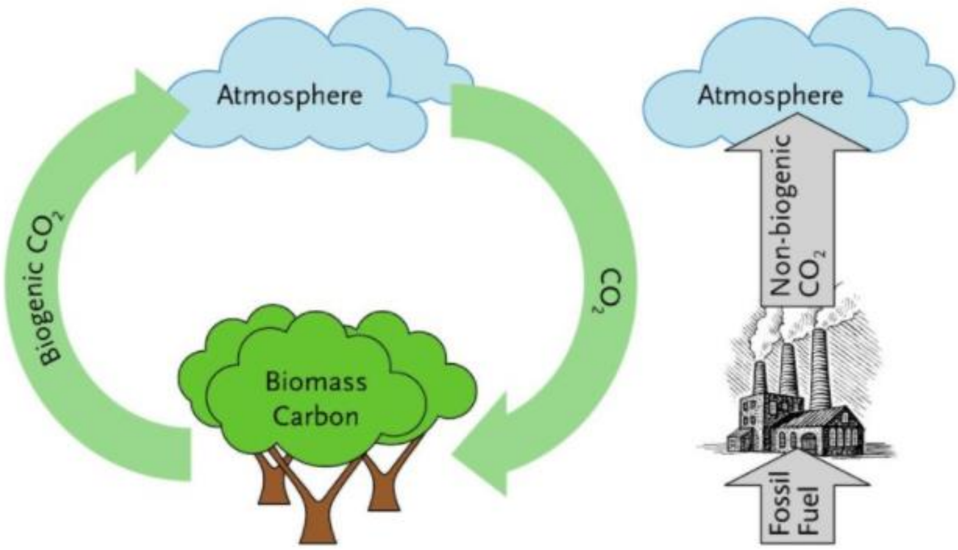


FIGURE 3: DEPICTION OF THE SHORT-TERM CARBON-CYCLE WITH BIOGENIC CO2. RETRIEVED FROM: (IEA BIOENERGY, 2018).

develop (Berner, 2003). The nature of carbon used as energy thus can have a direct effect on the total circulating amount of carbon in the atmosphere. Figure 3 visualizes the short carbon cycle and figure 4 the long-term carbon cycle.

CCS and BECCS technologies may have a large role in future emission reduction. As mentioned prior, in order to avoid catastrophic events of global warming, humanity is bound to a carbon budget (Rogelj et al., 2016). This carbon budget is likely to be depleted, meaning that achieving safe levels of global warming, eventually emissions will need to become net-negative if humanity wants to return to 1.5 degrees of warming in comparison to 1990. The concepts of negative and fossil carbon, as well as emissions from renewable energy are shown in figure 5. Grey represents carbon from fossil sources and green from biogenic sources. Blue represents renewable energy. The size of the arrows represents the relative size of flows of carbon. The lighter arrows represent biogenic CO_2 from the atmosphere. Fossil fuels emit directly to the biosphere that were supposed to be stored through the long carbon-cycle, making them complete positive emissions. When applying CCS to fossil energy production, close to all production emissions are captured and safely stored. Emissions are not entirely neutral due to possible leakage of CO_2 as well as the emissions from operations, but significantly reduce emissions overall in this process. Renewables like wind and PV are considered close to neutral. The electricity generated is CO_2-free, but also here operations and production require some form of fossil energy. In the fourth

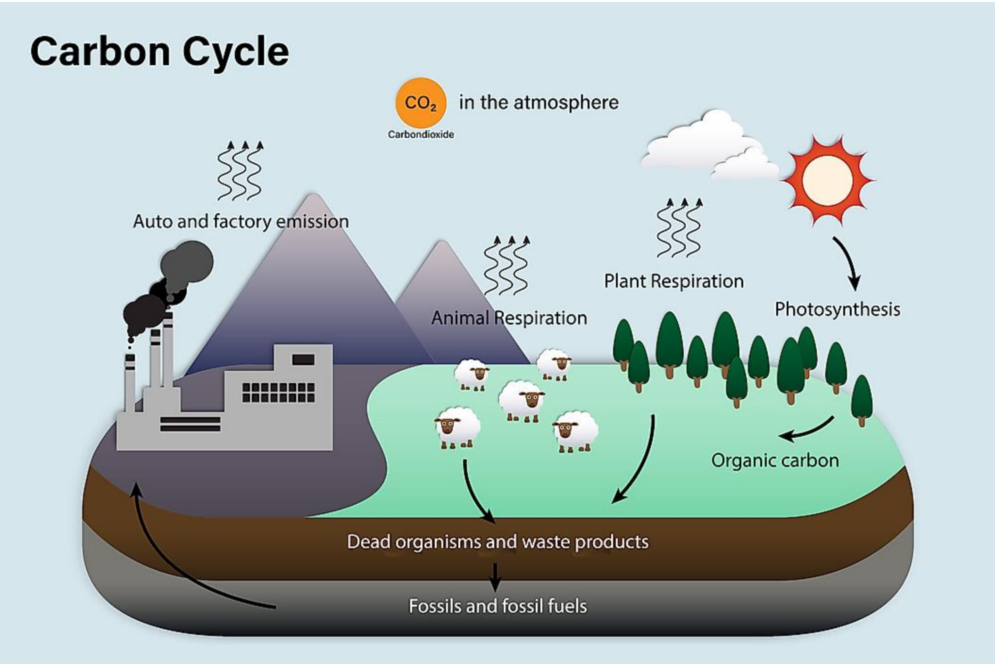


FIGURE 4: DEPICTION OF THE LONG-TERM CARBON CYCLE. RETRIEVED FROM: (WORLDATLAS, 2020).

case, bioenergy is displayed. CO_2 emitted from bioenergy originates from the biosphere itself, but overall emissions may be slightly positive due to the factors mentioned before. The final example displays BECCS. In theory, energy from biomass in combination with CCS can result in a net-negative stream of emissions, taking into account emissions from operations and production. It should be emphasized that bioenergy use assumes neutral emissions under the notion that all biomass used is regenerated. Overall, this means that biomass regenerates at least as fast as it is harvested. When critically considering the carbon budget for 1.5 degrees, this assumption on bioenergy will be realistic when attempting to adhere to the 1.5 degree warming scenario. Regarding the pace of current global emissions, the life cycle of biomass is too long to be considered net-neutral. Under today's emissions, the carbon budget will be depleted sooner than the time for overall regeneration of biomass. Therefore, the classification of biogenic emissions to be labelled net-neutral is considered false and not in line with emission targets. It should also be considered that over the whole production chain, emissions must be net-negative, including processing, transport, land-use and other life-cycle emissions, which implies extensive accounting of emissions (Bui et al., 2017).

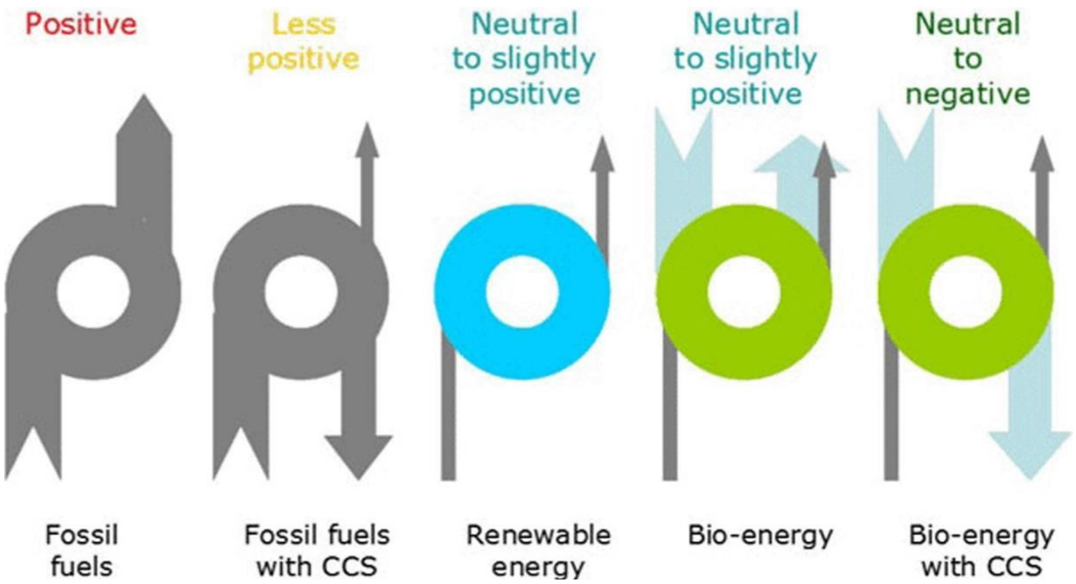


FIGURE 5: THE POTENTIAL NET-EFFECTS OF BIOGENIC AND FOSSIL CARBON IN COMBINATION WITH CCS TO THE ATMOSPHERE. RETRIEVED FROM BUI ET AL. (2017).

In order for negative emissions to be established, some concerns must be answered. Tanzer & Ramírez (2019) conducted a literary review on the definition of negative emissions and found four common aspects from mentions in 286 studies. The four common aspects entailed:

1. Physical greenhouse gases are removed from the **atmosphere**;
2. The removed gases are stored out of the atmosphere in a manner intended to be **permanent**;
3. **Upstream** and **downstream** greenhouse gas **emissions** associated with the removal and storage process, such as biomass origin, energy use, gas fate, and co-product fate, are comprehensively estimated and included in the emission balance;
4. The total quantity of atmospheric greenhouse gases removed and **permanently stored** is **greater** than the total quantity of greenhouse gases **emitted** to the atmosphere.

Regarding BECCS, the first point demands that biomass cultivation and consumption has a net-neutral carbon footprint over its lifetime. In addition, the carbon in this biomass must stay put in a designated location, other than the atmosphere. In this case, geological storage in places where fossil carbon was formed and captured provide this function.

The second point demands the permanency of storage emissions. This must be achieved avoiding any leakage in the full capture, transport, and storage chain.

The third point puts focus on life-cycle emissions from BECCS. From cultivation of biomass to the storage of CO_2, the net-effect of all captured and emitted carbon must be negative. This means that fossil emissions from operationality (Harvesting, transport, energy generation) are all taken into account for determining net-emissions.

The fourth point consolidates the need for an overall net-negative contribution of CO_2 to the atmosphere. This considers all scopes (1-3) of carbon emissions.

To account for carbon emissions, an elaborate calculation must be made that goes further than direct emissions from combustion of fuel at the end-user (Scope 1 emissions). Two scopes of emissions were added in the GHG protocol to take a more accurate picture of CO_2 emissions regarding up and downstream production factors. These scopes are defined in table 1. Hertwich & Wood (2018) emphasize the complexity of determining total emissions, since the sourcing and production of fuels and products can be a big part of a company's carbon footprint. The scope 3 emissions of a fuel producer like Shell can be considered a downstream user's scope 1 or 2 emissions. This highlights the problem of 'double accounting' and the importance of determination of direct and indirect emissions: If energy or fuel is generated in another country that is not included in the scope of emission calculations, these will be absent on the carbon balance, even though GHG-emissions are still emitted. The standards for carbon emissions related on a per unit of fuel production chain are found in detail in the European commission's Renewable Energy Directive annexes (European Union, 2018).

TABLE 1: DEFINITIONS OF CARBON EMISSION SCOPES 1-3. QUOTED FROM HERTWICH & WOOD (2018, P.2).

Scope	Description
1	''Direct emissions of an organization.''
2	''Emissions associated with the production of electricity and fuel, following the GHG protocol.''
3	''Emissions associated with the inputs other than electricity and those associated with the combustion of fuel (those accounted for in scope 1 and 2), and potentially also includes emissions associated with the use of sold products and commuting of employees.''

These scopes are relevant to the carbon emitted from production and use of products, but do not encompass the potential for negative emissions.

Rosa et al., (2021) researched the BECCS potential in Europe. Given the EU's aspirations to become carbon neutral in 2050, BECCS would have to sequester around 7.5 Giga tonnes of CO_2 up to that point. The amount of biogenic capturable carbon is however only 200 Mega tonnes of CO_2, which applies to only 5% of all GHG emissions. To achieve the necessary amount of biogenic CO_2 capture in Europe for these emission targets, Rosa et al. conclude that other Negative Emission Technologies must be implemented, or a vast amount of biomass needs to be imported.

2.1.2 Fossil and bioenergy

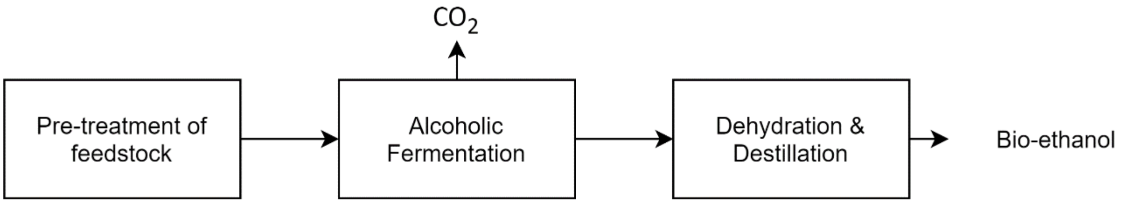
This part shall cover the technical aspects of biomass, its forms, uses and outputs. It will do so by discussing the chains that are used in this research, hence will not provide and exhaustive conceptualization of BECCS pathways. The same applies to fossil CCS: not all possibilities shall be discussed, only the ones used in the case-studies. This section will give an overview of different bioenergy and biofuel production fit for a basic understanding of the biomass concept of this research.

Harnessing around 450 Gt of carbon, plant material contains most of the organic carbon on earth. The chains and uses for biomass are often direct plant material, or derivatives of it. Plant material[2] is the most used as source of biomass for bioenergy and biofuels and is called lignocellulosic biomass. It contains hemicellulose, cellulose and lignin (Kaltschmitt, 2019). All kinds of wood fit this category and are also utilized as processed (waste) wood e.g., sawdust and wood scraps. Another form of biomass are herbaceous crops. These include cereal crops, pastures, oilseed crops, tubers and legumes, flowers and herbaceous biomass of gardens (Lago et al., 2018). Energy crops are crops that are solely grown to generate energy. They have high energetic content and are grown relatively fast. Among others, they include corn, switchgrass, sugar beet and sorghum. It should be emphasized that these crops can also often be consumed as food products, and are a potential threat to food security (Basu, 2018). A wide category of other types of biomass include animal excrements, sewage sludge and residual household waste. Used cooking oils are also a valuable source to function as a feedstock for biofuel production (Kaltschmitt, 2019). All biomass feedstocks have advantages and disadvantages. For some biomasses, cons are the overall availability, or the underdeveloped technologies to process. Food-crops for example are perceived negatively because they can also be consumed be people and they inflict land-use change. Lignocellulosic biomass is only limitedly available in Europe and competes with other practices for cultivation area (Rosa et al., 2021).

The production of *bioethanol* via the biochemical path relies on the process of anaerobic fermentation. In essence, sugar is converted to alcohol, or ethanol. Before glucose is derived, some feedstock processing steps are needed, which is more complex for 2nd generation bioethanol because. Complete fermentation of glucose results in close to 49% of mass output as a pure stream of gaseous CO_2 (Kaltschmitt, 2019), making it an efficient process, also because there are no extra outputs. First and

[2] An in-depth analysis of biomass is provided in appendix II.

second-generation bioethanol differ in feedstock and production process. A general representation of bioethanol production is displayed in figure 6. The challenge in feedstock pre-treatment lies in the



separation of sugar molecules from lignocellulosic materials. This demands different hydrolysis technologies, like enzymatic hydrolysis and the less developed acid-catalysed hydrolysis.

FIGURE 6: THE GENERAL PROCESS OF BIOCHEMICAL BIOETHANOL PRODUCTION.

First-generation bioethanol is the method that not only creates biofuels, but also alcoholic drinks. It produces ethanol from sugar and starch intensive crops like sugar cane and sugar beet. Starch containing crops like maize and wheat can also be used for this method. First generation Bioethanol is a mature technology (TRL[3] 9).

Second-generation Bioethanol is the lesser developed pathway to bioethanol and utilizes lignocellulosic material that converts cellulose to alcohol. Along with cellulose, lignin and hemicellulose are the main substances in lignocellulosic, often woody biomass. All cellulose containing biomass can be used for this process, including wastes like stems, leaves, and husks. Also non-food crops like switchgrass, wheat straw and cereals can be used (Dahman et al., 2019). The technology to efficiently isolate cellulose from these feedstocks is still in demonstration phase (TRL 6-7) (Kaltschmitt, 2019). Bioethanol can also be derived via a thermochemical path. By using pyrolysis (heating in absence of oxygen) and gasification (partial oxidation to form gas), a gas called ‘syngas’ is formed. Syngas is a mix of carbon monoxide and hydrogen. Bioethanol is then synthesized in a catalytic process , along with other types of alcohols (Robak & Balcerek, 2018).

The development of biofuels for aviation is entering an advanced stage. *Hydro-treated Ester and Fatty-acids*, or *HEFAs*, are fuels from waste oils like cooking oils from plants and animal fats. HEFA jet-fuels have less heavy CO_2 emissions and are more energy-efficient than conventional jet-fuels (SkyNRG, 2020). HEFA fuels are currently in TRL 8-9 (Kaltschmitt, 2019). *Alcohol to Jet (AtJ)* another example of a SAF. Here ethanol is converted through a chemical process of dehydration, oligomerization, and hydrogenation to become kerosene. Development is however still in demonstration phase (TRL 6) (Kaltschmitt, 2019).

[3] TRL, short for ‘Technology Readiness Level’ is explained in Appendix III.

Bioenergy from incineration can also be considered a way to capture biogenic carbon. This may either be achieved through direct firing of biomass or in combination with coal, called co-firing. *Co-firing* is a common way of power generation and has an advantage because biomass can be easily retrofitted into coal-fired power stations. Co-firing involves burning of woody biomass. A necessary pre-treatment is the conversion of wood to smaller 'wood pellets'. Co-firing is considered a transition technology that will reduce the carbon footprint from sole coal burning. When considering the firing of wood pellets, the supply of woody biomass is often issued (Kaltschmitt, 2019). For Europe, wood often must be imported from oversea. Incineration can be conducted on multiple biomass feedstocks, like manure from different animals.

Incineration plants are also large sources of biogenic carbon emissions. Larsen et al. (2013) found a ratio of around 50 to 70 percent of all household waste emissions from incineration to be biogenic. Waste from animal manures can also be used electricity generation with incineration, as well as residual waste and woods like stems, leaves and husks (Kaltschmitt, 2019). Waste incineration generates electricity from heat and subsequent steam production. The steam is led through a turbine to generate electricity. The residual heat from steam can be used for district heating (Clean Energy Wire, 2021).

Anaerobic digestion is the biochemical processing of organic matter to biogas. Bacteria anaerobically digest feedstocks like municipal solid waste, wastewater sludge, manures, and energy crops to create biogas, which consisting of methane and CO_2. Additional upgrading can provide pure methane. Biogas and methane are used for heating and power generation. Biogas and methane are commercialized technologies (TRL 9) (Kiran et al., 2016).

Biomass gasification can be performed with residual household wastes and lignocellulosic materials like wood pellets. The technology allows for syngas to be produced and subsequently hydrogen. Other applications are combined heat and power from these gasses. Syngas is formed, which is upgradable to pure hydrogen (Kaltschmitt, 2019).

Blue hydrogen is hydrogen produced from fossil energy with capture of carbon. The process involves electrolysis of H_2O, splitting the molecule in oxygen and hydrogen. This is an energy-intensive process, which makes the energy efficiency of hydrogen currently very low. By capturing the emissions from fossil electricity, the carbon footprint can be significantly reduced (Howarth & Jacobson, 2021).

Refinement and combustion of fossil fuel energy and fuels is the final category considered. Fossil fuels are produced from coal, oil, and natural gas. The fuels do often not differ much on a molecular level with biofuels, only that the carbon source is fossil. In a process called 'cracking', oil is refined to transport fuels like naphtha, kerosene's, diesels, and gasolines. Natural gas can be upgraded to liquified natural gas or compressed natural gas as transport fuels. Coal is incinerated for heat, steam and electricity purposes (Ritchie & Roser, 2020).

An overview of all considered paths to CCS are provided in table 2.

TABLE 2: CONDENSATION OF ALL CONSIDERED CSS AND BECCS PATHWAYS.

Pathways	**Conversion type**	**Feedstock**	**CO_2 origin**	**TRL**
1st generation bioethanol	Biochemical	Sugar and starch wielding crops	Biogenic	9
2nd generation bioethanol	Biochemical	Lignocellulosic biomass	Biogenic	6-7
2nd generation bioethanol	Thermochemical	Lignocellulosic biomass	Biogenic	4-6
HEFA	Thermochemical	Used cooking oils and fats from plants and animals.	Biogenic	8-9
AtJ	Thermochemical	Ethanol	Biogenic	6
Biomass firing	n.a.	Wood pellets	Biogenic	9
Biomass co-firing	n.a.	Coal and wood pellets	Fossil & biogenic	9
Incineration plants (Heat steam and electricity)	n.a.	Household waste, manure, lignocellulosic waste	Fossil & biogenic	9
Anaerobic digestion (Biogas and Biomethane)	Biochemical	Municipal solid waste, wastewater sludge, manures, energy crops	Biogenic	9
Biomass gasification (Syngas and Hydrogen)	Thermochemical	Wood pellets, waste material	Biogenic	9
Blue Hydrogen	Electrochemical	Fossil energy, water, Syngas	Fossil	9
Refining and combustion of fossil fuels	Thermochemical	Crude oil, coal, natural gas	Fossil	9

These technologies differ in TRL and feedstocks. These variables have impact on the likelihood of project development of bioenergy or fuel plants; a second generation bioethanol can be considered to have a favourable feedstock type that a first generation bioethanol plant, because energy crops can often be used as food. Technological readiness does not yet allow a second-generation bioethanol plant to run commercially, but may be more popular in the future compared to current biofuel plants.

2.1.3 CCS

The idea to sequester carbon from a point source was first proposed by Marchettie (1977), by means of funnelling CO_2 in an undercurrent ocean stream in the Mediterranean. CCS in this research applies to the geo-physical sequestration of CO_2 in saline aquifers (SAs) or depleted oil and gas fields (DOGFs). The process of capturing CO_2 can be divided in three methods: post-combustion capture, Pre-combustion capture and Oxy-fuel combustion with capture. The information on capture of CO_2 capture is from Bellona, a non-profit organization on sustainable environmental solution (*Capture of CO2 - Bellona.Org*, 2020).

Post-combustion

This is the most common way of capturing carbon and involves a stream of CO_2 originating from combustion in for example power and heat generation. The flue gas is led through a gas-scrubbing tank where a liquid (often amine) solvent absorbs CO_2. After separation of compounds by heating and cooling the mixture, the solvent is reused for the same purpose. This method of CO_2 capture requires high capital costs for machinery to the large amounts of flue gas that is processed, as well as operational costs for the high energy demand. Because this technology can relatively easy be retrofitted on powerplants, post-combustion is the most widely used carbon capture method.

Pre-combustion

This process removes the CO_2 before combustion takes place by converting fuel to CO and H_2 through a steam reformer. The CO and steam is then converted to H_2 and CO_2, of which the CO_2 can be captured with post-combustion technology. An advantage regarding post-combustion is that here the gas stream is smaller, thus less machinery is required for this method. The output H_2 can have further purpose in power and fuel generation. The pre-combustion technology is more complex than post-combustion, making retrofitting on existing plants harder than post-combustion capture technology.

Oxyfuel combustion

Regular combustion in a fossil-fuel power plant takes place with fuel and air. In this specific technology, pure or enriched oxygen is used to increase the CO_2 percentage in the flue gas in a boiler or gas turbine. This method requires an air-separation unit that removes nitrogen, increasing the O_2 content of air. The combustion of fuel produces power and CO_2. The CO_2 comes free with water vapour, which after dehydration and compression becomes a potential 100% pure stream.

Transport

Unless capture of CO_2 takes place on the storage location, sufficient transport techniques are required. Before CO_2 can be transported it needs to be dehydrated and compressed to a pressure of 73.9 bar or higher where it turns in its liquid phase. Transport options include pipeline transport, both on land and offshore, as well as ship transport. The gas must be clean of impurities, which can cause corrosive reactions to pipeline walls.

Storage

Storage of CO_2 takes place in saline aquifers or depleted oil and gas fields. Saline aquifers are geological formations of porous sedimentary rocks that house salt water. Oil and gas fields can be utilized for CO_2 storage, even when not depleted, in the form of EOR (Bui et al., 2018). The current state of storage technology is therefore mature and operational. Leakage of CO_2 from storage is the main concern for this technology. Safe storage can be achieved by the following factors (ZEP, 2021) :

- **Residual trapping**: Trapping CO_2 in tiny pores of the rocks where they cannot move.
- **Dissolution trapping:** A trapping method where CO_2 dissolves in the surrounding water
- **Mineral trapping**: On the long-term, the CO_2 dense solution may sink to the bottom of the reservoir where it reacts with minerals.

Leakage of CO_2 is considered an anomaly in current CCS, although it is a concern for people that may live in the vicinity of CCS projects. The IPCC modelled the retainment of CO_2 in such formations as *very likely*, or 99% effective over 100s of year, as well as over a timespan of 1000s. In fact, leakage risk is decreased in the long-term due to mineralization (IOGP, 2019). Both onshore and offshore storage is possible in these storage types. The potential for European underground storage is around 134Gt CO_2 (Terlouw et al., 2019). Comparing this to the European commission's '1.5 tech' scenario, a emission reduction scenario heavily relying on use of technological innovations, 298 Mt of CO_2 is captured by 2050 through geological storage, showing the potential for Europe to decrease emissions through CCS over time. An overview of potential pathways from CO_2 capture to storage is found is figure 7.

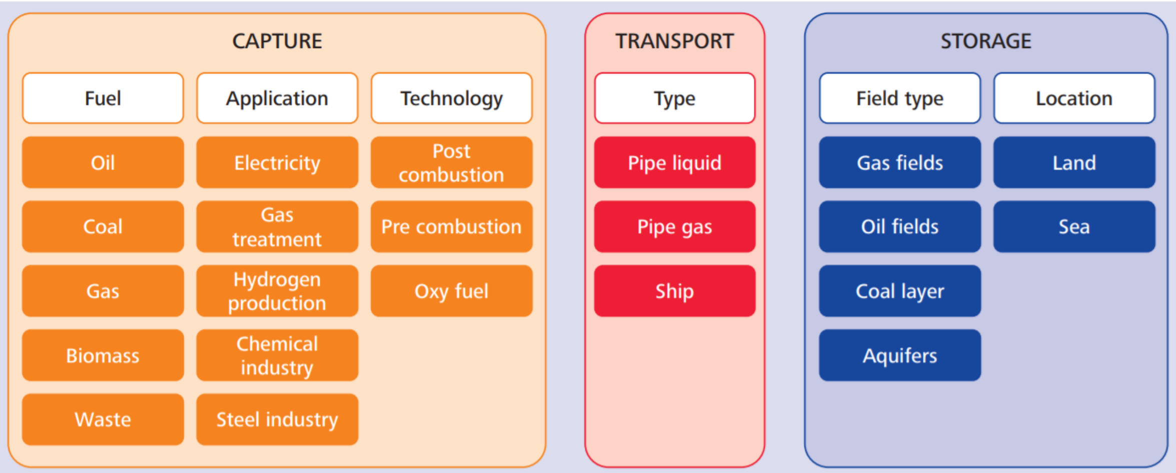


FIGURE 7: POTENTIAL CCS PATHWAYS. SOURCED FROM VAN EGMOND & HEKKERT (2012).

2.1.4 EU application of CCS and BECCS

Currently in 2021 Europe including Norway and the U.K. have a total of 44 CCUS projects operational, in development and planned (International Association of Oil & Gas Producers, 2021). These include all kinds of capture and storage facilities, including CCU, enhanced oil recovery and bioenergy with

CCS. All total CCS, CCU and BECCS are expected to sequester 60 Mt CO_2 per year in 2030 with the current level of operational CCS (International Association of Oil & Gas Producers, 2021). Aforementioned, this research will focus on the BECCS and CCS projects of Drax and Porthos. The technical specifics per project are condensed in table 3. Porthos and Drax shall have a significant share of CCS in the region.

TABLE 3: CONDENSATION OF CASE-STUDIES REPRESENTING THE EUROPEAN LEADERS IN CCS APPLICATION. RETRIEVED FROM: (INTERNATIONAL ASSOCIATION OF OIL & GAS PRODUCERS, 2021).

CCS project	**Description**	**Type of capture**	**CO_2 sequestration per annum**	**Operationality**	**Participants**
Porthos (NL)	Industrial capture from cluster of industrial companies. Storage in the North Sea. Developed by Gasunie, Port of Rotterdam and EBN.	Post-combustion	5 Mt	Final investment decision in 2022, operationality planned in 2024	Shell, Exxon, Air Liquide, Air Products.
Drax (UK)	CO_2 capture from biomass and natural gas combustion for energy. CCS Developed by Zero Carbon Humber.	Post-combustion	9,5 Mt	Under construction, operationality planned in the mid 2020's	Drax, Equinor, British Steel, Centrica Storage, Nationalgrid, Mitsubishi Power, Uniper

2.2 Transition risk and opportunity

2.2.1 TCFD framework

As mentioned, the TCFD composed a framework for financial and non-financial institutions that contains multiple recommendations for climate risk and their subsequent disclosures for internal and external reporting. Adhering to this framework will improve the uptake of CRDs and hence improve the company's resilience against climate risk. The framework's general recommendations are condensed in figure 8**.** This research focusses on the inherent transition risks and opportunities for CCS and BECCS, hence, it will focus on some distinct topics. *Identification of climate risk and opportunity*, as well as *management* and *impact assessment* of these risks are essential in answering the research question. In addition, there will be attention to the policy on disclosure of different scopes of emissions, which is closely related to transition risk. The TCFD framework is also used in this research to function as a reflection tool of how transition risk hinders the uptake of CCS and BECCS from a public perspective. This way, it can be used to assess problems around current policy and incentives for CCS and BECCS.

Recommendations and Supporting Recommended Disclosures

Governance	Strategy	Risk Management	Metrics and Targets
Disclose the organization's governance around climate-related risks and opportunities.	Disclose the actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning where such information is material.	Disclose how the organization identifies, assesses, and manages climate-related risks.	Disclose the metrics and targets used to assess and manage relevant climate-related risks and opportunities where such information is material.
Recommended Disclosures	**Recommended Disclosures**	**Recommended Disclosures**	**Recommended Disclosures**
a) Describe the board's oversight of climate-related risks and opportunities.	a) Describe the climate-related risks and opportunities the organization has identified over the short, medium, and long term.	a) Describe the organization's processes for identifying and assessing climate-related risks.	a) Disclose the metrics used by the organization to assess climate-related risks and opportunities in line with its strategy and risk management process.
b) Describe management's role in assessing and managing climate-related risks and opportunities.	b) Describe the impact of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning.	b) Describe the organization's processes for managing climate-related risks.	b) Disclose Scope 1, Scope 2, and, if appropriate, Scope 3 greenhouse gas (GHG) emissions, and the related risks.
	c) Describe the resilience of the organization's strategy, taking into consideration different climate-related scenarios, including a 2°C or lower scenario.	c) Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organization's overall risk management.	c) Describe the targets used by the organization to manage climate-related risks and opportunities and performance against targets.

FIGURE 8: THE CONDENSED TCFD FRAMEWORK WITH RECOMMENDED DISCLOSURES. RETRIEVED FROM: (TCFD, 2017B).

Uncertainty is an important characteristic of transition risk, particularly when considering the trajectory of future emissions. As mentioned before, transition risk in combination with physical risk are the two categories of climate risk. Transition risk has an inverse relationship with physical climate risk: the more we exert pressure on transitioning to a low-carbon economy, the more physical climate risk will be mitigated. Vice versa, under a business-as-usual scenario, meaning no more decarbonization than applied today, the transition risk of mandatory innovation and regulatory restrictions to carbon emissions are decreased. Physical climate risk will then increase due to a lack of mitigation efforts, as is illustrated in figure 9 (TCFD, 2017b). The degrees at the end of both axes represent the projected inherent increase in temperature compared to 1990: 6 degrees will imply highly increased physical climate risk; 1.5-2.0 degrees warming substantially lower physical climate risk.

FIGURE 9: THE TRADE-OFF WITHIN CLIMATE RISK AND SUBSEQUENT GLOBAL WARMING SCENARIOS. RETRIEVED FROM: (TCFD, 2017A).

2.2.2 Transition risk

Transition risk, as used by the TCFD, is all risks inherent to a future low-carbon economy. As mentioned before, the TCFD structures these risks in the categories of Market, Policy, Legal, Technology and Reputation risk, but other research describes transition risk in a less diverse way. In general, transition risk concerns the pace of technological change and the sudden introduction of climate policies (Monasterolo et al., 2018). Thomae et al. (2016) point out that transition risk finds its origin in the term carbon risk or carbon asset risk, which describe the financial risk associated to a low-carbon economy. In essence, this revolves around the accuracy of asset and security pricing regarding proper risk-assessment and of e.g., carbon pricing policies and mandates. This pricing also involves the calculations for potential 'tail risk'. Tail risk is assigned to phenomena with very low probability but with large impactful outcomes (Krueger et al., 2020). Within transition risk, these may be expressed as severe mandates on carbon emission reporting or higher carbon prices. A consequence of this risk is for assets to become 'stranded' (Thomae et al., 2016). Stranded assets can be defined as ''an asset that lost its value prematurely in its economic cycle due to changes in legislation, regulation, market forces, disruptive innovation, societal norms or environmental shocks'' (Caldecott, 2016, p. 2). A simple example of a stranded asset due to transition risk is a hypothetical power station running on coal becoming unprofitable due to governmental mandates on renewable energy. Stranded assets are deemed the most extreme outcome to transition risk (Monasterolo, 2020). Transition risk is also associated to the pricing of bonds. Battiston et al. (2017) show that carbon risk may influence credit markets, eventually translating to higher interest for financial contracts like loans, which may in turn affect financial performance of companies and households.

The TCFD's conceptualization of transition risk can be described as the following:

Policy risk is described as ''the risk associated with the implementation of carbon-pricing mechanism to reduce GHG emissions'' (TCFD, 2017, p. iii). The European Emissions Trading System, or EU ETS is one of such mechanisms. The EU ETS is designed to gradually reduce emissions. It does so by setting a cap on total emissions to all assigned industries, which will over-time be reduced to zero. Within this cap, companies are able to buy and sell emission 'allowances' to account for emissions, or sell 'avoided' emissions (European Commission, 2020). It can therefore pose a risk but also an opportunity depending on the net-emissions. Carbon taxes are also popular carbon pricing mechanisms to reduce emissions. Carbon taxes set a fixed price on the per unit emitted CO_2. The EU ETS, Carbon tax and other carbon pricing mechanisms shall be assessed in detail later.

Market risks, as defined by the TCFD (2017, p.6) are ''ways which markets can be affected by climate change: shifts in supply and demand for certain commodities, products, services about climate-risk''. It can hypothetically be the reduction in demand for red meat due to a change in consumer preference or an import tariff. This risk can thus be indirectly linked to other transition risks like policy risk. The TCFD identifies that the increased prices for certain resources, as well as increased costs of energy are main drivers of market risk. This has effect on transport methods, considering prices for oil (in maritime shipping) and electricity or coal (train transport). In literature, market risk is described as the risk of sudden price-changes in commodities and is also known as systematic risk, emphasizing that it affects all players in a market (Grout & Zalewska, 2006). The TCFD describes this risk as complex and is determined by many factors, and may potentially changing entire value chains (TCFD, 2017b).

Technology risk is described by the TCFD as sudden technological developments in energy-efficient and low-carbon economic systems. For a hypothetical fossil energy company this would include the rise of renewable energy, battery storage and CCS (TCFD, 2017). This category is concerned with the loss of value from investments through early write-offs (eventual stranded assets) and costs afflicted to transitioning to lower-emission technologies. A competition aspect is central here, given the risk of potential superior substitutes through technological innovation. Examples may be the development of more energy-efficient electrolysers for hydrogen production, leaving old infrastructure stranded.

Substitutes revolve around energy-efficient alternatives for BECCS and CCS like renewables and other NETs.

Legal risk applies to the risk of legal claims from property owners, municipalities states, insurers, shareholders, and public interest organizations'' (TCFD, 2017, p.5). These claims are often the result of poor climate-risk assessment and mitigation, and lead to increased costs due to fines and judgments. A prime example is Shell's past operations in Nigeria. The winning of oil resulted in immense environmental catastrophes due to poor management of the oil fields, resulting in vast destruction of arable land. Shell has recently been plead guilty by the Nigerian court and now has to compensate Nigerian farmers for 111 million dollars (BBC, 2021). A fairly new manifestation of legal risk can be found in multinationals facing pressure from within the company. Shareholder collective 'Follow this' assert pressure on fossil energy producers like Equinor and Shell by demanding organizational change through the power of shares (Follow This, 2021). Legal risk affects mainly project developers and requires proper stakeholder management and overall risk assessment to be avoided (TCFD, 2017b).

Reputational risk is described by the TCFD as risk of changing customer or community perceptions of the company in question regarding its contribution to or detraction from the transition to a lower-carbon economy'' (TCFD, 2017, p.6). Reputation is in this context focussed on the perception of a company. Rayner (2004) defines this perception to be not only from customers, but all stakeholders the company is dealing with: suppliers, business partners, employees and also government. Although not very well quantifiable, reputation can be assessed through public opinion assessment. A characteristic identified by Rayner is the fragility of a 'good' reputation. It takes time and trust to gain a positive reputation, whereas it can be diminished in a short time. This is explained by the many liabilities to a reputation: the opinion of all aforementioned stakeholders and the potential negative voices to be heard. Rayner (2004) identifies that a positive reputation changes the attitude of all stakeholders of the company. For example, shareholders may hold shares longer, suppliers are more likely to partner up and potential recruits are more willing to join a company. Proper assessment and management of stakeholders has shown to be vital in the past for CCS and BECCS in order to create public acceptance (Terwel et al., 2012).

2.2.3 Transition opportunity

In addition to transition risk, the TCFD also refers to climate opportunities. These opportunities can be considered the opposite of transition risk in many cases and will later be merged with the transition risk categories in the method section for the sake of simplicity. The classification of categories for opportunity shall therefore be discussed briefly. Transition opportunities according to the TCFD can be classified in the following categories: resource efficiency, energy sources, products and services, markets and resilience (TCFD, 2017b).

Opportunities in *Resource efficiency* imply the reduction of operating costs across the production chain by increasing energy efficiency and smarter use of materials, water, and waste management. Technological innovations also aid in this process, e.g., retrofitting buildings or employing geo-thermal heating. Resource efficiency is of great importance considering the achievement of climate goals (Cherry et al., 2018). Resource efficiency can be applied in three types of strategies. Product sharing, which aims to improve asset utilization. Second is the product lifetime, which focusses the increase of product longevity. Finally, efficient products, that are characterized by efficient design and modularity. Durability and recyclability are essential in aspects of these products (Cherry et al., 2018). Resource efficiency is also closely related to the principle of 'circular economy'. This principle is based on circularity of value chains with the end-goal of 'closing the loop', implying that all inputs on products used in products and services are from renewable sources and the recyclability of output waste (EMF, 2017). In the context of circularity, CCS and BECCS can be seen as temporary options given the finite amount of storage space of CO_2. The development of resource efficiency and an eventual complete circular economy strongly depends on the development of renewable energy. The environmental benefits to resource efficiency are considered to bring economic benefits as well, like increased production capacity, better workforce management and increased value of fixed assets (through energy-efficient buildings), making it a double-edged sword (TCFD, 2017b).

The *Energy source* opportunities apply to the fast development of cost-efficient renewable sources of energy like wind and solar. The increased investments made in these technologies in combination with the technological development are promising for significant emission -and cost reduction. This also brings reduced operational costs, reduced exposure to fossil fuel price increases, more investor capital, and reputational benefits. Not even mentioning the endless supply of renewable energy, this resource is essential for the transformation away from fossil energy. Cost-reduction from 2010 to 2019 has been 82% for Photovoltaics (PV), 47% for Solar power, and 29-39% for wind energy (IRENA, 2020), showing promising technological development. The switch to a cleaner source of energy is essential for the overall carbon footprint of CCS, given its high energy consumption. Due to the uncertain flow of electricity from renewables, energy storage and a fitting energy-grid network are necessary to supply renewable energy to places it is needed (Hunter et al., 2021).

The category *Products and services* revolves around the development of new low-emission technologies, products and services that may improve competitive position. Customer preference towards products with a lower carbon footprint is a driver of this transition opportunity, resulting in higher revenues. Other opportunities around services revolve around climate adaptation and the development of insurance opportunities. Understanding transition risk is essential in climate adaptation and the calculations of risk premiums. A better transition risk understanding could increase dealing with inherent policy risk in the future and thus a more accurate risk-premium assessment (TCFD, 2017b).

Markets revolves around investments in markets for low-emission technologies and products, often in partnership with governments, institutional investors, and small-scale entrepreneurs. This results in more diverse, transition-adapted investment portfolios that improve an investor's positioning in a low-carbon economy. Underwriting of loans and the financing of green bonds are also considered market opportunity, given a positive projection of the technologies they intend to support: wind energy is projected to grow its share in the global energy mix (International Energy Agency, 2020).

A by-product of adapting to transition risk is the gain of *Resilience.* This translates to the ability to outperform competition towards risk and opportunity around climate risk. This is particularly relevant to companies with long-lived fixed assets and large supply chains, as well as projects that need long-term financing (TCFD, 2017b). The complete section of the TCFDs transition risks and opportunities, as well as their financial impacts can be found in appendix I.

It is acknowledged that here is overlap in the TCFD's qualification of transition risk and opportunities (TCFD, 2017b). Different transition risks and opportunities result in same outcomes, often in the end related to profitability and losses. The EU ETS for example may be a policy risk for fossil energy focused companies but is seen as an incentive from producers of renewables and biofuels. In addition, gain of public acceptance is linked to increased demand and therefore revenue, as well as the opposite, making it both risks and opportunities.

2.3 Carbon pricing mechanisms

In order to reduce emissions from industries, governments implement carbon pricing mechanisms. Carbon pricing attempts to capture the external costs of emissions, also called the 'cost of carbon'. This relates to a wide set of phenomena incurred by the increased emission of GHGs. These effects are commonly paid for by the public with taxes. Apart from ecological damage to ecosystems, the cost of carbon also entails damage to agriculture, human health and effects from physical climate risks like flooding and heat waves (The World Bank, 2021). Carbon prices are set based on climate targets like the Paris agreement, but are often not sufficient to achieve the desired effect (Klenert et al., 2018). Carbon pricing results in higher prices for products and services that are carbon-intensive, and stimulates the use of low-carbon alternatives, Carbon pricing mechanisms have different facets and can stretch from a regional, to an international system. The US state of California has an 'Emission Trading System', as well as the European union (Center for Climate and Energy Solutions, 2017; EEA, 2021a). carbon pricing mechanisms vary in being mandatory or voluntary, as well as the application to industries and the extent of application. A necessary distinction should be made on the biogenic and fossil nature of CO_2, regarding potential incentives. Currently, EU ETS does not reward biogenic emissions: these are considered net-neutral. This also omits the incentivisation for sequestration of these emissions, which in theory have larger emission reduction potential.

Carbon pricing encompasses the following mechanisms (The World Bank, 2021):

Carbon tax: Taxation of carbon means setting a fixed price for emitting a unit of carbon, often per ton. This can be based on a tax rate on GHG emissions but also on the carbon content of fossil fuels. Here, no pre-determined cap on emissions is set, but rather a price per quantity of emissions. The emissions cap is thus not under control via this system, but the price of emitting is.

Carbon Offsetting: Compensating for CO_2 emissions by funding carbon-emission reduction projects elsewhere. These projects can vary from funds for renewable energy-projects to the planting of trees. Carbon Offsetting in administered by the organization that realizes and organizes these projects. These Carbon Offsetting credits can be bought from anywhere over the world, making them fit for hard-to-abate industries like aviation.

Result-based Climate Finance: Funding that is provided after a set target of emissions reduction or renewable energy production is achieved.

Internal carbon pricing: Tools for businesses that are used to drive decision-making towards low-carbon results. These tools are also used to identify climate risk and opportunities. An *internal carbon fee* is an example of internal carbon pricing: assigning a cost to the emission of carbon in existing projects that creates a fund for future low-carbon investments. Another tool is a carbon shadow price, where a figurative cost of carbon is assigned to investments to assess future projects on the projected emissions. This is a tool used for future planning and decision-making (Center for Climate and Energy Solutions, 2019).

Emissions Trading Systems: Participants in an ETS are trading emissions units, or often called allowances, in order to achieve emission targets or for profits. These targets can be achieved via reducing emissions via internal abatement or buy emission allowances. Two types of ETS systems are:

- Cap-and-trade systems: A pre-determined cap on emissions is set annually for all industries within the scope of the system. This cap is divided in a finite set of 'allowances', that are priced based on supply and demand. The cap is reduced every year to push emitters gradually towards emission reduction practices or buying increasingly expensive allowances. Allowances are given away for free by the monitoring institution or auctioned.
- Baseline-and-credit systems: pre-defined baseline emissions per entity are set by the monitoring institution. When exceeding this baseline, credits must be bought from entities that have reduced emissions compared to the baseline.

In these systems the overall cap on emissions is set, but the price of carbon allowances is determined by supply and demand.

2.3.1 EU ETS

The EU ETS is the main carbon pricing mechanism in the EU. It is a cap-and-trade system that has been implemented in 2005. All 27 EU member states plus Norway, Iceland and Liechtenstein are partaking in the programme. It currently cover around 43% of all EU emissions (EEA, 2021a). Its allowances are auctioned but also distributed for free by the EC. Current industries under the EU ETS are heat and electricity generation, oil refineries, steel works, aluminium, metals, cement, lime glass ceramics, pulp and paper, cardboard, acids, and bulk organic chemicals. In addition to CO_2, it also covers emissions of methane, N_2O and perfluorocarbons (EEA, 2021a). Companies will only fall under ETS when producing above a certain threshold, hence smaller emitters are relieved. One EU ETS allowances is equal to one ton of emitted or avoided $CO_{2.}$

The recently implemented 'fit for 55' (FF55) plan by the European Commission aims to use the EU ETS as the central tool to adhere to the most recent emission reduction targets (European Commission, 2021a). The newest plan includes maritime transport in the ETS. A separate ETS will be created for the use of fuels in road transport and buildings, and will apply more to upstream suppliers than households and car users (European Commission, 2021b). To include emissions from aviation outside the border of Europe, the European Commission (EC) is working with the other organizations to combine offsetting mechanisms into the ETS in the future (International Carbon Parnetship, 2021).

The current phase implemented a linear emission reduction of 2.2% per year until 2030, but due to recent developments in legislation from the FF55 plan, this percentage will be doubled from 2023 to accelerate the decarbonization of the EU. Over the cap of 1.6 billion in 2021 this would imply a decrease of around 67 million allowances. When not complying to the assigned cap of emissions, companies are fined for 100 euros per ton of CO_2 (European Court of Auditors, 2020). This amount is hard to determine for the governing party, but historical fines constituted up to hundreds of thousands of euros (Burges Salmon, 2019).

CCS was included in the EU ETS in 2013. For every ton CO_2 sequestered, an allowance can be sold. ETS are not provided for CCU and biofuels. A distinction between biogenic and fossil CO_2 is therefore not yet acknowledged considering potential EU allowances (EEA, 2021b).

2.3.2 Carbon pricing in Case-countries

The Netherlands participates in EU ETS, whereas the UK currently has its own 'UK ETS' system since its departure from the European Union.

The Netherlands have recently implemented a carbon tax of 30.48 euros in 2021, which will increase annually with 10.73 euros up to 127 euros per ton CO_2 in 2030. As in Sweden, industries that are under ETS pay this carbon tax to a smaller extent: companies pay the tax with deduction of one ETS allowance (which is determined every year before based on the December future price). This mechanic will pressure smaller industries to decarbonize and also further pressure ETS- relevant companies in case the tax gets higher than the EU allowance price (Nederlandse Emissieathoriteit, 2021).

The United Kingdom operates its own emissions trading system since May 19th, 2021. It has an emissions cap of 5%. It covers 33% of all UK emissions. It applies to similar industries as the EU ETS and allowances are set at a minimum of 25,57 euros per ton of CO_2. Currently the UK ETS price proceeded the EU ETS and was first to reach 50 euros per ton of CO_2. The UK also applies a carbon tax called the 'carbon price support'. It sets a fixed minimum floor price for carbon of 21.07 euros per emitted ton of carbon and applies to almost all power sectors until 2024. It aims to support renewable energy projects with a fixed revenue, due to fluctuating ETS prices (The World Bank, 2021; UK GOV, 2021).

2.4 Climate-target legislation in the EU

To calculate the efforts that are made with regard to emission reduction and the setting of climate-goals, carbon accounting rules are very relevant when interpreting the emission reduction targets and how the European Emission Trading System (EU ETS) is applied.

2.4.1 EU Green new deal

On December 11th, 2019, the EC presented the European Green Deal: Europe's most recent plan to reduce emissions and become a resource-efficient and economically competitive entity. The plan

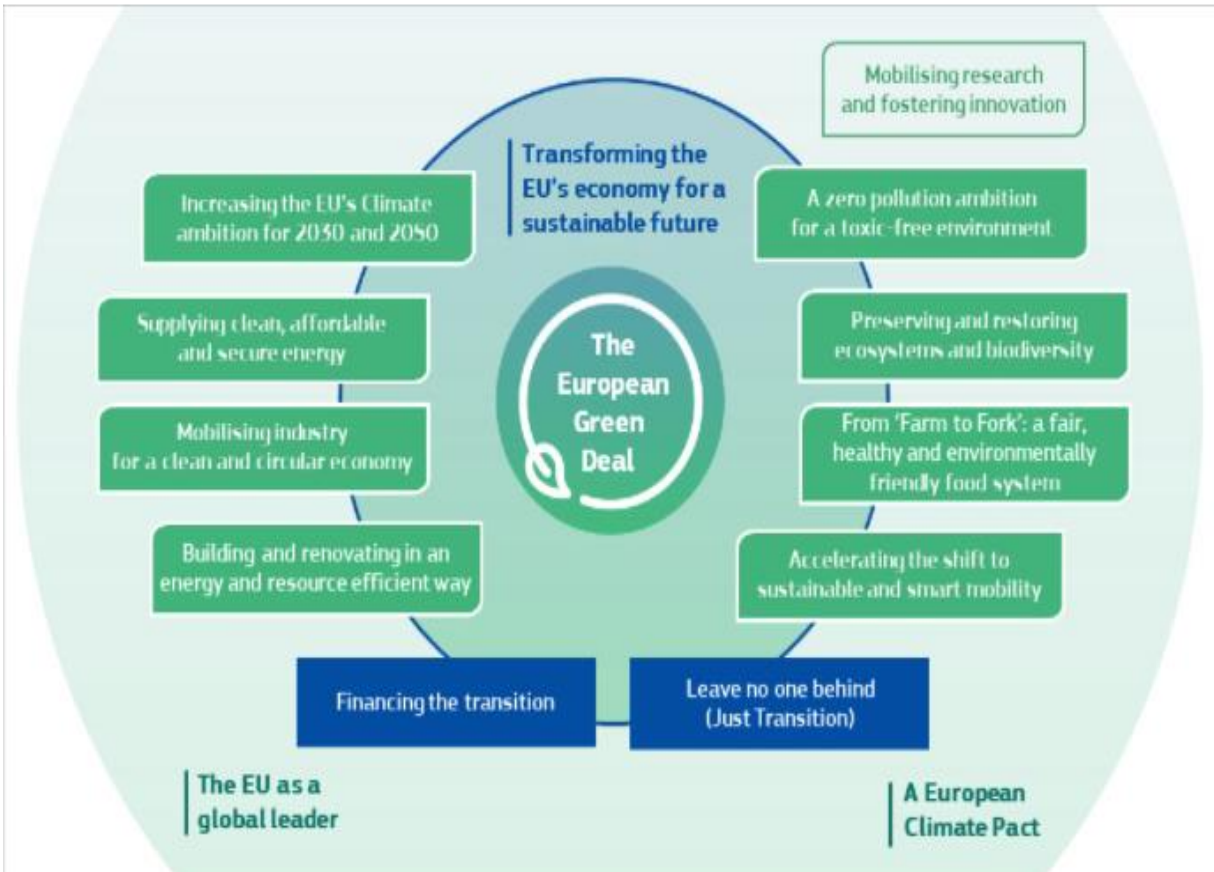


FIGURE 10: THE EUROPEAN GREEN DEAL, AS PRESENTED IN 2019. RETRIEVED FROM (EUROPEAN COMMISSION, 2020).

encompasses the funding of 1.8 trillion euros in order to improve transport, a clean biosphere and improved biodiversity, renewable energy, and sustainable industries and technologies (European Commission, 2020). A summary of building blocks on the complete original plan can be seen in figure 10. CCS is acknowledged as a technology to ensure emission reduction in hard-to-abate industries, especially in the long term. For power generation, CCS is considered more of a transition technology for cleaner fossil energy while transitioning to renewables (European Commission, 2019).

The EU ETS currently covers 43% of all emissions in the EU. The FF55 package proposes to expand the ETS in order to comply to the newly set targets for 2030.

The EU's Green deal is a highly ambitious plan for decarbonization of different industries. A problem arises when considering emissions beyond scope 1 and encompasses large implications to imports of products and services. Emissions that are avoided or reduced in the EU could be located elsewhere which is called 'carbon leakage' e.g., steel being imported from overseas. In the Fit for 55 plans, the EC proposed a mechanism to combat this: the Carbon border Adjustment Mechanism (CABM). It is a framework that ensures the domestic production and imports are subject to similar levels of carbon pricing. This CBAM can be achieved through inclusion of emissions through the three scopes. Currently the ETS only covers direct emissions and emissions from electricity and heat generation (scope 2). Scope 3, or 'cradle to grave emissions' is not included. The CBAM is being constructed out of these three options and will apply to different sectors. The inherent emissions of imported products shall be based on carbon contents, energy application and cradle-to-grave emission calculations will be used to determine a carbon 'import' premium. This premium should resemble the overall EU ETS price for the product if produced in Europe.

2.4.2 Emissions target 2030: Fit for 55

The most recent climate-targets put into place is the 'Fit for 55' plan, proposed by the European Commission in July 2021 (European Commission, 2021a). This target exceeds the original goals set in the Paris climate accord of 2016 and European Green New Deal, increasing emission reductions from 40% to 55% in 2030 with regard to 1990 (UNFCC, 2015). The original targets set in Paris were aimed to limit global warming to 2 degrees in comparison to 1990, but were adjusted to 1.5 degrees (IPPC, 2018). The 'Fit for 55' package shows changes to the EU ETS that support CCS technologies to a further extent: all modes of transport of CO_2 are now included, like shipping and truck transport (Global CCS Institute, 2021). The European commission also aims to double the funding of the original EU innovation fund budget for climate technologies like CCS (European Commission, 2021a) and will provide around 10 billion euros between 2020 and 2030 (RVO, 2021).

2.4.3 ETS and negative emissions

The current EU ETS can be well combined with point-source emissions from fossil industries. CO_2 emissions can be avoided by integration of CCS in systems, allowing for easy calculations. When considering the future role BECCS, it does not only reduce emissions, but also attracts them from the atmosphere, which can be considered a better version of fossil CCS when executed correctly. How to integrate negative emissions in the EU ETS was researched by Rickels et al. (2021) in four scenarios. The research applies the assumption that the EU ETS cap will eventually become negative and operates with 'Carbon Removal Certificates (CRCs). These certificates are supplied by the regulatory authority when negative emissions are achieved against some price. Figure 11 describes the four scenarios: the vertical line being the hard emission cap from the regular ETS and the blue line the effective emissions cap. The vertical axis represents the marginal costs and the horizontal axis the extent of emissions: abatement is possible until reaching net-zero, thereafter negative emissions are achieved. The effective emissions represent the gross emissions, which may exceed the 'set' cap because of negative emissions. The prices for regular ETS credits from abatement are described as p_A and CRCs from negative emissions as p_N..

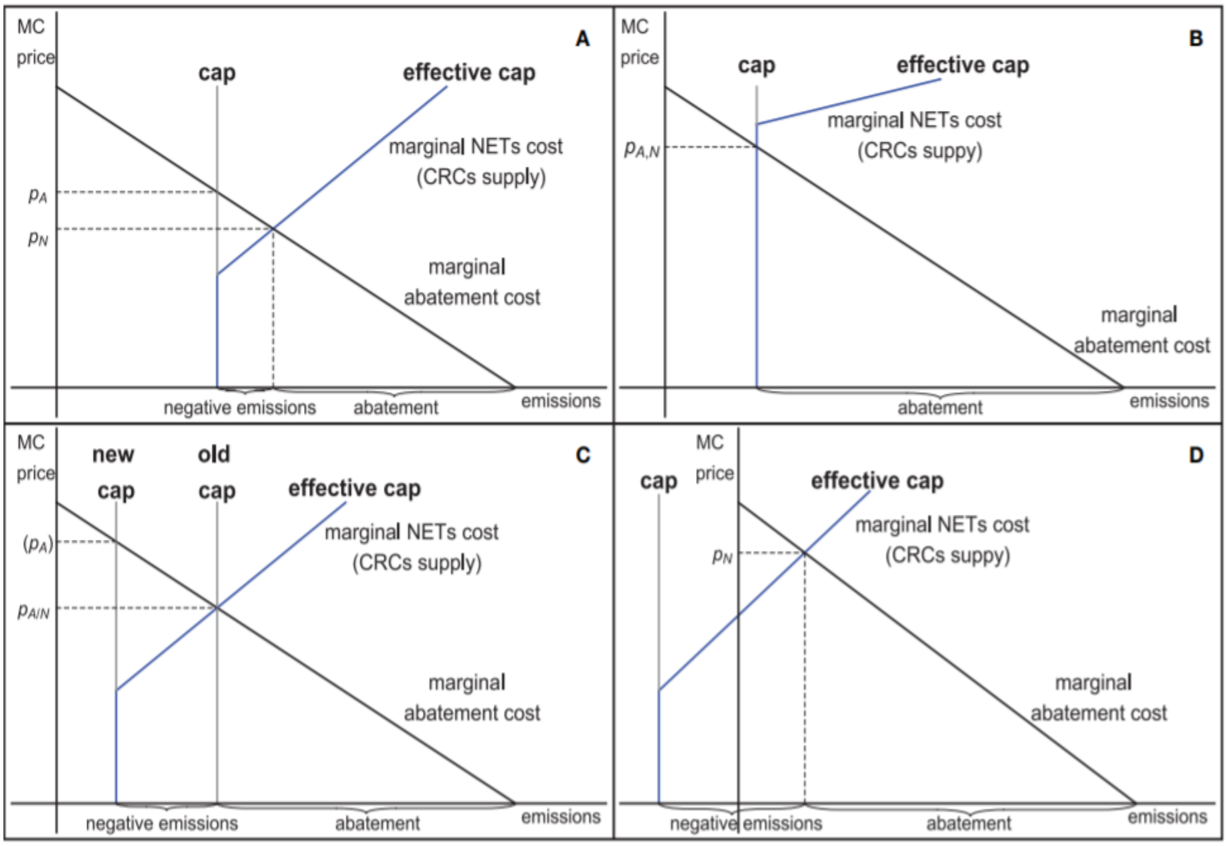


FIGURE 11: FOUR SCENARIOS OF INTEGRATING CARBON REMOVAL CERTIFICATES IN THE EU ETS. RETRIEVED FROM: RICKELS ET AL. (2021).

The four cases by Rickels et al. (2021) imply:

a. The first case implies that the moment that NETs will become competitive with regular emission abatement if the costs of NETs (p_N) are equal or larger than the price of ETS. The regulatory cap of ETS remains the same. The ETS and CRC are integrated in this case. In case the marginal abatement cost curve intersects with the CRC supply curve, the amount of gross emissions increase compared to the situation with no supply of CRCs, being displayed in box A. Integrating competitive supply CRC supply without adjusting the cap means the cap is achieved at lower costs

b. Panel B Shows the integration NETs with the ETS where abatement of CO_2 is more cost-efficient than negative emissions**.** The price for CRCs is now lower than the marginal costs of NETSs. In case A and B net-emissions remain unchanged.

c. Case C shows the integration of competitive NETs *with* adjusting the regulatory cap according to the number of supplied CRCs, such that the allowance price remains unchanged. This can be achieved by reducing allowance supply parallel with CRC supply. This integration and cap adjustment leads to more emission reduction, but also higher costs because allowance prices remain the same here. This is seen as the blue line moves up inelastically with the new cap, until gross emissions are achieved again. The amount in emissions and the cap decrease in parallel to the extent that CRC supply via NETs become competitive.

d. Panel D shows the integration of NETs in ETS for a negative cap, a scenario relevant to post-2050, when negative emissions are projected to be achieved. This would imply integration of the ETS with CRCs, because the ETS emission cap only goes to 0. It requires for CRCs to outnumber gross emissions, otherwise no net-negative effect will be achieved.

Rickels et al. (2021) propose that instead of direct interaction between companies trading emission rights and providers of CRCs, the regulatory authority could also demand a minimum amount (floor) of CRC use instead of and emissions cap (ceiling). For the EC to implement carbon-removal in the ETS it aims to keep the amount of allowances controlled, while creating new rules for the ETS that will ensure sound removal and storage of carbon (IPPC, 2018).

The integration of negative emissions in the EU ETS depends on how the system is designed, but primarily on the cost-competitiveness of NETs like BECCS with other abatement technologies. This will differ per application of BECCS and will depend first on the acknowledgement of biogenic CO_2 to gain value through sequestration, which it currently does not.

2.5 Research tools

This section discusses the relevant research tools to this research. All tools are qualitative of nature and consist of expert interviews, the stakeholder matrix and case-study approach.

2.5.1 Stakeholder matrix

In order to make a proper assessment of stakeholders interacting with each other and the amount of management needed to keep parties satisfied, a stakeholder matrix is a useful tool to create overview. Ilinova et al. (2018) created a specific stakeholder management tool for CCS projects that describes the groups of controlling organizations, policymakers, investors, industry, local public, Media, NGOs and contractors.

These can be described with two variables: Influence and importance assessment and appointed to a specific management strategy: keep satisfied, manage closely, monitor and finally keep informed. An example can be found in figure 12. An overview of a stakeholder matrix provides a quick recommendation on the identification and the management of all stakeholders. It is relevant in this research to give context to case-studies explaining different motivations and potential risks.

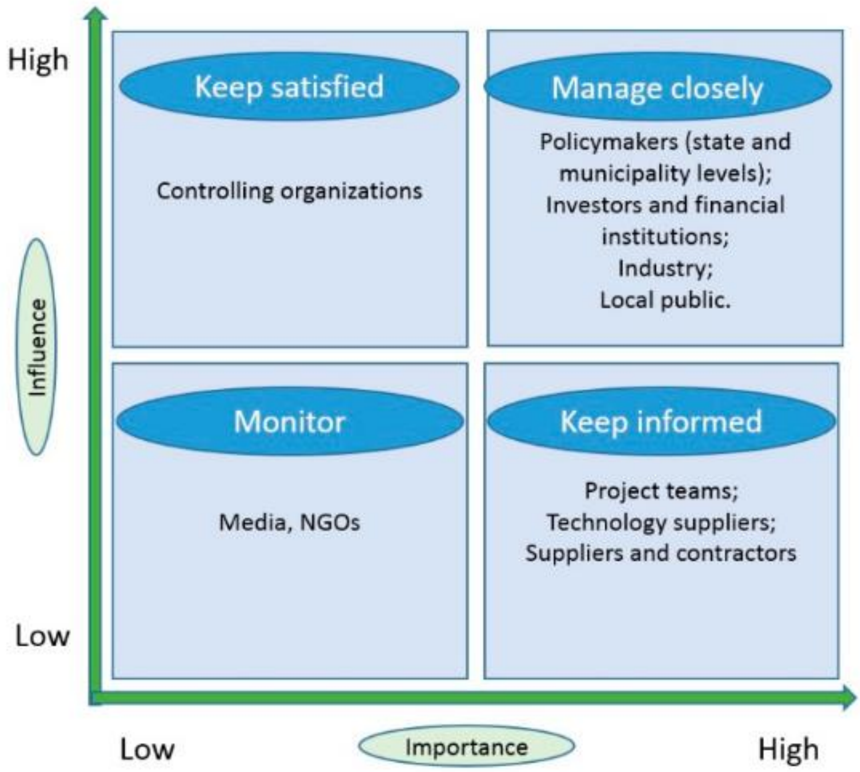


FIGURE 12: STAKEHOLDER MATRIX FOR CCS PROJECTS. RETRIEVED FROM (ILINOVA ET AL., 2018).

To assess the place in the matrix of the different stakeholders, a list of assembled questions can be answered. The list consists of five questions for both categories of impact an importance. These questions are equally weighted. When answering more than three questions with 'yes', a stakeholder is considered to be in the higher part of the relevant axis. The questions are displayed in figure 13**.**

Impact Assessment Questions (1)	Importance Assessment Questions (2)
(1) Can this stakeholder influence the financing of the project? (1.1)	(1) Do the knowledge and level of education of this stakeholder affect the resulting project performance? (2.1)
(2) Can this stakeholder influence the project timeline? (1.2)	(2) Can this stakeholder contribute to the technological development of the project? (2.2)
(3) Can this stakeholder influence the choice of location? (1.3)	(3) Can this stakeholder contribute to the formation of an opinion about the project in the external environment? (2.3)
(4) Can this stakeholder influence the creation of a favorable institutional environment? (1.4)	(4) Can this stakeholder contribute to the staffing, product and service supply of the project? (excluding financial and technological resources) (2.4)
(5) Can this stakeholder completely stop the project? (1.5)	(5) Are representatives of this category of stakeholders replaceable? (assessment of category flexibility) (2.5)

Figure 13: Questions for assessing importance and impact for a stakeholder matrix. Retrieved from: (Ilinova et al., 2018).

2.5.2 Expert interviews

The use of expert interviews is a frequently used method in qualitative research and are useful for gathering both exploratory and standard information (Bogner et al., 2009). This research in particular applies this aspect by using semi-structured method as an interview approach as described by Adams (2015). Semi-structured interviews (SSIs) use both standardized and open questions (why and how). Questions revolve around the topic, but not determine the course of the conversation. SSIs may take different conversation paths than outlined in the interview questions that can result in finding completely new insights and data. Follow-up questions can be asked that differ from the initial script in order to achieve this. A standardized list of mandatory questions does not give the desired results. SSIs are intensive research methods. First interviews must be set up, then conducted. They are recorded to be later transcribed in full. Finally, these results are coded and analysed. The quality of the interview heavily relies on the knowledge and skill of the interviewer. If an interviewee is talking too much about something irrelevant to the research a good interviewer will lead the conversation back on track by interfering (Adams, 2015).

2.5.3 Case-study approach

Among many definitions, the case-study is described most fittingly as:‘’In-depth study undertaken of one particular 'case', which could be a site, individual or policy" (Green & Thorogood, 2009, p. 284). Case studies vary in form and methods, combining qualitative and quantitative methods. They are generally structured in the following sections (table 4) (Crowe et al., 2011):

TABLE 4: PROCEDURAL STEPS FOR CONDUCTION OF A CASE-STUDY. ADAPTED FROM CROWE ET AL. (2011).

Research step	**Description**
Research context	A description about the phenom that is researched in a particular setting.
Objectives	A clear description of what this research aims to achieve, as well as scope of this research.
Study design	The type of case study. A case study can be instrumental: focussed on singular case, or collective: an approach applying multiple cases simultaneously for broader understanding of a phenom.
The case	Which manifestation of the phenom is researched?
Data collection	How was data collected and from what kind of sources?
Analysis	What kind of analysis was applied?
Key findings	What were the key findings from this study and how can they be compared to other cases?

Research tools are often interviews, historical research and scientific literature research. Case studies often revolve around policy, law, and business. Case-studies differ from the related Grounded theory because they are not solely dependent on data from human subjects limits the research objective by omitting tools and sources, as well as potential triangulation. This approach provides a more collective context that for insight from a transition-risk perspective. It allows to test cases for transition risk and opportunity as well as compare cases against another. The case study approach fits this research because it can test the framework findings on real cases. Results may provide confirmation or novel insights on the collected transition risks.

3 Methodology

The former section provided insight on CCS and BECCS, as well as transition risk and opportunity. Most of these parameters on risks and opportunities were found in the TCFD framework and will be interpreted and operationalized for this specific research. This section shall discuss all methods for data-collection and analysis which involves the use of literature research, semi-structured interviews, and case-studies. Then, the research design shall be presented, giving a structured overview of all considered steps and gathered data. Then, transition risk and opportunity will be operationalized in the context of CCS and BECCS. Finally, the Case-studies of Porthos, Alco and Shell are operationalized. Essentially, this research provides a supplemental instrument in the form of a framework on transition risk focussing on the potential risk and opportunity relevant to CCS and BECCS projects. It did so by answering the research question: *'How can transition risk and opportunity be specified for CCS and BECCS in the EU?'*.

3.1 Data collection

This section shall cover the data collection of this research. First, the research design is discussed, whereafter the use of methods shall be described. A multi-method approach was applied using qualitative primary and secondary data sources. Primary data was found in expert interviews and secondary data was found in literature research. First, to assess transition risk and opportunity for BECCS, a literary study was conducted to explore all possible related transition risks and opportunities to CCS and BECCS.

Research design

The elements of this research and overall methodology are condensed in the following research design (figure 14). The structure of this research contains an orientation phase, research phase and final assessment. The Orientation involved gathering background data and understanding of the central topics of this research. The research phase applied the found knowledge to methods for research. The final assessment analysed all found transition risks and opportunities for BECCS and CCS, with the necessary context to provide better understanding. The final framework consists of upgraded transition risk and opportunities for CCS and BECCS related to the initial risks and opportunities from the TCFD.

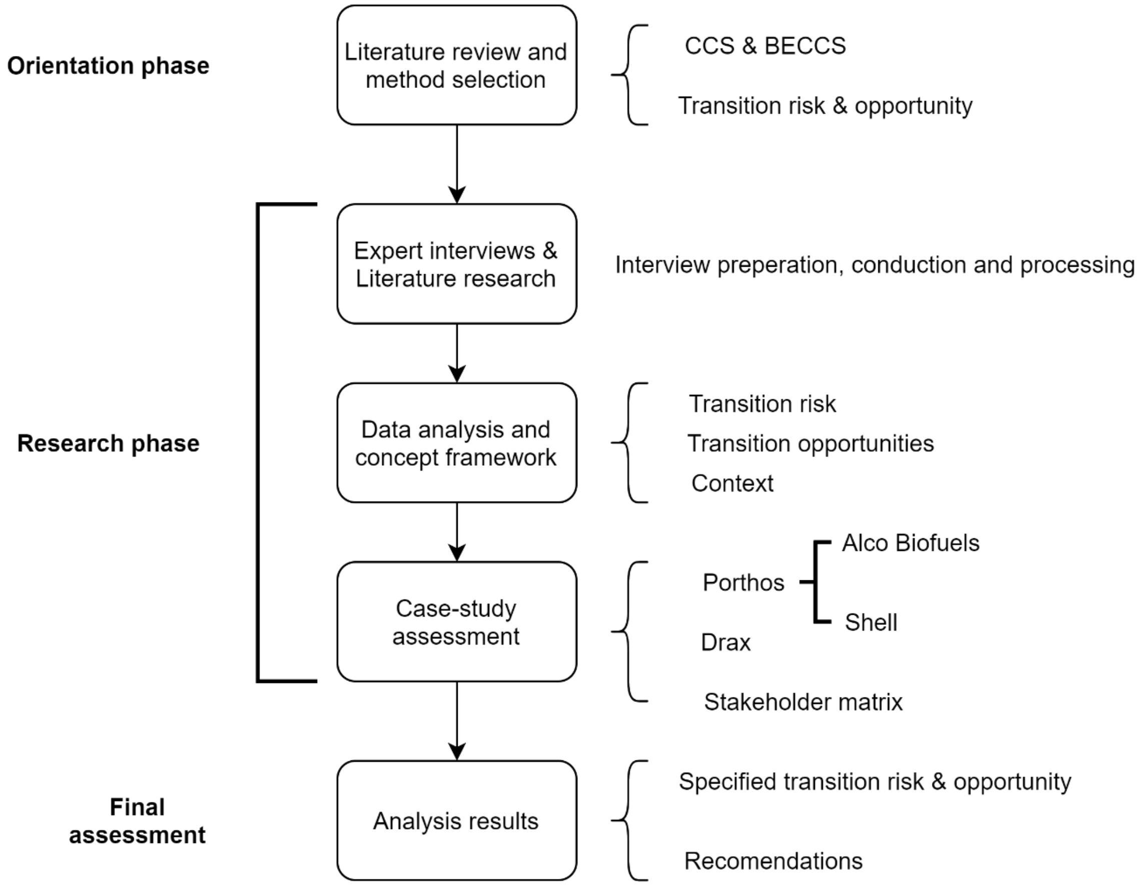


FIGURE 14: VISUALIZATION OF THE RESEARCH DESIGN. CONTAINING ALL RESEARCH PHASES, STEPS AND CONCEPTS.

Literature research

These sources were primarily grey literature like the TCFD's Final report. From there on, academic literature provided background information for the final selection of parameters for assessment. In total, 141 literary sources were utilized, consisting of governmental websites, grey literature, academic literature, and carbon market information. Literature sources included academic literature databases Google Scholar and the UU university library database. Grey literature sources included the TCFD and the IPCC reports, government databases and court rulings, and institutional research data from the EC. For case-studies information was retrieved from company sites, as well as from NGO sites. News articles from papers were also used for data collection, mainly for data triangulation.

Semi-structured interviews

Nine semi-structured interviews were conducted by use of method as described in Longhurst (2003). Preparation of interviews included contacting respondents, writing interview guides and questions, conducting interviews, and finally analyzing data. Respondents were found via the professional networks of the thesis supervisor and Platform Duurzame Biobrandstoffen (Platform Duurzame Biobrandstoffen, 2021). Interview guides were prepared per respondent after background research. The questions were aligned to the expertise of the interviewee. Specific topics were often discussed in more depth by posing follow-up questions. Purposive sampling as described by Tonco (2007) was applied, meaning that respondents were selected based on respondent background and expertise. In addition, snowball sampling was applied to gather additional respondents, resulting in interviews with people from Porthos and Shell. All respondents were in some way affiliated with CCS and BECCS. Respondents were categorized as the following:

- Project developers: This group is considered as the action-taking party to develop and operationalize CCS and BECCS. The application potential of CCS is widespread within power and fuel production, as discussed in the theory and can differ vastly in capture technology required as well as transport method. In some cases, project developers only need to make minor adjustments to operations e.g., a post-combustion mechanism on a biomass CHP, but often altercations cannot be retrofitted easily.
- Investors: Organizations that manage funds and invest, possibly on behalf of a smaller investor, in assets, securities or loans. Banks are the prime example, but smaller organizations are also considered.
- Policymakers: This group corresponds to public parties like local governments, government agencies and European policy makers. CCS and BECCS often need both private and public funding, which indirectly are provided by the European commission.

Table 12 in appendix V displays a shortlist of these respondents in their field of expertise and their role. The interviews were conducted via Microsoft Teams due to Covid-19 restrictions and because it is a widely adopted communication tool. Interviews ranged between 30 and 45 minutes. Extensive summaries of these interviews are found in appendix V.

Case-studies

The case-study approach was chosen to assess the present transition risks and opportunities of different potential CCS and BECCS companies. The CCS project of Porthos was assessed as a single case-study to provide knowledge on transition risk of the hub-project. Additionally, case studies were conducted on Alco Energy Rotterdam and Shell Pernis (referred to as Shell in this research). These cases have in common that both applied for Porthos and that they produce or will produce biofuels in the Port of Rotterdam. Therefore Alco and Shell are researched as a *collective case-study*, as described by Johnson & Stake (1996). This means that the same variables are used and compared between cases. Drax is another case-study that was conducted but was researched into less depth due to lack of primary data found. However, this case did provide useful results on transition risk for BECCS and is therefore included in this research.

The case-studies were chosen to apply the found transition risks and opportunity This research scope was initially set to a broader EU context with additional cases in Norway and Sweden, but due to limited primary case-data, this was not realized. The case in the U.K. was also limited to primary data and discusses the four aforementioned cases for review. The data collected from expert interviews focussed more to the case of Porthos, meaning that the found data is more skewed towards the Dutch case-studies instead of the broader intention of the EU.

Stakeholder matrix

To give a broader understanding of the relevant stakeholders to CCS operations, a stakeholder matrix was constructed for Shell. Using the Ilinova et al. (2018) checklist, stakeholders were identified and classified to 'importance' and 'influence'. Importance means ''the stakeholder's contribution to the development of the project (Ilinova et al., 2018, p. 8) '', and influence ''the strength a stakeholder has in the project's management (Ilinova et al., 2018, p. 8)''. This tool was implemented to better understand the stakeholders in the PoR and how to manage them. Although this tool is specified for companies in progress of developing CCS.

3.2 Operationalization

This section tells how the methodology and concepts are operationalized in this research. First, transition risk and opportunity are defined in the context of CCS and BECCS in the forms of parameters, which are structured under the TCFD's risk categories. Then the case studies are described. It should be noted that the scope of this research encompasses both fossil CCS and BECCS. Some results are only applicable to one of these categories of technologies. This distinction shall be highlighted in the results section.

3.2.1 Transition risk and opportunity parameters of (BE)CCS

Operationalization of the TCFD's transition risks and opportunities was conducted by first merging the categories of transition risk (Market, Reputation etc.) with transition opportunity (Energy source, Resilience etc.). This was decided because of similarities between parameters and for an enhanced overview of risks and opportunities. For example, 'Resilience' is a category that can be placed under technology risk because it can be considered the opposite of a failed investments and stranded assets.

All parameters will be assessed with qualitative methods and sources. It was decided to put parameters in one category, where in some instances an overlap in relevance can be detected, e.g.: demand for low-carbon products and the development of carbon markets through ETS. The parameters are given a '+' for opportunity and a '-' for risk. In some instances, both apply. The operationalizes transition risk and parameters are condensed in table 5. In the results section these parameters were tested with findings, upgrading them and adding new found parameters as well.

Policy risk and opportunity

The policy category revolves around the carbon emission regulating policies. The inclusion of indirect emissions as well as the way climate-targets are framed are important when making up the balance. The parameters relevant here are: *The presence of carbon pricing, like the EU ETS (+, -); the presence of a carbon tax(-).* The latter is going to be interesting in the future because of the 'fit for 55 'carbon border tax proposed. Fridahl & Lehtveer (2018) identify policy incentives like price guarantees, carbon taxes and subsidies as drivers for BECCS. A carbon tax is a commonly heard measure to withdraw carbon-emissions and research shows its effectiveness when mandatory (Downar et al., 2019).

Enhanced emission reporting (+, -) is another parameter proposed by the TCFD. This entails the strictness in emission reporting frequency and the expansion to indirect emissions (Scope 2 and 3). Additionally, emission targets may become more ambitious, which can be indicated by unilateral agreements like the Paris Accord (UNFCC, 2015). This can be seen as *Stricter emissions policy (-).*

Market risk and opportunity

Market demand for low-carbon technologies is a sub-category parameter that has a wide variety of applications. In the most complete sense, every product and service used could be assessed with a life-cycle assessment and compared to alternatives. The system's boundaries are put in the products that are produced which are CCS or BECCS compatible. A demand for low-carbon technologies can be relevant to a sector that emits largely: energy and fuel production (IEA, 2021). Three distinguished parameters from this sub-category are: *Demand for bioenergy with CCS (+); and Demand for Emission reduction (+, -)* and possible *negative emissions (+).* A market for negative emissions is researched because of their salience in emission reduction scenarios used by the EU and IPCC (IPCC, 2021). Negative emissions in the current ETS system are currently absent which is pointed out as a flaw (Zakkour et al., 2014). Aalbers & Bollen (2017) show that implementation of negative emissions in the EU ETS may result in 75% cost reduction in the decarbonization roadmap. This evidently relies on the development of ETS, which is more relevant to policy risk and opportunity. *Demand for* CO_2 (-) as a commodity can be seen as an opportunity for potential revenue, but this does not apply to CCS. It may improve the competitive position of CCU for utilization in e.g., food products, metals, and chemicals. According to the International Energy Agency (or IEA) the global demand for CO_2 is about 230 million tonnes (International Energy Agency, 2019).

Market supply limitations of resources for (BE)CCS (-): Biomass feedstock availability can also be considered in this category, as well as available energy. Bioenergy relies on often scarce resources, resulting in import.

Technology risk and opportunity

This category is rather broadly described by the TCFD. It also overlaps with the demand for low carbon products but focusses more on the rise of new innovations. In a sense, *competition of substitute technologies* can be assessed as comparison of the current-day available technologies. Direct Air

Capture and storage has similarities with point-source CCS and can be seen as competing technology for CCS and BECCS. When powered with renewable energy, DACCS can even provide potential negative emissions. This can also be coupled to demand for CO_2 for CCU, as mentioned earlier.

Synergies of adjacent industries (+) is the result of circular thinking, using smart waste-stream management to reduce waste-outputs as much as possible.

Lower operational costs due to efficient technology (+) can be considered as technological innovations in capture, transport and storage technology that will eventually reduce costs of overall CCS.

Risk of investment (-) is the risk of failure of a project, resulting in sunk costs. For CCS this can potentially be a tariff on coal, making it more expensive to run a coal-fired power plant.

Legal risk

Legal risk can occur as *danger to lawsuits and claims (-)* inherent to the project development and operationality of CCS and BECCS. To ensure safe capture and transport, much land must be used for pipelines. This is a scenario where society can express disapproval due to fear of leakage and 'not in my back-yard' behaviour. Claims can also be relevant when being sued for negligence of emission-reduction targets, but this is not necessarily relevant to companies aiming to operate CCS and BECCS.

Permit procurement (-) is another risk for development of CCS and BECCS. If a group of developers want to initiate a CCS project this means that the regional and national authorities must provide green light first. If operations cross urban areas or protected wildlife areas, this may for instance hinder the process of getting started all along.

Shareholder risk (-) is related to shareholders that go against the current strategy or business model of a company. Since shareholder are part owner of a company, they can possibly enforce change.

Reputational risk and opportunity

The reputational risk affiliated with BECCS and CCS can be expressed in different ways, overall to describe the consumer perception. *Social acceptance (+, -)* is the overall goal of creating positive public perception. It is an important indicator of reputational risk, in the case of CCS very applicable for onshore storage. An example of a failed CCS project is near the town of Barendrecht (Netherlands), which was terminated due to social resistance to the project. Despite of the understanding that CCS is for the good, the CCS project in Barendrecht, eventually went bad. The procedural Environmental Impact Assessment provided green light for the project, but the project was eventually cancelled. Proper assessment and management of stakeholders has shown to be vital in the past for CCS in order to create public acceptance (Terwel et al., 2012). Terwel et al. (2012) indicated the negative attitude towards the project was due to the fear for decreasing property prices and safety. Respondents also indicated that the process of decision-making had been conducted unfairly, feeling that operator Shell had too much influence and all other stakeholders (Municipality, activist groups, civil society) had too little. This emphasizes the importance of proper stakeholder assessment and information dissemination among all actors. *Reputational shocks/boosts (+, -)* can occur when social acceptance is positive in combination with successful operations. CCS and BECCS are vital technologies in achieving emission reductions and eventually negative emissions, thus can provide a positive image. Vice versa, when a project fails in the eyes of the public, the opposite is achieved (Terwel et al., 2012). When CCS is applied to heavy-emitting process, like energy generation from coal, the technology can be perceived as a lifeline for the fossil industry, resulting in *stigmatization of the sector (-).* This is influenced by the consumer sentiment and can be a factor given the consumer's take on renewable, low-carbon energy. This may influence the acceptance of CCS for fossil energy, even when the total energy sector may be regarded as rather climate friendly. An overview of all initial operationalized transition risk and opportunities is condensed in table 5.

Table 5: Condensation of transition risk and opportunity accustomed to CCS and BECCS. Originally sourced from (TCFD, 2017b).

Transition risk and opportunity for CCS and BECCS	**TCFD definition**	**Operationalized parameters**
Market risk	Ways which markets can be affected by climate change: changes in supply and demand for certain commodities, products, services with regard to climate risk. Carbon intensive services like transport can also be considered under market risk.	Market demand • Demand for (bio)energy generation with CCS (+, -) • Demand for CO_2 (+) • Demand for emission reduction, negative emissions (+) Market supply • Supply limitations to resource scarcity (e.g., available sustainable biomass) (-)
Policy risk	The risk associated with the implementation of carbon carbon-pricing mechanisms to reduce GhG emissions.	Carbon pricing mechanisms • Risk through carbon tax (-) • Risk through Emission allowances (+, -) • Risk of enhanced emission reporting (-) • Stricter emission policy (-)
Legal risk	Risk of legal claims from property owners, municipalities, states, insurers, shareholders, and public interest organizations.	• Danger to lawsuits and claims: liability to lawsuits regarding (BE)CCS (-) • Permit procurement (-) • Shareholder risk (-)
Technology risk	Improvements in energy-efficient and low-carbon economic systems. Improved battery storage and CCS.	• Competition of substitute technologies (DACCS, Afforestation, CCU) (-) • Synergies of adjacent industries with CO_2 emissions (+) • Risk of investment (+, -) • Lower operational costs due to efficient technologies (+)
Reputational risk	Risk of changing customer or community perceptions of the company in question regarding its contributions to or detraction from transition to a lower-carbon economy.	• Reputational shocks/boosts (+, -) • Public perception/Social acceptance (+, -) • Stigmatization of the sector (-)

3.3.2 Case-studies

The case-study approach as described by Crowe et al. (2011) was used. It provided a framework of analysis to assess transition risk and opportunity in a structured manner (table 6). The cases of Porthos, Alco and Shell were all assessed based on the transition risk and opportunity found in the TCFD framework, as well as new risks found in the interviews.

TABLE 6: CASE-STUDY RESEARCH STEPS. ADAPTED FROM: CROWE ET AL. (2011).

Research step	**Description**
Research context	A description about the phenom that is researched in a particular setting.
Objectives	A clear description of what this research aims to achieve, as well as scope of this research.
Study design	The type of case study. A case study can be instrumental: focussed on singular case, or collective: an approach applying multiple cases simultaneously for broader understanding of a phenom.
The case	Which manifestation of the phenom is researched?
Data collection	How was data collected and from what kind of sources?
Analysis	What kind of analysis was applied?
Key findings	What were the key findings from this study and how can they be compared to other cases?

3.3 Data analysis

Data from literature research and interviews was first analysed on a higher level and then condensed as general findings. These findings were coupled to central themes within this research. Some findings were contextual and did not directly relate to the research question but provided necessary information for broader understanding of the context. From the findings in interviews and literature, the case studies were constructed and assessed for transition risks and opportunity. The collective findings served to define specified and some novel transition risks and opportunities for CCS and BECCS.

4 Results

This section provides the findings an analyses of this research and consists of new identified risks and opportunities and more contextual findings. First, the results shall be presented in a generic fashion under the subsequent transition risk and opportunity categories. Then, case studies shall be discussed and lastly the final assessment of risk and opportunity parameters.

4.1 Generic results

4.1.1 Market

Demand for low-carbon technologies

The supply and demand of CCS and BECCS chains is considered an opportunity for future emission reduction targets. CCS projects are often initiated as 'hubs', providing transport for whole industrial clusters (Drax, 2021; PORTHOS, 2021). Heavy-emitting sectors like the chemical and energy industry show interest and demand for CCS to decrease carbon footprints ((IOGP, 2019; *Interviews - Herman van der Meyden, Pablo Vercruysse*). The identified products and markets for low-carbon alternatives are primarily biofuels, power and chemicals according to interviews with Pablo Vercruysse and Hennie Zirkzee. These are industries that are currently contributing vastly to GHG emissions (IEA, 2021) The development of these low-carbon products are restricted to funding, technology readiness levels and lacking risk information *(Interview - Dick Boddeus).*

Interviewees were convinced wind energy in combination with CCS has great potential for the Netherlands (*Interviews – Herman van der Meyden, Maarten Gnoth)*.

Incentivising CCS

The current business case for CCS constitutes of subsidies and the Emission allowances of the ETS. Bram Sommer expressed confidence in the positive development of the business case and backs this up with the results from Schenkel (2019) that assesses the alternative options of CCS and CCU. If subsidy will be provided for the coming two years for Porthos, economic stability will be achieved for the duration of the project, as predicted by Bram Sommer. In addition, fossil CCS is part of the EU ETS. Correspondence found that ETS-prices will be rising from now on, with around 50 euros per ton, increasing incentivisation around CCS (*Interviews – Maarten Gnoth, Pablo Vercruysse).* A cost assessment of Porthos was made in 2020, calculating cost per sequestered ton of CO_2 to be around 53 euros (Xodus Advisory, 2020). The costs are compensated by subsidy and ETS, up to the break-even point. The assumption of an increase in ETS price exceeding 50 euros can provide a break-even business case in the worst scenario, making CCS a legitimate abatement technology for all participating companies. The current EU ETS price is currently (October 2021) around 60 euros per ton of CO_2 and is rising steadily (EMBER carbon prices, 2021).

Biofuel potential and demand

Currently, a minimum mixing percentage is mandatory for certain countries for biofuels in fossil fuels. These emissions are considered biogenic, and thus net-zero according to the RED II. From 2025 on, there will be a better business case for biofuels due to improved carbon accounting, according to Marnix Brinkman and Dominique Vrins. This will be elaborated later. Bioethanol shall be in high demand in the future**.** For example, bioethanol is in demand for Alcohol-to-Jet biokerosene production and from petrochemical producers like Shell (*Interview - Pablo Vercruysse*).

Negative emissions and the NEa

Findings from the interviews display that negative emissions are not valued yet, nor will be in the future. The NEa (i.e., the Dutch government) does not disclose any position on negative emissions but the necessity in the future to establish the targets in the Paris climate accord is recognized. BECCS is perceived to be best techno-economic solution for this (IPCC, 2021; *Interviews Marnix Brinkman, Maarten Gnoth*). However negative emissions are likely to stay absent in the ETS *(Interview - Marnix Brinkman)*. Bram Sommer confirms the necessity for negative emissions and the potential in the PoR. Due to available infrastructure and the possibility of retrofitting capture technology the PoR will possibly even change the perception of CCS and BECCS through its practicality and potential.

Some respondents were more reserved about negative emissions and the viability (*Interviews – Sander van Egmond, Hennie Zirkzee*). Hennie Zirkzee sees negative emissions as an administrative problem that is not realizable, mainly due to the uncertainty in permanent storage, as well as overall chain-wide negative emissions. He also questioned the functionality of CCS, referring to carbon leakage as a problem. The best thing achievable is emission reduction. Short-term negative emissions are currently very far-fetched due to the variability in the short carbon cycle. This is expressed in an inconsistent overall biomass portion: there will be fluctuations of total biomass. This makes it harder to estimate and justify negative emissions.

CCU and CO_2 as a commodity

The technological field of CCS is closely linked to CCU. Although this research focusses on CCS and BECCS, due to the potential competition for CO_2, CCU for horticulture is included in case-study assessment. In the PoR, Shell and Alco have been selling by-product CO_2 to horticulture in the near Westland area. Other industries that demand CO_2 are the food and beverage industries, as well as chemical industry, particularly biogenic CO_2 (Interviews - *Pablo Vercruysse, Herman van der Meyden, Maarten Gnoth).* CCU was also mentioned with regard to E-fuels (fuels derived from CO_2 and hydrogen), where both Shell and Alco are researching potential for. Shell also applies carbonation technology for cement production in their Moerdijk refinery. This process uses CO_2 to form calcium carbonate, which stores the CO_2 (Shell, 2021a). This use of CO_2 displays the potential competition for CO_2 based on the current usages, which is elaborated on in the next section.

4.1.2 Technology

Competition with alternative technologies

There are two potential problems to be identified considering developing CCS(*Interview - Bram Sommer)*. Offshore wind park development may suffer when routing of pipelines interferes with physical structures from wind parks. For horticulture the demand for CO_2 is bound to rise (*Interviews - Pablo Vercruysse, Bram Sommer*), as well as the chemical industry (*Interview - Herman van der Meyden)*. Hydrogen from renewable energy is also considered to be in high demand for chemical products. Hydrogen is a frequently used component for producing biofuels, implying possible production costs *(Interview - Pablo Vercruysse)*. Schenkel (2019) assessed the alternative uses for CO_2 in the PoR, including CCU. It was concluded that the current application of CCS was a cost-effective way of abatement, but other options would become viable for abatement from 2021, including CCU and heat from biomass (Schenkel, 2019). This did not implement any EU ETS forecasts and predictions on inclusion of CCU within the system.

The largest bottleneck for BECCS is the limited availability of biomass feedstock (*Interview – Maarten Gnoth)*. In comparison to renewable energy from PV and Solar, the price of biomass will not decrease, and because of more future demand, may increase.

CCS and BECCS have possible high energy consumption, with some exceptions like alcoholic fermentation. Taking in mind the life-cycle emissions of a process, a large amount of renewable energy shall be needed to run CCS. This demand for renewable energy can be identified for other low-carbon technologies and fuels, like Hydrogen production e-fuel production (Lau, 2021). Obviously, household consumption also has large demand for clean energy. This implies that for successful development of CCS, but also CCU requires a large amount of renewable energy. Upgrading the Dutch national electricity grid to be able to handle non-continuous flow of renewable electricity is essential for successful distribution of power (*Interview – Brams Sommer*).

Sander van Egmond questions the overall implications of large-scale BECCS. According to him, it will take at least 15 years to get a BECCS project operational and running, which exceeds the carbon budget for energy reduction. In light of the development pace of renewables like wind and PV, but also the increased capacity of battery storage, BECCS and general CCS are very debatable. CCS with power production is therefore a station passed, he argues. Technological innovations on renewable energy are bringing more emission reduction than potential BECCS projects. In fact, biofuels shall also be outcompeted by electrification of transport, with an exception for aviation. Here, e-fuels will find potential value.

Synergies with products and services in adjacent industries

The bio-ethanol chain with CCS has potential to supply additional proteins for animal feed, in addition to biofuel and biogenic CO_2. It was mentioned that the use of maize as a feedstock is heavily criticized by politicians and NGOs. Pablo Vercruysse counter this, arguing that every part of the output is used in Alco's bio-ethanol production process. A third of all input maize is turned into protein for animal feed whereas the rest becomes bioethanol. He mentioned this is valuable research since Europe will face a protein shortage in the future. The sustainability aspects should be considered through an LCA perspective: Maize being cultivated in Europe, whereas soy products for animal feed originate all the way from South America.

Bram Sommer envisions that the development of CCS may expand towards international cooperation. The need for emission reductions is something many European countries must adhere to, although not all of them are located near depleted gas and oil fields or saline aquifers. The technical potential for CCS in the North-Sea provides the possibility of international CCS projects where networks of pipelines through borders may help countries to assess

Limits to Biofuels mixing

The Dutch climate law prescribes a minimum percentage of biofuel to be mixed in fossil fuels. However, a technical shortcoming is that biofuels can be mixed up to a certain percentage until it becomes unusable in current engines (around 65%) (*Interview - Dominique Vrins*).

Retrofitting old infrastructure

Maarten Gnoth recommends starting CCS projects in the vicinity of already available infrastructure. The initial investment in capture, transport and storage are very high. Another criterium is the availability of sufficient storage capacity. According to him, the most lucrative place to start CCS is the North Sea. This 'reverse system' with old oil and gas fields should be exhausted before operating saline aquifers. The use of existing infrastructure is applied by Porthos (Bram Sommer).

Risk of unsuccessful investments - Stranded assets

Interviews highlighted the importance of considering the time perspective of fossil investments. It often takes years for these initiated fossil projects to be operational, and life cycles are often decades long (*Interview – Sander van Egmond)*. The life-time of onshore oil projects is estimated to be 15 to 30 years (PE, 2015), implying an investment in such projects may face increased transition risk and may be phased-out prematurely. This is an example of potential stranded assets.

Investment risk biomass and biofuel projects

Unsuccessful investment can be the result of poor risk assessment. Biomass projects are diverse and therefore cases are hard to compare on risk (*Interview – Dick Boddeus).* The process of assessing risk focusses on three essential indicators:

1) Input: Is a feedstock available for the long-term, is it sustainable and is the price constant?
2) Throughput: Are installations dependable? Do they perform towards expectations? This is researched by a third party.
3) Output: Technical risk associated with production and contracts. This involves how much production can be achieved with regard to costs.

In comparison to renewable energy projects, biomass and biofuel plants are harder to assess risk. The uncertainty surrounding risk is reflected in higher interest rates for loans. The most important factor for financing of biomass and biofuel projects is a projected stable cash-flow and/or suitable collateral. Cash-flows are often granted through contracts, setting procurement prices for a feedstock or energy for 10 years. The minimal maturity of technology is perceived to be TRL 7 for financers. Lower than TRL 7 often requires equity to finance such projects (*Interview – Dick Boddeus).*

4.1.3 Policy

ETS incentives

The EU's ETS is perceived as an essential mechanism to provide incentives for emission reductions. Maarten Gnoth sees a business case developing with a minimum price of 50 euros per ton CO_2. He tells that from this price onwards investors will find enough incentive to back biofuel projects with CCS. Pablo Vercruysse sees this price rising to 100 euros per ton in the future.

Risk and opportunity of enhanced emission reporting

Risk of enhanced emissions reporting was acknowledged by all respondents. This would emerge in the form of expansion of emission scope reporting. The recent presentation of the FF55 that included expansion of the ETS and the CABM justify this sentiment. These expansions should however consider the problem of double accounting in these expansions.

Stricter certification

For biomass sourcing, the International Sustainability and Carbon Certification (ISCC) system is applied. It certifies all sustainable feedstocks, circular materials and renewables (ISCC, 2021). Respondents differed in opinion of the efficacy of such certificates (*Interviews - Sander van Egmond, Dominique Vrins*). Due to fraud cases in biofuel production, certification shall become stricter in the Netherlands, as well as audit procedures starting next year (*Interviews - Dominique Vrins, Marnix Brinkman*).

Auditing of biomass chains

Effective certification for biomass and even biofuel production were deemed essential for the success production and social perception of these products *(Interviews - Maarten Gnoth, Dominque Vrins, Marnix Brinkman)***.** Current ISCC-certification is needed for sourcing of biomass (ISCC, 2021). Certification should be stricter and apply 'blacklists' for companies for malpractices (*Interview – Maarten Gnoth).*

Carbon-accounting of biofuels

Interviewees point out that there are particular systems of CO_2-reduction accounting that are unfavourable for biofuels and CCS (*Interviews – Marnix Brinkman, Dominique Vrins)*. In the Netherlands, emission reduction is calculated based on the amount of renewable energy used or produced. When combining CCS with Biofuel production, this still results in the same amount of renewable energy produced but does not account for the reduced emissions in the entire production-chain. Only emissions from combustion are included in emission calculations for biofuels. The NEa is currently working on such a system, which will be implemented around 2025 (*Interview – Marnix Brinkman).*

4.1.4 Legal

Permit procurement

Permit procurement was deemed one of the biggest barriers for CCS, but also for other projects concerning renewables. Whenever a permit is distributed it indicates the government's 'blessing' for a project, giving a signal to potential investors (Interview **-** *Dick Boddeus***)**. A permit for CCS involves strict safety protocols and monitoring in the Netherlands (Wettenbank Overheid, 2020).

Legal claims to public and private organizations

The Dutch government has been demanded by the Dutch court to increase emissions reductions towards 20% in 2020 compared to 1990 because climate policy measures were not up to par with emission reduction targets (Hoge Raad, 2020). The case was started by Urgenda, a legal foundation that aims to push climate-related legal cases (Urgenda, 2021). In 2019, the definitive court-decision determined that the Dutch government should increase their efforts to combat climate change. It was mentioned that the counterargument of the government was that BECCS will endure the future emission reductions for an extensive part *(Interview – Sander van Egmond)*. Van Egmond described this as a 'double mortgage on technologies that are not completely developed', emphasizing the uncertainty surrounding both technologies and their overall effectiveness.

In addition, Shell has recently been obligated by the Dutch court to improve their strategy towards decarbonization. Milieudefensie, a Dutch NGO for sustainable practices for biomass, energy and climate, won a court case on May 26^{th}, 2021, against Shell. Shell has to reduce its carbon footprint with 45% by 2030 (Milieudefensie, 2021). Although Shell is appealing this judgement, it is a strong statement against heavy emitters, according to Sander van Egmond. Both the Dutch government and Shell are perfectly capable of calculating the necessary emission reductions, if the Paris agreement of 2015 is adhered. This emphasizes that emission reduction may not be taken as seriously as is portrayed by these entities, particularly because 90% of all shell's investments are still in fossil fuel projects (*Interview - Sander van Egmond).* Recently, Shell CEO Ben van Beurden stated that Shell will not abide to this judgement. Van Beurden tells that Shell is doing everything in its power to convert towards renewables is simply not capable of transitioning at a faster pace (The Guardian, 2021).

Bram Sommer acknowledges that Porthos has not yet had any legal claims. The on-land pipeline to the sea is already available and is situated in industrial area, negating the risk of direct hazard through residential area. He acknowledges that any operational malfunction could cause leakage of CO_2. Porthos is currently not measuring the perception of this pipeline by residents in the vicinity of the infrastructure yet (*Interview – Bram Sommer)*.

Biodiesel fraud

A danger in the application of biofuels is the possibility of fraud. The RED prescription abatement of CO_2 for biofuels differs per feedstock used *(Interviews – Dominique Vrins, Marnix Brinkman)*. In this fraud case, used cooking oils were replaced with other oils, possibly palm oils (ILT, 2020). The RED prescribes biodiesel from UCO to be accounted as double the abatement, making it twice as valuable as biodiesel from other sources, like animal fats of category 3 (European Union, 2018). In this case, sustainability certificates were falsely applied to biodiesel batches, mixing lower amounts of UCO diesel than stated prior. This way, a large profit was able to be made since buyers like Shell preferably buy this type of biodiesel. Dominique Vrins mentions that the ILT detected the fraud through incoherent mass balances in the books. The amounts of certified sustainable UCO biodiesel did not correspond to the purchase of UCO. She emphasizes the importance of adequate authority to check these production chains.

Methods exist to recognize biodiesel fraud but have limitations. For blending, the percentage of fossil fuel in a fuel mix can be detected through identification on Carbon isotopes: fossil carbon has a C12 isotope and biogenic carbon a C14. This is however not detectable in the aforementioned fraud case because all feedstocks had a biogenic nature (*Interview – Dominique Vrins)*. For sustainable sourcing of biomass, Hennie Zirkzee suggests the use of blockchain technologies and remote sensing technologies to improve traceability and monitoring of biomass supply chains.

Biofuel production audits

In the biodiesel fraud-case of Sunoil, certification was initially provided by ISCC (Follow the Money, 2021). A third-party auditor, Control Union, provided a positive response to management. Shortly after, ISCC released in a separate investigation that Sunoil did not comply to the claimed production of certified UCO biodiesel. This lack of thoroughness is confirmed by Dominique Vrins and says that the current bio-diesel system as fraud-sensitive. The fact that mixing different feedstocks was and is often not detected is bad for the sector and for achieving emission reductions. The NEa and ILT will work together from 2022 to do the audits in the biodiesel sector to ensure stricter monitoring. There are currently stricter laws on bookkeeping and chain certification. This improved transparency aims to reduce the fraud of mixing different sources.

Shareholder risk

The risk of shareholders turning against the company for insufficient movement towards a low-carbon business model was highlighted by Shell (*Interview – Herman van der Meyden)*. ‘’Follow This’’ is an organization that owns shares of Shell in order to accelerate its transition from fossil fuels (Follow This, 2021). Follow This buys shares of Shell on behalf of people who support the organization or receive donations from them. Currently, people can buy a (partial) Shell share for 9 euros (Follow This, 2021). Shell is currently pushed to accelerate decarbonization and stop investments in fossil resources. The Follow This groups exerts power by pushing strategy change through votes during general assemblies. Votes issued by Follow This saw a rise in ‘yes votes’ from 5.5% in 2018 to 14.4% in 2020 (Follow This, 2020). The exact resolutions of Follow This are created based emission reduction stated in the Paris accord and the containment of global warming to 1.5 degrees compared to 1990 (Follow This, 2020; UNFCC, 2015) Not only Shell, but also Exxon, British Petrol and other big fossil companies are persuaded by Follow This shareholders. There also, shareholder votes during assemblies are initiated, with growing but little success.

Sustainability of biomass

The perception on the sustainability aspect of biomass differed between respondents. A consensus was that biomass for electricity generation was a ship that had sailed. The hard-to-abate sectors like chemicals and steel were ought to be legitimate options for use of biomass *(Interview - Sander van Egmond, Hennie Zirkzee)*.

Opinions differed on the sustainability aspect of biomass. By-product of forest management provides waste woods that is currently used as a stock for in the Netherlands. Biomass cultivation potentially endangers so called ‘High Conservation Value Forest’ (HCVFs), impacting biodiversity and their large carbon stocks. Production forest was considered potentially sustainable, under the condition it being well managed. Current forestation certificates are a step in the right direction but are not water-tight (*Interview - Maarten Gnoth).*

Maarten Gnoth identifies that cost-efficiency is an important aspect for BECCS and CCS. BECCS is twice the cost of coal CCS and can be considered low hanging fruit before switching to biomass in the long-term. According to him, the higher costs of biomass in comparison to (fossil) alternatives are justified by the necessary future role of BECCS to achieve negative emissions.

Sander van Egmond however was more sceptical on the overall sustainability of lignocellulosic material from production forest. European countries like the Netherlands source a large part of its biomass from abroad. He mentions doubts on sustainability of trim-wood and production forests, the transparency on the locations where wood originates from and the lack of distinction in sourcing of trim-wood and wood from production forest. He also questioned the real effectiveness of biomass use versus letting a forest grow and obtain more carbon. Dominique Vrins is also sceptical on the sustainable viability of biomass, particularly considering a rise in future demand and sourcing issues.

Marnix Brinkman was on the other side of the issue and mentions that sustainable lignocellulosic biomass has great potential. He is convinced that wood production can be sustainable and says that bad practices are scarce. One of the main barriers for biomass is the limited supply. Given demand is going to grow in the future, sourcing from abroad shall be (even more) necessary to ensure continuous energy production (*Interview - Maarten Gnoth)*

4.1.5 Reputational

Reputational boosts

Reputational boosts were not likely to be received from operating CCS. The concept of biofuel production, as well as CO_2 is not considered to be common knowledge, as are the positive effects of biogenic CO_2 and CCS *(Interview - Pablo Vercruysse)*.

Social acceptance/public perception CCS

Although the PoR does not measure public acceptance, respondents think the perception of CCS is not positive by the public (*Interview – Bram Sommer)*. CCS is often negatively displayed in the news due to uncertainty and costs, and some politicians use this publicity to voice resistance to CCS, but this often seems not to stick in the public conversation. Overall, politicians are for the current development of CCS in the Netherlands. Porthos being offshore CCS is considered less controversial than onshore CCS.

Correspondence with Sander van Egmond finds that the exact form of CCS is important for its public acceptance. In 2010, the Dutch town of Barendrecht turned against a planned CCS project. Labelling the project as ‘grey coal’, being a cleaner source of energy was not a good application of CCS according to van Egmond. It ended up being cancelled, also because of pressure from NGOs and public acceptance. Van Egmond argues that if this CCS project was not bound to energy from coal, but rather to steel production, the outcome may have been different. This would be similar with an application of bioenergy using biomass from production forest. Only certain applications of BECCS, like industrial applications from waste streams like manure, would generate social acceptance according to him.

Perception of CCS

CCS is not well received by NGOs. Bram Sommer tells that Porthos receiving SDE++ subsidy is considered a bad use of money according to Greenpeace. Greenpeace argues that this money is better spent on renewable energy and hydrogen (Greenpeace, 2021). Bad publicity towards fossil energy companies like Shell and Exxon originates from the perception of 'public money to big dirty companies' and 'money that could be better spent on renewables', according to Bram Sommer.

Stigmatization of the sector

Biofuel producers face negative attention for the use of certain types of biomass. Waste-related biomass like household waste, manure, waste woods and used cooking oils are examples of sources of biomass that do not find repercussion from politicians and the public (*Interview – Pablo Vercruysse*). The use of a food-source is especially stigmatized, according to Vercruysse. He counters this sentiment by saying that Alco's bioethanol still has 99% abatement of CO_2 compared to fossil fuels. Use of LCA data is essential in determining the sustainability of a feedstock. This sentiment is shared by politicians, who are not willing to acknowledge the potential inherent sustainability of food crops when cultivated properly.

The fact that biofuels are often negatively portrayed in the media due to fraud cases influences the perception of the sector. Dominique Vrins mentions that fraud is easy to commit in biofuels by using alternative feedstocks and fossil fuels. The Dutch ministry of transport released a report that extensive biodiesel fraud was detected. In 2015, 31.6% and in 2016 22.6% of all sold biodiesel was detected to be uncertified (ILT, 2019). New cases are still occurring in the Netherlands in 2019 and 2020, making it a relevant issue (ILT, 2020).

CCS stakeholder assessment

Bram Sommer identifies the following stakeholders in CCS projects taking Porthos as an example: Municipality of Rotterdam, the Province of South Holland, the companies operating in the vicinity of the PoR, civil society living in this area and NGOs.

Perception of biomass

Dick Boddeus says that biomass is under a lot of scrutiny and that there is an active discussion about its real sustainability. Public opinion is therefore hard to assess. From an investment perspective, indicators of 'acceptable' risk to biomass projects are when politicians are for certain projects and when permits for development have been provided.

4.2 Case-studies

This section will assess the results of the single case-studies of Porthos and Drax, as well as the collective case study of Alco Energy and Shell.

4.2.1 Porthos

The Porthos project is a combined effort from three parties, PoR, EBN and Gasunie to realize a CCS project in the Port of Rotterdam, the latter two being governmental gas companies. It aims to create an open-access pipeline that transports CO_2 from the Rotterdam harbour to offshore storage locations in the North Sea (figure 15). Apart from geological storage, another option is to use CCS for horticulture as a carbon source. Technical potential was initially estimated to be 2.5 to 5 Mt CO_2 per annum, leaning more towards 5 Mt. In 2019 the Port started looking for partnering companies who could make a bid for capture capacity. Shell, Exxon, Air Products and Air Liquide were assigned to this storage space.

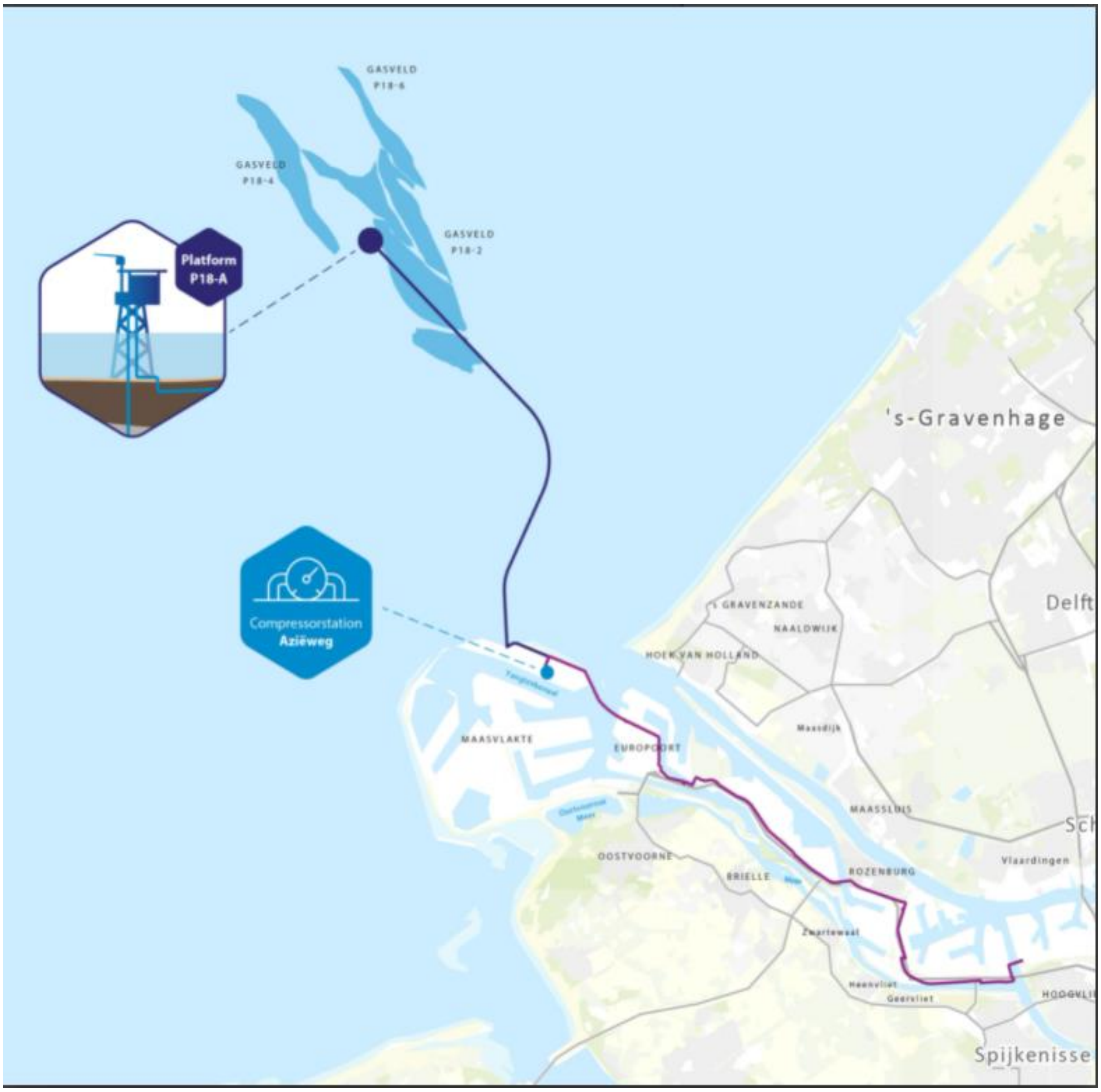


FIGURE 15: THE PROJECTED PORTHOS PROJECT INFRASTRUCTURE. RETRIEVED FROM: (PORTHOS, 2021).

Porthos is momentarily completing financing and awaits its final investment decision in 2022. This was taken a step close in February 2021 when the CEF subsidy for infrastructure from the European Commission was received (Porthos, 2021). Porthos aims to extend the network of pipelines to other ports like Antwerp in its vicinity through the TransPort project. Infrastructure possibilities for this project and common interests for both parties are currently examined (Global CCS Institute, 2020).

The Porthos project can be considered essential for the achievement of emission reduction targets set for the industry by the Dutch Government. In 2030 the industry must have reduced annual emissions by 14.3 Mt CO_2. CCS is aimed to provide half of these emissions reductions (Porthos, 2020b). To stimulate investment in CCS, the Dutch government has a subsidy for emission reduction technologies: the SDE++. This was reserved for investment in Porthos and will supply funding for storage when operational. It will fund the storage costs up till the cost-price of storage of Carbon. It takes into account income from EU ETS, hence, it will not cover complete costs: Costs of storage equals EU ETS gained the subsidy received. Xodus Advisory (2020) calculated the cost of sequestration to be around 53 euros per ton of carbon. The funding process is visualized in figure 16. Results from transition risk and opportunity analysis are displayed in table 7.

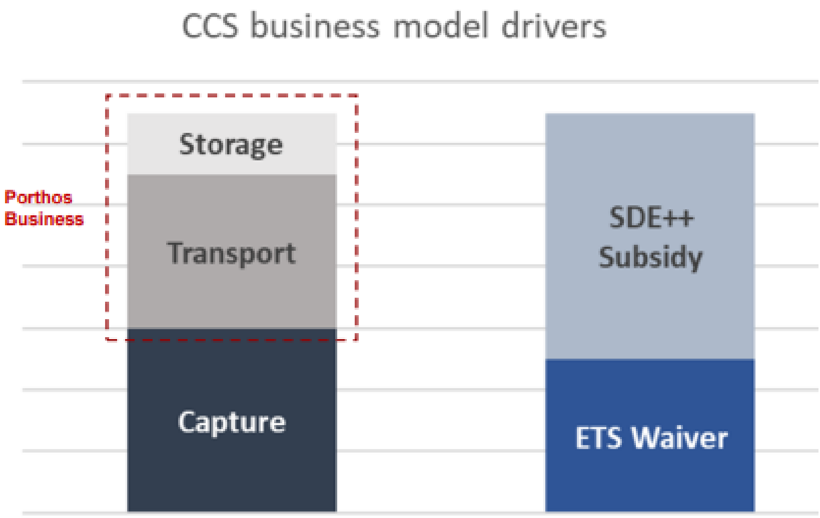


FIGURE 16: THE ESTIMATED COSTING OF PORTHOS' CCS AND THE INHERENT FUNDING PRINCIPLE. RETRIEVED FROM XODUS ADVISORY (2020).

TABLE 7: IDENTIFIED TRANSITION RISK AND OPPORTUNITY FOR PORTHOS.

Transition risk and opportunity	**Porthos**
Risk of investment	Awaiting its final investment decision in 2022, Porthos is close to a green light for construction. Porthos received 102 million euros from the EU innovation fund in 2020, and from interviews, it was predicted that Porthos continuation is stable and will be secure if another round of Dutch subsidy from the SDE++ will be provided (Porthos, 2020a; *Interview - Bram Sommer*). The fact that the Dutch government provides subsidy for transport and storage hedges a large part of the costs that would be made in a scenario of a lacking EU ETS system.
Public perception/Social Acceptance	Porthos is perceived by NGOs to be providing an 'escape route' for fossil industry to keep existing. Subsidies that would preferably go to renewables is now confiscated by Porthos according to them. Overall public perception of Porthos is not good according to interviews, but this also relates to the complexity of the technology (*Interview – Bram Sommer).*

Alco Energy Rotterdam

Alco Energy has two refineries, one in Ghent and one in Rotterdam. Alco Energy Rotterdam (AER) primarily produces 1st generation bioethanol, but also electricity, CO_2 and 'Distiller Dried Grains with Soluble' (DDGS), which is animal feed. Alco produces this from maize. AER produces around 550 million litres of bioethanol annually (Alco Energy Rotterdam, 2021). The production process of bioethanol utilizes 2/3 of the maize mass, leaving 1/3 for DDGS production so all maize is used. Alco also generates its own energy but depends on natural gas to keep operations running. Alco emits around 300 kt biogenic and 340 kt fossil CO_2 annually (Khandelwal & van Dril, 2020). Given the feedstock, Alco has potential to create negative emissions, but depends on the upstream production, processing, and transport of maize. From interview, Pablo Vercruysse emphasizes the need for LCAs to determine a more complete emission picture.

Carbon capture takes place after the fermentation process of maize. Alco currently sells this CO_2 to the Westland. It is transported via OCAP's pipeline network towards the north to the Westland Horticulture. This is considered a business opportunity to Vercruysse, but he emphasizes the cost of capture, purification, liquefaction, and transport. The cooperation with OCAP saves AER a lot of investment costs in this chain: the capital costs of infrastructure for carbon capture is a barrier for investment, he mentions. The capture and purification require large amounts of energy, inflicting operational costs. It was mentioned that the capture cost from fermentation is significantly lower to capture of fossil emissions from exhausts. The purity of CO_2 from the bioethanol process is 99% and does not need to be upgraded. The upgrading process becomes more expensive when reaching higher levels of purity.

Currently, Alco does not receive ETS credits because CCU is not a capture method implemented in the ETS. Although Alco applied to the Porthos CCS project, capture capacity was already acquired by Shell, Exxon, Air Liquide, and Air products. Vercruysse explains that big players like Shell have more lobbying power and are granted a place in such projects at the cost of smaller refineries. Alco is however still working to join other CCS projects like Athos, a CCS project north to Porthos in the North Sea. Alco's current business model for CO_2 is limited to horticulture. Pablo Vercruysse mentions that there is a general demand for CO_2 from the chemical industry, but incentive is lacking from the ETS for CCU. For fossil CO_2, emission rights need to be paid, and biogenic CO_2 is considered neutral, so not there is no incentive there. (*Interview – Pablo Vercruysse*).

Even if this form of CCU is implemented in the ETS, it's price must be higher than the selling price of CO_2 of the commodity. This could also apply to CCS: if operational expenditure and capital expenditure are higher than the ETS benefit, the current business model may be more profitable.

Alco's Bioethanol process produces more than just fuel. The DDGS product is a sustainable source of protein. Pablo Vercruysse says that Europe faces a protein-shortage. The fact that products are valued on their energy content and not on nutritional values is a shortcoming in the European thinking (Jensen et al., 2021).

Shell

Shell is currently aligned to the Porthos CCS project in Rotterdam. In Rotterdam, Shell produces fuels like kerosene, diesel, and gasoline from oil, as well as hydrogen from fossil energy. Shell's strategy to decarbonization includes a reduction of fossil fuel production of 55% in 2030, as well as complete reformation of facilities, creating 5 chemical and energy hubs, of which Rotterdam will be one (Shell, 2021d). This strategy will include Shell's latest plans to build two biofuel plants in Rotterdam: One producing HEFA for diesel and kerosene, and one producing electricity from chicken manure. The HEFA and the energy plant will be connected to Porthos, making Shell and Porthos responsible for sequestering biogenic CO_2. Shell's HEFA production facility aims to run primarily on waste-product UCO. Shell's most recent article explains this will be in addition to sustainable vegetable oils like rapeseed until more sustainable feedstock become available. Shell emphasizes it will not use palm oil for HEFA (Shell, 2021d). Shell will be producing 820 kilo tons of biofuels in this facility, avoiding up to 2.8 Mega tons of CO_2 emissions.

The bioenergy plant from chicken manure was recently acquired from BMC Moerdijk by Shell and is called 'TulipGreenCO2 project' (Shell, 2021e). This demonstration project utilizes a novel 'solid sorbent' technology to capture CO_2 from flue gasses. This technology can be used for hydrogen production, gas-fired power plants, and industry like steel production. The final capacity of the power plant is 150-200 tonnes of CO_2 per day. In time, this project will be added to the Porthos pipeline network, storing biogenic CO_2 (*Interview – Herman van der Meyden).* The novel carbon capture technology provides improved efficiency for carbon capture, reducing capture costs with 25% and establishing purity levels of 95% of CO_2 (Shell, 2021b).

Interviews with Herman van der Meyden point out that Shell Pernis also supplies CO_2 from hydrogen production to horticulture via the OCAP pipeline network.

Shell's ambitious decarbonization strategy for 2030 still allows for fossil fuel production through CCS. Shell will change its business model by transitioning to an electricity provider in the future (*Interview – Herman van der Meyden).* Shell's Mayflower project won the 'Massachusetts Offshore Wind' tender for most outstanding offshore wind project in 2019 (Greentech Media, 2019). Shell focusses on wind-energy in their transition to decarbonization, but is currently involved in biofuels, hydrogen and CCUS projects (*Interview - Herman van der Meyden).* Although Shell is ambitious in reducing its fossil fuel production, the recent court-case against Milieudefensie was perceived as a loss (Milieudefensie, 2021). Shell is appealing in this case, and it may take time before Shell will eventually honour the court's request (*Interview – Sander van Egmond).*

This shareholder risk is echoed by pension funds as well. PME, the largest Dutch pension fund has decided to no longer invest in fossil fuels on September 3rd 2021 (Trouw, 2021).

Interview results point out the different perceptions of the pace at which Shell is decarbonizing its operations. Interview results show Shell is positive on their current pace of decarbonization (*Interview – Herman van der Meyden).*

Shell acknowledges the threats of carbon pricing. In their risk reporting, the TCFD is used to disclose their strategy on climate-related financial risks. Regulatory risk is perceived as a short-term (3 years) risk that involves restrictions on use of fossil fuels, increased compliance costs like carbon costs (carbon pricing). The reputational category is called 'societal risk', and encompasses business to consumer relations, business to business relations, risk of lawsuits, stakeholder criticism (Shell, 2021c).

This part shows the stakeholder assessment for CCS stakeholders by Ilinova et al. (2018). For the case of Shell and Alco, the identified stakeholders are shown in table 8. This framework is specified for entities occupied with CCS, so this does not apply to Alco. By using the checklist method from Ilinova et al. (2018) the stakeholder matrix was filled in (figure 17). The scoring of the checklist is found in appendix IV.

TABLE 8: IDENTIFIED STAKEHOLDERS FOR CCS IN THE PORTHOS AREA. ADAPTED FROM ILINOVA ET AL. (2018).

Stakeholder type	**Description**
Policy makers (EU, National, Regional)	These parties concern the European Commissions, the Dutch government, The Province of South-Holland, and the Municipality of Rotterdam. They have interest in emission-reduction activities and aim to stimulate them via legislation, carbon pricing and incentives like subsidies. Local authorities are more inclined in the public acceptance and the security surrounding CCS projects.
Investors & financial institutions	Holders of Equity and suppliers of liquidity. Finance is essential for CCS projects to develop. Investor interest is often centred around return on investment. However, recently shareholder groups like Follow This have shown to prioritize decarbonization over profit, showing a different perspective. Investment funds and banks estimate risk based on stable cash-flows and the collateral.
Industry (emitters and participants of technological chains)	Industry values the successful deployment and business development of CCS. This group is equally depending on the success of a project as the developer, prioritizes business development. In Porthos, this includes Shell, Exxon, Air Liquide and Air Products.
Local public	People living in the vicinity of Shell Pernis and the transport pipeline. This group may be affected in the way of life and provide a so-called 'social license to operate': a standard for ethical and just social practices that may be caused by CCS operations.
Controlling organizations	Work in cooperation with government. The NEa would be a controlling organization for checking emission accounting.
Media	Papers, television, news apps that report on CCS.
NGOs	Organizations like Greenpeace and Milieudefensie.
Project teams	Internal workforce in completing the CCS project. Working conditions and provisions like a decent wage are essential for these teams to function effectively.
Technology suppliers	Porthos: EBN, Gasunie and Port of Rotterdam: partners in transport and storage. These entities thrive on the demand for CCS in the port.
Suppliers and contractors	The Port of Rotterdam fort the Porthos network of pipelines.

In order to ensure continuation of Shell's business within Porthos, it is essential to keep all parties in the top right corner of the stakeholder matrix satisfied. Institutional entities have the power to directly stop a CCS project when malpractices are reported by controlling organizations. They as well provide opportunity for incentivisation through subsidy and carbon pricing, potentially through a higher EU ETS price.

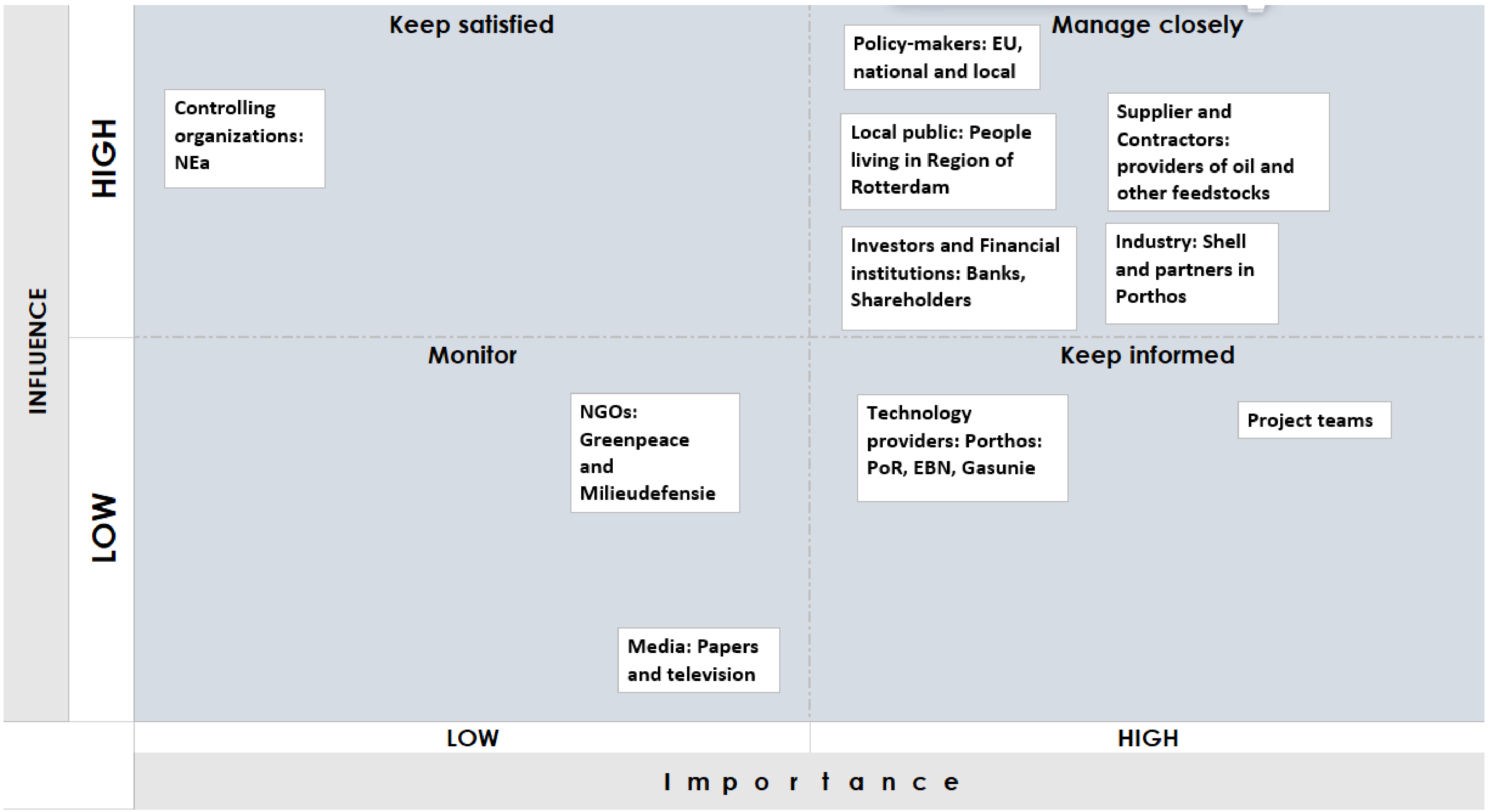


FIGURE 17: STAKEHOLDER MATRIX FOR SHELL IN THE PORT OF ROTTERDAM. THE MATRIX WAS CONSTRUCTED BASED ON ILINOVA ET AL (2018).

The overall results from transition risk and opportunity from the collective case-study of Alco and Shell are shown in table 9.

TABLE 9: COLLECTIVE CASE-STUDY RESULTS FOR ALCO AND SHELL.

Transition risk and opportunity	**Alco Energy**	**Shell**
Potential synergies from production	DDGS, CO_2 and electricity are generated through production of 1st gen bioethanol. Electricity is formed through cogeneration (AER, 2021).	Using captured CO_2 in own chemical park operations.
Retrofitting of infrastructure	Alco used the OCAP pipeline system for CCU purposes in the Westland	Shell operates the same chain towards the Westland from Shell Pernis.
Shareholder Risk	There is no shareholder group working against Alco's practices.	'Follow This' Shareholder initiative by Mark van Baal currently owns a share in Shell. Via votes in general assemblies, Follow This pushes for cleaner investments.
Competition for CCS	Alco is not participating in Porthos but aspires to participate in CCS. It was found that lobbying power as well as (financial) resources were key factors for being included in Porthos. Future expansion to other DOGFs was considered very plausible (*Interview – Bram Sommer).*	Participant in Porthos along with Exxon, Air Liquide and Air Products.
Carbon pricing (EU ETS)	Apart from potential EU ETS sale of allowances from additional free allowances, Alco does not generate income from CO_2 emissions. The biogenic nature of CO_2 could be very valuable in the future when considering its potential for emission reduction and negative emissions. The possible integration of negative emissions in the ETS is something	Shell will generate EU ETS allowances through sequestration of their fossil carbon. Shell will also be able to sequester biogenic carbon through its new HEFA plant in the PoR. Any biogenic emissions captured in the production shall not provide EU ETS allowances under the current regulation.
Public perception	People are likely to not comprehend the process and uses of bioethanol. Food-feedstocks are not loved by policy-makers and politicians (*Interview – Pablo Vercruysse)*.	Shell is considered a bad company due to its historically large carbon footprint, although it is currently working on decarbonizing its business model (*Interview – Herman van der meyden)*.
Fraud risk	Alco's products and operations do not appear to be at risk of fraud.	By creating HEFA biofuels, mixing of other biogenic oils is potential risk for Shell.

4.2.2 Drax

Drax is the largest proposed BECCS project in the in the vicinity of the EU. The Drax energy station produces electricity from co-firing of coal and wood-pellets. Four out of six energy stations have transitioned from coal to sustainably sourced wood-pellets, of which one is projected to be fully operational with CCS. If all four units are converted, Drax has potential to generate 16 Mt CO_2 of negative emissions annually (Drax, 2021). Drax is part of the Zero Carbon Humber CCS hub project, which will provide carbon transport and storage to British Steel, Equinor, Mitsubishi power, Uniper, SSE Thermal and Centrica, as can be seen in figure 18 (Zero Carbon Humber, 2021). However, capture of carbon is estimated around 10 Megatons of CO_2 in 2030 -which does not include overall negative emissions (International Association of Oil & Gas Producers, 2021). Drax aims to be the first carbon-negative company in the world by 2030.

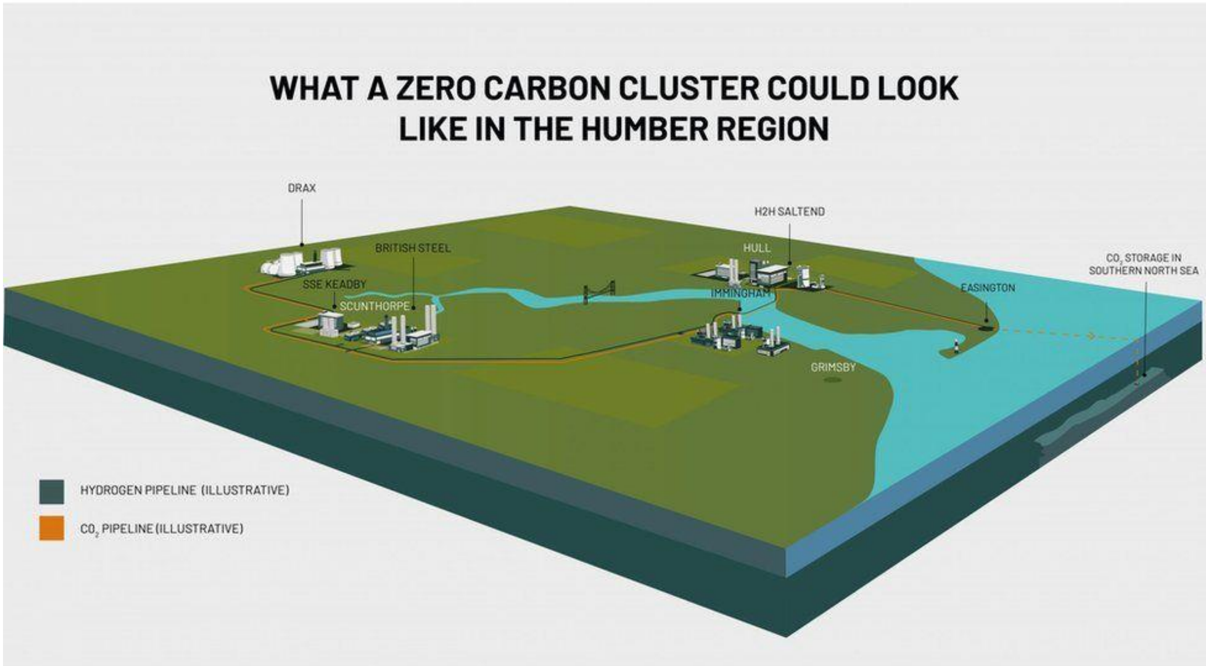


FIGURE 18: DISPLAY OF THE ZERO CARBON HUMBER PROJECT INCLUDING DRAX. RETRIEVED FROM: (*STORIES - DRAX*, 2021).

Wood pellets are sourced from production forests in the UK and North-America (Drax, 2021). It pursues sustainable sourcing through procurement of wood that is certified by the voluntary ‘Sustainable Biomass Program’, along with other third-party certification. Additionally, Drax conducts its own audits (Drax, 2021; SBP, 2021).

Drax’ sustainable sourcing of biomass is essential if it wants to achieve net-negative carbon emissions over time. Recent reporting has found that the sourcing of wood pellets will likely be under high risk of becoming unsustainable. Macdonald & Harrison (2021) found that under current regulation, Drax would require to source wood from primary forests, which differ from sustainable production forests. These forests resemble HCVF areas, meaning they are rich in biodiversity and have high carbon content.

In addition, they find that regulation is not strict enough to accomplish negative emissions, and possibly, Drax could even be more CO_2-emitting than a regular coal plant (Stephenson & MacKay, 2014). MacDonald and Harrison conclude that for Drax to become operational, extensive subsidies will be needed, increasing the annual energy costs per citizen of the U.K. with 16 pounds. Macdonald & Harrison conclude that bioenergy with CCS is not a long-term sustainable use of biomass, but would serve preferably for industry uses like biofuels, hydrogen and steel because of increased abatement.

The viability of a wood-pellet firing power plant is disputed in expert interview (*Interview – Sander van Egmond, Maarten Gnoth).* Maarten Gnoth describes BECCS from wood-pellet firing as a biomass sourcing and placement problem. A sustainably sourced BECCS plant needs to be in the vicinity of the energy user. It requires a sufficient amount of sustainable wood-pellets, preferably from near the area itself. Sourcing wood from overseas is already necessary for Drax to run BECCS, which makes it harder to achieve overall negative emissions. The Groenfonds only funds biofuel projects when sourced from local sources within 100km of project to avoid this problem *(Interview – Boddeus).*

The Drax project has a bad perception with NGOs. ClientEarth reports that Drax is not sustainably sourcing its wood in the U.S., also using hardwood. Drax is also criticised for stating its emissions targets with the assumption of neutral emissions from biomass. Biogenic emissions are still emissions in the eyes of the NGO. Now, targets for emissions reduction and negative emissions are considered to be greenwashing to frame the use of woody biomass as a 'good cause' (ClientEarth, 2021). Transition risk and opportunity are found in table 10.

TABLE 10: TRANSITION RISK AND OPPORTUNITY TO DRAX.

Transition risk and opportunity	**Drax**
Supply limitations of resource scarcity	Drax is putting in effort to assure sustainable sourcing of wood. Literature and interviews suggest that sourcing of sufficient amounts of biomass will overall be restricted by availability, implying that imports are unavoidable.
Public perception/Social acceptance	The fact that Drax will require more subsidy, directly related to people's energy expenses, may possibly create a bad perception. NGOs argue the overall sustainable sourcing of woody biomass, as well as the claim of potential negative emissions. It is emphasized that Drax considers biogenic carbon to be net-neutral, which makes it easier to achieve emission reduction. The burning of wood-pellets in co-firing would be considered to zero emissions.
Demand for negative emissions	Demand for negative emissions comes from the U.K. government. They subsidize this program and will possibly require 30 billion pounds more to achieve these negative emissions. In a scenario where negative emissions are included in the UK ETS, this may change.

4.3 Transition risk categories and parameters

From the analysis of expert interviews and subsequent literature research, the TCFD's operationalized parameters of transition risk and opportunities was enhanced. Additionally, some new parameters were found and are shown in the category of 'novel parameters'. All parameters are accustomed to the relevant stakeholder within this research: Investor (I), Project developer (PD) and Policymaker (PM). Additionally, a risk can be related to fossil CCS (***CCS***), BECCS (***BECCS***) or both (***(BE)CCS***). By completing this list, sub-question 1; *'Which parameters of transition risk and opportunity regarding CCS and BECCS in the EU can be identified for project developers and investors?',* can be answered.

Policy

Carbon pricing (+, -; PD, I, PM; ***(BE)CCS****):* In the EU, the carbon pricing in all countries is the EU ETS system. Given the latest proposed plans of expansions on the ETS in the form of car-transport and the potential expansion to inter-continental aviation, the ETS may also be changed in favour of biofuels and energy. biofuel producers may face more demand. The most recent plans for increasing the linear factor of the allowances cap, a rise in price of the EU ETS may be expected. Interview results point out that a price of 50 euros per ton of CO_2 is sufficient to garner a business case for sustainable projects.

Stricter climate policy targets (+; PD, I): The Fit for 55 plan proposed carbon emission reduction to 55% instead of 49% in 2030 compared to 1990. This translates to an expansion of the ETS and a potential Carbon Border Tax in the form of the CBAM. This may reduce 'carbon leakage' and it will therefore be seen as a risk and opportunity for CCS and BECCS.

Enhanced emissions reporting (+, -; PD, I; ***(BE)CCS****):* It was found that in biodiesel production in the Netherlands companies will need to justify the use of feedstocks and subsequent output with corresponding bookkeeping. This will combat potential biofuel fraud. It will therefore be seen as a risk and opportunity. This development may also occur in biomass certification, as many parties voice concern on overall effectiveness. This is also acknowledged as an opportunity because it may indirectly increase public perception of BECCS by decreasing biomass fraud cases.

Market

Supply risk and availability of resources (-; PD; ***BECCS****)*: This risk concerns the price-changes and availability of resources for the stable operation of CCS and BECCS. For example, the finite availability and production capacity of woody biomass but also energy crops can be a bottleneck for BECCS projects, requiring import from oversea. An increase in future demand would result in a shortage of woody biomass. Imports from over sea are currently even necessary to operate biomass plants. Biomass does not gain cost-efficiency through technological development like renewables. Risk concerning biomass supply can originate from a production and perception point of view. For project developers it is thus important to consider biomass supply chain that are resilient to this risk, by for example choosing a decentralized location for bioenergy production and biomass sourcing. This could potentially be combined with an energy carrier like hydrogen, or even with steel production.

Demand for CO_2 (+, -; PD, PM; ***(BE)CCS****):* There is demand for CO_2 from multiple industries like chemical production, horticulture and the food and beverage industries. The demand for CO_2 depends on the purity of the product and often the nature of the carbon (biogenic or fossil). If future demand will rise, the price of CO_2 as a commodity may be competitive to the EU ETS price.

Demand for negative emissions (+; PD, I; ***BECCS****):* Demand for negative emissions can be found with the U.K. government, funding Drax. It aims to be carbon-neutral in 2030, with the caveat that biogenic CO_2 is considered neutral. Other cases displayed willingness to couple biogenic emissions to CCS, but did not have intentions to generate a complete net-negative value-chain. Net-negativity is something governments expect to play a big part in the future, considering the argument of the Dutch government in the Urgenda case: Relying on BECCS to compensate for current emission target failures. Constructive plans to incentivise negative emissions were not found in this research.

Change of customer demand (+, -; PD, I; ***(BE)CCS****):* Consumers may change their product and service choice to low-carbon alternatives. Assuming BECCS will be applied on a large scale in the future and will be generating net-negative emissions, consumers may want to change energy providers. CCS for industrial purposes may significantly reduce carbon footprints, possibly changing customer behaviour towards these products and services. This research finds that CCS, let alone BECCS are not largely applied and that qualitative findings can only speculate on future demand.

Technology

Risk of substitutes and competition (-; PD, I; ***(BE)CCS****):* Options to decarbonize industry are related to renewable energy and fuels. The technological development of alternative abatement technologies can decrease the competitiveness of CCS and BECCS. CCS and BECCS are however recommended to abate hard-to-decarbonize industries like steal and chemicals. CCU can also be considered competitive, but if CCU is not part of the EU ETS, it will rely on other incentives.

Production synergies (+; PD, PM; ***(BE)CCS****):* Synergies related to production of energy and fuels were shown in the form of Alco's DDGS production. Excess biomass product from production can serve as a source of protein, which is a valuable commodity found in this research.

Risk of investment - Resilience (+, -; PD, I; ***(BE)CCS****):* This risk focusses on the risk of pre-mature cancellation of a project, resulting in stranded assets, as well as the capability to be resilient to this effect. Stranded assets in the context of fossil CCS can occur in the hypothetical case where fossil resources are taxed to a large extent, or in an extreme scenario, CCS with fossil resources is exempted from the EU ETS. Thus, this is closely related to policy risk. On the other hand, investing in renewable, more sustainable technologies may result in more incentives like funds and ETS revenues, making an investment more resilient against future changes in regulation. The support of government institutions in the form of subsidy was found to be an indicator of positive continuation of the project. Government funding implies that it depends on a project's success and thus can be seen as a form of collateral.

Legal

Permit procurement (-; PD; ***(BE)CCS****):* This relates to the process of procuring permission to construct and operate (BE)CCS projects. Stakeholder assessment is very important to avoid any dispute and negative attention. Operating in industrial areas and storing offshore are found to be useful strategy when developing (BE)CCS projects.

Legal claims (+, -; PD, I, PM; ***(BE)CCS****):* Legal claims against (BE)CCS projects may occur if malpractice is witnessed during construction and operation of CCS. Legal claims relate to the prior risk parameter in the sense that stakeholders are integral parts that can hold project developers accountable. Legal claims also apply to biomass fraud, involving mixing of clean plant oils in with waste oils like UCO. Sourcing of biomass feedstock is essential considering overall sustainability, and fines or termination of business can be the result of illegal practices. Legal claims for not adhering to climate targets was identified for both public as private entities led by organizations of Urgenda and Milieudefensie in the Netherlands.

Shareholder risk (+, -; I; ***(BE)CCS****):* Shareholder risk may be considered a driving factor for a company to increase decarbonization efforts. In the case of Shell, CCS may be considered a positive development by shareholder group 'Follow This'. Vice versa, if a particular shareholder group is not in favour of CCS, pressure can be outed via votes in general assemblies to move away from CCS.

Reputational

Stigmatization of the sector (-; PD, I, PM; ***BECCS****):* This parameter considers entire sectors that (BE)CCS can be applied in chemical industry, power and fuel production, steel as well as waste disposal. The biofuel sector in the Netherlands was portrayed negatively in the news due to illegal mixing of feedstocks, which reflects bad on the entire industry. In addition to the negative perception on lignocellulosic and food-feedstocks, the biofuels sector can be stigmatized because of bad perception of some chains.

Public perception/Social acceptance (+, -; PD, I; ***(BE)CCS****):* Public perception of (BE)CCS is essential for the success of the project. CCS is often portrayed negatively in the media and is used by politicians to raise attention. NGOs see CCS as a lifeline for fossil fuels to exist, and BECCS as a technology detrimental to carbon stocks and biodiversity. Overall, CCS is a hard-to-grasp concept for the public according to this research. Storage of carbon is seen as an unknown, scary technology by the public. Therefore, CCS is nowadays primarily developed offshore.

Novel identified transition risks and opportunities

Retrofitting infrastructure (+; PD; ***(BE)CCS*** *):* The use of existing oil and gas infrastructure was considered low-hanging fruit for CCS by respondents because infrastructure costs for transport and storage are high. Often, these pipelines lead to industry hubs, allowing increased practical operationalization. This opportunity parameter can be classified under the technology category since it applies to risk of investment.

Supply-chain physical risk (-, PD, I, ***(BE)CCS****):* As a result of physical climate risk, supply chains may face continuation problems. Due to droughts, storms or flooding, cultivation of biomass may be hindered, as well as transport infrastructure like railways, airports and dried-up canals. A shorter supply chain with independent parts would allow for better adaptation to these risks. This risk would apply to the market category since it directly affects supply of resources.

5 Discussion

5.1 Theoretical implications

This research adds to the use and implementation of the TCFD framework, as well as a practical assessment of CCS and BECCS. It analysed and operationalized transition risk, adding to the understanding of the phenom. It therefore helps to fix the discrepancy between climate-risk translation to a company's metrics and targets. It did so by describing a context of investment of these technologies focussing on the EU. The research identified factors that drive or inhibit the uptake of CCS and BECCS and added to the TCFD framework for climate-related financial disclosures.

Transition risk and physical risk both result in financial risk for companies e.g., in the form of a carbon tax or a tropical storm hitting physical assets. The trajectory of climate change will determine the extent of both types of climate risks. The trade-off between physical and transition risk assumes that imposed transition risk will in fact lead to fewer emissions, which can be questioned. Carbon leakage through external sourcing and production may occur, as well as fraudulent practices, which both question the validity of regulatory systems to effectively provide emission reductions. Although climate-change effects like sea-level rise can be modelled to some extent, transition risk does not allow for an accurate prediction of for example carbon pricing, technological development or increased legal risk. The TCFD therefore describes the use of 'scenario planning' for individual companies to assess in what kind of scenario the extent of risk is. This scenario planning and risk assessment is something institutional investors also do in a sense. Loans are provided based on assessment of future cash flows, collateral, future contracts for biomass and electricity, and contracts for output. Hedging as much uncertainties as possible is essential in risk calculation but is impeded by biomass availability and rising costs. Paying attention to developments like the 'Fit for 55' climate plan, and in particular the EU ETS can be essential in scenario planning to recognize barriers and incentives for CCS and BECCS, and will result in increased resilience.

It is acknowledged in global warming scenarios that negative emissions shall become necessary in the future, EU legislation is not applying any incentives to increase uptake in NETs. The EU ETS could be combined with negative emission certificates, or CRCs. This would allow for a more competitive position of NETs like BECCS, because they would generate additional income for sequestering emissions. As found by Rickels et al. (2021), this essentially relies on the cost-competitiveness of NETs with other abatement technologies, which is far away if these technologies are incentivised by EU ETS and NETs are not. A starting point for BECCS would be the acknowledgement of biogenic CO_2 as 'impactful' to the environment like fossil CO_2, allowing it to gain value in combination with geological sequestration. Given the biogenic nature of CO_2, this form of ETS could be considered more valuable than fossil CCS, which may help the competitive position of NETs. This research finds that negative emissions are likely necessary in the future, which was acknowledged by the majority of respondents. However, the barriers for biogenic CO_2 sequestration in addition to the permanency principle as well as the chainwide net-negative emission effect seem to result in too much uncertainty to currently entertain the idea of negative emission certificates. The EU ETS implies that, given the linear reduction rate of 4.4%, EU ETS industries will become net-neutral by 2038. This predicts that from then on, NETs like BECCS will be integrated in EU ETS, as well as energy and fuel industry.

For BECCS, first generation biofuels are confirmed to be easy applications because of low capture and purification costs. Anaerobic digestion as well as alcoholic fermentation are technologically ready and commercially applied. Alcoholic fermentation is particularly useful because of purity CO_2 by-product. Many biofuel chains rely on controversial feedstocks. However, LCA was a confirmed method by multiple respondents, as well as in literature, to determine real sustainability. In Dutch politics, results of LCAs are often not considered by Dutch politicians when speaking on the matter in media. BECCS as power from incineration of lignocellulosic material is hard to apply in the EU without imports from oversea. This production chain was not considered attractive in this research.

This research finds that CCS shall need to be applied to both low-hanging fruit like hard-to decarbonize industries, as well as on a long-term scale to achieve negative emissions. It suggests that existing infrastructure may serve to be very useful for future development of (BE)CCS, and the North-Sea provides plenty of old gas and oil pipelines. Norway, which has historically produced lots of oil and offshore gas, is a seen as a suitable place for CCS. This research confirms that onshore CCS is seen as controversial and will not easily gain public acceptance. For non-coastal countries, a transcontinental CCS network was proposed to supply offshore (BE)CCS to non-coastal countries. This may facilitated by a trans-European operation.

The overall effects of transition risk and opportunity are understood by case-studied companies; reducing emissions through CCS is an effective way to decrease emissions and reduce risk. CCS is therefore planned in the near future (Drax, Shell) or pursued (Alco). For CCS, companies like Shell and Alco are willing to invest because of the high potential of emission reduction. Government funding is also widely made available in case-countries of the Netherlands and the U.K. to stimulate development. Fossil CCS and BECCS applications are projected to be the most cost-effective and technologically ready solution to large-scale emission reductions, as well as for potential negative emissions. This notion was supported by most respondents and literature. A caveat is that CCS and BECCS focus only on point-sources of emissions, whereas DACCS and afforestation do not depend on point-sources. Additionally, the energy transition relies on more factors for systemic decarbonization, imposing limits to resource availability. Available renewable energy, electrification of transport, as well as technological development in bioenergy technologies are factors that determine the outlook of energy use and emissions. However, multiple technologies shall be needed to retain or recover to a 1.5 degree warming scenario. Transition risk and opportunity are relevant to this in the Market and Technology category, and can be assessed to better understand a potential business-case for developing BECCS and CCS.

5.2 Future research

As Rickels et al. (2021) suggested, certificates for negative emissions can be developed and integrated in the EU ETS. Barriers to chainwide negativity can be researched through remote sensing technologies and blockchain technologies to assure just practices on biomass sourcing. In addition, the cost-competitiveness of BECCS should be increased. Research on increased efficiency of CCS is necessary for improved energy efficiency, like Shell is doing with their 'solid sorbent technology'.

Expansion of overall CCS and BECCS chains for research is recommended to provide a better overall view of possible applications. This can be done by performing more case-studies on transition risk and opportunity.

Research should be conducted to forecasting the technology development of (BE)CCS and alternatives, as well as the design future energy systems. The technology risk category emphasizes the risk of competitive technologies of (BE)CCS, including all abatement technologies like hydrogen, CCU technologies and renewables. CCU resembles CCS and should therefore be added to the scope of this research. CCU is an integral part of the future decarbonization of industries with potential for e-fuels, building material and commodity purposes. Providing detailed costs and expenses in capital and operation expenses are essential to conduct this. In addition, competition for (BE)CCS resources like (renewable) energy for capture and resources inherent to feedstocks, like land. Here it should be emphasized that the alternative for these feedstocks, like food consumption, materials and resources should be also considered.

5.3 Limitations

5.3.1 Practical implications

Some practical limitations were encountered when conducting this research.

Due to a lack of resources, the technological scope of this research was adjusted to CCS and BECCS. CCU was intended to be researched during the internship research, but was not possible to exhaustively perform. However, CCU was still researched in the expert interviews and provided insight on the potential competition for CO_2 between (BE)CCS and CCU projects. The initial plan was to include CCU technologies because the competitive effect of both technologies would provide a more complete picture of the ideal use of CO_2.

The scope of the EU was chosen because of the common institution of the European Commission and therefore corresponding law. Norway and Sweden were part of the case-studies with applications of CCS but were later omitted due to lack of representative respondents in the researcher's network. Although countries like the U.K. and Norway are not part of the EU, they are in a situation where EU climate legislature and carbon pricing mechanisms do apply. Norway participates in EU ETS and the U.K. applies a practically identical system concerning the UK ETS. The inclusion of non-EU countries affects validity but can still function as representative cases for the EU. The smaller sample of countries also affects validity, but given the small number of CCS and BECCS projects in Europe, is not too bad.

This research is in essence a conceptualization of transition risk and opportunity for a specific group of technology. The theoretical framework highlights parameters concerning transition risk and opportunity in general. These parameters were improved specifically for CCS and BECCS in my results section based on expert interviews and additional literature, but not without overlapping parameters. A potential benefit of this is more triangulation of data, but also brings vagueness of process. The research design was constructed as such that literary research would serve as the foundation as well as the validation of the complete research.

Also, the case studies were not assessed on an even level: The case of Drax was not assessed via expert interview of an associate or employee. This should be taken into account when interpreting these results. Interviews were conducted with nine respondents, all varying in expertise. The intention was to include more CCS and BECCS cases researched, but due to lack of time and resources, was limited. Concludingly, results were prone to be subjective because most insights were gained from expert interviews.

Validity of the research is achieved by the set-up research design. Using identified transition risks from the TCFD framework as a starting point, these were operationalized to the context of (BE)CCS. These were then researched via expert interviews and additional research. Results were thus triangulated to some extent, with an exception for novel transition risks and opportunities. Validity between respondents could be improved by interviewing more than one person from the same organizations, as well as more organizations that apply to the scope. More people within Porthos could be interviewed, as well as people from other CCS projects in the EU. In addition, quantitative analysis that models the potential carbon prices under different emissions scenarios was not added. A suggestion for future research is to perform this quantitative analysis to make improved future scenarios for climate-risk assessment.

Transition risk and opportunity are concepts that are broadly applicable considering the effects of carbon pricing, legal claims for enhanced emission targets, and social acceptance. This study therefore did generate high-level insights that can be used in risk and opportunity assessment and scenario planning for investors and project developers. A good addition to this study is to perform a techno-economic assessment of potential costs which completes the analysis of cost-competition of options. Substitutes were assessed based only transition risk, which is not a conclusive investment framework.

Fossil CCS and BECCS have communalities regarding capture and storage of CO_2, but may vary interdependently in the vast types of applications of these technology chains, e.g. HEFA biodiesel production from UCO with CCS or biomass co-firing for electricity. The particular researched chains generated novel insight on how transition risk and opportunity manifest itself on a granular level. However, they only touch the surface of all assessable BECCS and CCS chains.

The results of this research show an operationalized set of parameters along the transition risk and opportunity categories of the TCFD framework. This research also added novel parameters to the operationalized framework in the form of '*Retrofitting of infrastructure'* and *'Supply-chain risk'* that can provide use for CCS and BECCS development. This research can be considered a first step in holistic transition risk and opportunity assessment for CCS and BECCS.

5.3.2 Methodological implications

This research dealt with three methodological implications.

Reliability is an inherent problem in qualitative research. Although literature research can be triangulated with multiple sources, case-studies and expert interviews can generate insights that may not be reproducible. The qualitative nature of this study does not allow to make hard statements of the effect of transition risk and opportunity to certain projects. One to one expert interviews are time-consuming and were integral for this research. It took additional time to finalize the set of interviews because research was conducted during the summer vacation break, indicating the reliability on respondents to conduct this kind of research. In addition, case-studies are conducted by a single researcher, bringing the danger of bias. A bias may steer the research towards a certain direction and will inhibit objectivity.

The case-studies were performed with grey literature and company websites, as well as interview results. They were conducted focussing on different risks and opportunities, and were not conducted through a strict guideline, which is a shortcoming of the case-study approach.

The qualitative nature of this research limits it in answering its main research question. Although fitting for identifying transition risk and opportunity, measuring risk requires quantitative techniques that determine probability and impact. The effect of transition risks and opportunities for CCS and BECCS were thus determined from interviews and literature research. This gave a subjective sense of the extent that risk and opportunity could occur and affect these technologies but gave no exact results on distribution and weight.

6 Summary and Conclusions

6.1 Summary

This research was set up to increase understanding of transition risk and opportunity related to fossil CCS and BECCS technologies in the EU. It builds on the TCFD's framework that helps companies improve their understanding and resilience of climate risk by sharing recommendations on climate-related financial disclosures. This framework applies the elements of 'transition risk and opportunity' in the process of developing climate-related financial disclosures. The TCFDs transition risk and opportunity were used to assess the technologies of CCS and BECCS to increase transparency and eventual increased uptake. The research applied qualitative research methods in the form of literature review, case-studies, and expert interviews to identify and assess transition risk for both technologies. The TCFD's transition risks and opportunities were operationalized as parameters for CCS and BECCS. Subsequently, these were tested on case-studies in the U.K and the Netherlands. The results can largely be considered to apply to both BECCS and fossil CSS

In order to answer research sub-question 1; *'Which parameters of transition risk and opportunity regarding CCS and BECCS in the EU can be identified for project developers and investors?'*, the identified transition risks and opportunities were categorized under the TCFD's risk and opportunity categories of Market, Policy, Technology, Legal, and Reputation. Novel transition risks and opportunities were added to the original selection made in the initial operationalization. The final transition risks and opportunities are explained in depth in section 4.3.

To answer the second research sub-question; '*How do these parameters inhibit or encourage project development and investment for CCS and BECCS?'*, the following findings are relevant:

Transition risk and opportunity were found to likely have effect on investment and project development of CCS and BECCS. BECCS projects with firing of wood pellets were very dependent on the sustainable sourcing of wood. It was found that in the EU, lack of available production forest requires import of biomass. Drax import biomass from over sea, increasing complexity and travel distance in the supply of wood. Although certification for sustainable biomass is applied, the overall sustainability sourcing is questioned by academic sources and respondents. Controversy around BECCS is also found in the use of food-crops as feedstock like Maize in 1st generation bioethanol production. Considering it has nutritional value generates opposition from politicians, and other groups.

Biofuels from waste products like HEFA seem to be non-controversial for their feedstock but are prone to fraud because of feedstock mixing from alternative biogenic sources.

A life-cycle assessment could however best determine the overall sustainability and carbon footprint of a biomass feedstock.

It was confirmed by case studies that there is a demand for CO_2 from different industries, including horticulture, the chemical industry and food. In the case of Alco, bioethanol production provides a pure biogenic stream of CO_2 that is can be transported after liquefaction. This purification more expensive for flue gasses from fossil-fired processes. Additionally, CO_2 from bioethanol is considered more attractive due its biogenic nature.

Carbon pricing mechanisms have increased effect on the business case for CCS. Given the current rise in value of the EU and UK ETS, incentives for CCS are currently around the cost price of sequestration. Subsidies and other finance heavily influence the uptake of CCS projects. The EU ETS currently does not cover negative emissions but can be expanded with Carbon Removal Certificates that can compete with EU ETS from abatement technologies.

Foremost, for CCS and BECCS projects to commence, permits by local authorities need to be provided. if not strictly adhered to, permits can be withdrawn, resulting in cancellation of a project.

CCS can be hindered through legal claims when dealing with risk of carbon leakage, or when project are planned in the vicinity of existing infrastructure or residential areas.

In the case of Shell and Milieudefensie, a legal case could hypothetically accelerate the uptake and investment of CCS and BECCS. Judge's ruling held Shell accountable for doing too little to decarbonise, which Shell will appeal to. If Shell eventually loses this case, CCS and BECCS may be options to adhere to these rulings. This depends on more factors than just Shell, but it does provide an impulse to develop more BECCS or CCS.

Social acceptance and public perception are important factors to consider for the successful realization of CCS and BECCS. The public, and particularly local residents can NGOs see CCS as a lifeline for polluting industries to relief decarbonization efforts, yet most respondents see CCS as a viable technology for hard-to-abate sectors to increase CO_2 abatement.

In some BECCS chains, synergies from by-products were discovered that may potentially generate value. Alco is selling the waste part of maize as animal feed, which is lucrative due to the protein deficiency in Europe. Considering all inputs and outputs may enhance the case for some biofuel chains.

A risk to CCS and BECCS may be the competition from CO_2-demanding industries like horticulture, food and beverages and the chemical industry. However, under the current system, EU ETS does not value biogenic CO_2.

By answering the second research sub-question, the central research question; *'How can transition risk and opportunity be specified for CCS and BECCS in the EU?',* was assessed as well. Transition risks have the power to cripple income from BECCS and CCS as well as completely terminate such projects. For investors and project developers this would result in stranded assets, losing direct value.

Historically, CCS and BECCS have little positive examples, except when regarding EOR projects. Transition opportunities can likewise provide life to BECCS and CCS, when properly executed. The understanding of emission reduction and even possible negative emissions is vital in the public perception of CCS and BECCS and may allow stakeholders to understand the necessity and urgency of these technologies.

6.2 Recommendations

6.2.1 Recommendations for policymakers

CCS and BECCS are vital technologies to achieve overall emission reductions, as well as overall negative emissions. Biogenic CO_2 however is currently considered as a neutral emission in the RED II, which makes it worthless when stored via CCS. This makes the business-case for BECCS in the EU currently non-existent. Biogenic CO_2 sequestration is the most effective form of emission reduction with potential to negative emissions. Integration of negative emissions in the ETS is an opportunity to for a market incentive for BECCS and other NETs. This is relevant considering the linear reduction rate of 4.4% implies that net-neutrality will be achieved in 2038. After that, only negative emissions can help to achieve atmospheric carbon reduction.

CCS projects come often in the form of 'hub projects' like Porthos and Zero Carbon Humber. The choice of participants for these hubs are based on lobbying efforts and overall financial affluency. Smaller biorefineries like Alco Energy Rotterdam generate up 0.4 Mt of biogenic carbon each year, which currently sold for CCU. The selection of participants of CCS projects should be more focussed on emitters of biogenic carbon. This will stimulate the CCS case for biofuel producers, as well as transition companies like Shell faster to biofuel production.

1st generation bioethanol is considered unsustainable because of use of food-feedstocks like maize. Life-cycle assessment indicates that this is still more sustainable than sourcing soy from overseas, implying that thorough chain-wide analysis is needed before banning a certain kind of feedstock. In addition, biofuel production should be valued to all kinds of outputs. Given a potential protein deficiency in the EU, all useful by-products should be considered on qualities like nutritional value, not only on energy content.

BECCS for biofuels and energy from waste are the production chains that receive least controversy according to this research. Second generation bioethanol from waste woods or HEFA fuels from UCO should be considered for fuel production.

Climate-related disclosures should become mandatory in all of Europe. Clear rules on carbon accounting should be assigned and standardized per industry. Additionally, scope 3 emissions should be considered to be reported and accounted for by producers of fuels, which will incentivise biofuel production.

6.2.2 Recommendations for investors and project developers of (BE)CCS

CCS projects are funded in hubs, because they can attract most funding due to storage potential. This also divides risk and makes governments want to complete the project. For the EU, the north-sea has plenty of potential storage capacity, as well as infrastructure from oil and gas drilling. Exploiting this potential by creating a reverse system is low-hanging fruit for cost-effective CCS development.

6.3 Final remarks

Although negative emissions are likely to play a big part in the future to combat climate-change, BECCS should be operated with caution. In particular, large-scale biomass firing for BECCS demands imports of biomass due to lack of local available production forests. Imports from other countries contribute to transport emissions, possibly defeating the purpose of negative emissions. Fossil CCS can be seen as a trade-off between fast decarbonization of current industries, but therefore delaying the transition to real low carbon technologies for energies and fuels. Transition risk and opportunity should be considered to be essential in assessing which decision to make when investing in CCS and BECCS. For biofuel and energy producers, carbon pricing mechanisms are likely to give more favourable incentives for CCS in the future. The question is whether to wait on newer technologies like 2nd generation bioethanol and next generation gasification or go with existing technologies that face backlash for using feedstocks that require more land area and potential food products.

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8 Appendices

Appendix I – TCFD transition risks and opportunities

Examples of Climate-Related Risks and Potential Financial Impacts

Type	Climate-Related Risks[32]	Potential Financial Impacts
Transition Risks	Policy and Legal	
	– Increased pricing of GHG emissions – Enhanced emissions-reporting obligations – Mandates on and regulation of existing products and services – Exposure to litigation	– Increased operating costs (e.g., higher compliance costs, increased insurance premiums) – Write-offs, asset impairment, and early retirement of existing assets due to policy changes – Increased costs and/or reduced demand for products and services resulting from fines and judgments
	Technology	
	– Substitution of existing products and services with lower emissions options – Unsuccessful investment in new technologies – Costs to transition to lower emissions technology	– Write-offs and early retirement of existing assets – Reduced demand for products and services – Research and development (R&D) expenditures in new and alternative technologies – Capital investments in technology development – Costs to adopt/deploy new practices and processes
	Market	
	– Changing customer behavior – Uncertainty in market signals – Increased cost of raw materials	– Reduced demand for goods and services due to shift in consumer preferences – Increased production costs due to changing input prices (e.g., energy, water) and output requirements (e.g., waste treatment) – Abrupt and unexpected shifts in energy costs – Change in revenue mix and sources, resulting in decreased revenues – Re-pricing of assets (e.g., fossil fuel reserves, land valuations, securities valuations)
	Reputation	
	– Shifts in consumer preferences – Stigmatization of sector – Increased stakeholder concern or negative stakeholder feedback	– Reduced revenue from decreased demand for goods/services – Reduced revenue from decreased production capacity (e.g., delayed planning approvals, supply chain interruptions) – Reduced revenue from negative impacts on workforce management and planning (e.g., employee attraction and retention) – Reduction in capital availability

FIGURE 19: THE TCFD'S DESCRIPTION OF DIFFERENT TRANSITION RISKS, AS WELL AS THEIR FINANCIAL IMPACTS. RETRIEVED FROM TCFD (2017B).

Examples of Climate-Related Opportunities and Potential Financial Impacts

Type	Climate-Related Opportunities[33]	Potential Financial Impacts
Resource Efficiency	– Use of more efficient modes of transport – Use of more efficient production and distribution processes – Use of recycling – Move to more efficient buildings – Reduced water usage and consumption	– Reduced operating costs (e.g., through efficiency gains and cost reductions) – Increased production capacity, resulting in increased revenues – Increased value of fixed assets (e.g., highly rated energy-efficient buildings) – Benefits to workforce management and planning (e.g., improved health and safety, employee satisfaction) resulting in lower costs
Energy Source	– Use of lower-emission sources of energy – Use of supportive policy incentives – Use of new technologies – Participation in carbon market – Shift toward decentralized energy generation	– Reduced operational costs (e.g., through use of lowest cost abatement) – Reduced exposure to future fossil fuel price increases – Reduced exposure to GHG emissions and therefore less sensitivity to changes in cost of carbon – Returns on investment in low-emission technology – Increased capital availability (e.g., as more investors favor lower-emissions producers) – Reputational benefits resulting in increased demand for goods/services
Products and Services	– Development and/or expansion of low emission goods and services – Development of climate adaptation and insurance risk solutions – Development of new products or services through R&D and innovation – Ability to diversify business activities – Shift in consumer preferences	– Increased revenue through demand for lower emissions products and services – Increased revenue through new solutions to adaptation needs (e.g., insurance risk transfer products and services) – Better competitive position to reflect shifting consumer preferences, resulting in increased revenues
Markets	– Access to new markets – Use of public-sector incentives – Access to new assets and locations needing insurance coverage	– Increased revenues through access to new and emerging markets (e.g., partnerships with governments, development banks) – Increased diversification of financial assets (e.g., green bonds and infrastructure)
Resilience	– Participation in renewable energy programs and adoption of energy-efficiency measures – Resource substitutes/diversification	– Increased market valuation through resilience planning (e.g., infrastructure, land, buildings) – Increased reliability of supply chain and ability to operate under various conditions – Increased revenue through new products and services related to ensuring resiliency

Figure 20: The TCFD's defined transition opportunities, as well as financial impacts. Retrieved from: TCFD (2017b).

Appendix II – Biomass in-depth

Biomass is the oldest used energy-carrier in the world and is still a necessity for power and heat generation in some places. Biomass in general is the product of the process of photosynthesis that requires energy, water and CO_2 to form energy-yielding sugars and O_2, as is simply put in in figure 21.

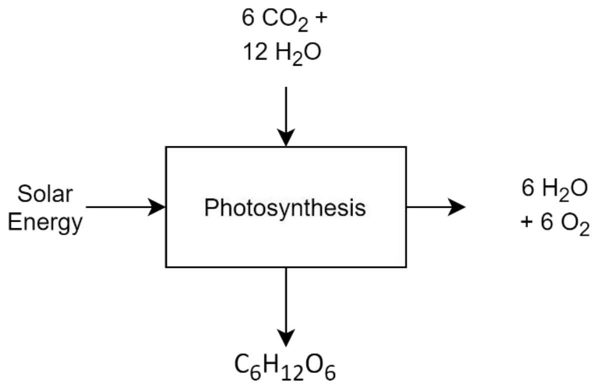

FIGURE 21: THE GENERAL PROCESS OF PHOTOSYNTHESIS.

Photosynthesis can be conducted organisms that incorporate chlorophyll, often recognizable by its green colour. Not only plants, but also algae and bacteria contain these organelles, making them ‘primary producers’ (Kaltschmitt, 2019). This classifies them as autotrophic organisms since CO_2 is an inorganic energy carrier. The energy produced from photosynthesis can also be converted to amino-acids and proteins, lipids and starches. Heterotrophic organisms, like animals and other bacteria depend on the production of organic carbon trough photosynthesis, and are logically available in a far smaller quantity, as can be seen in figure 22 where the organic carbon distribution of earth is disseminated. This depicts the small amount of living organisms on earth and in sea in comparison to the vast quantity of carbon from autotrophs.

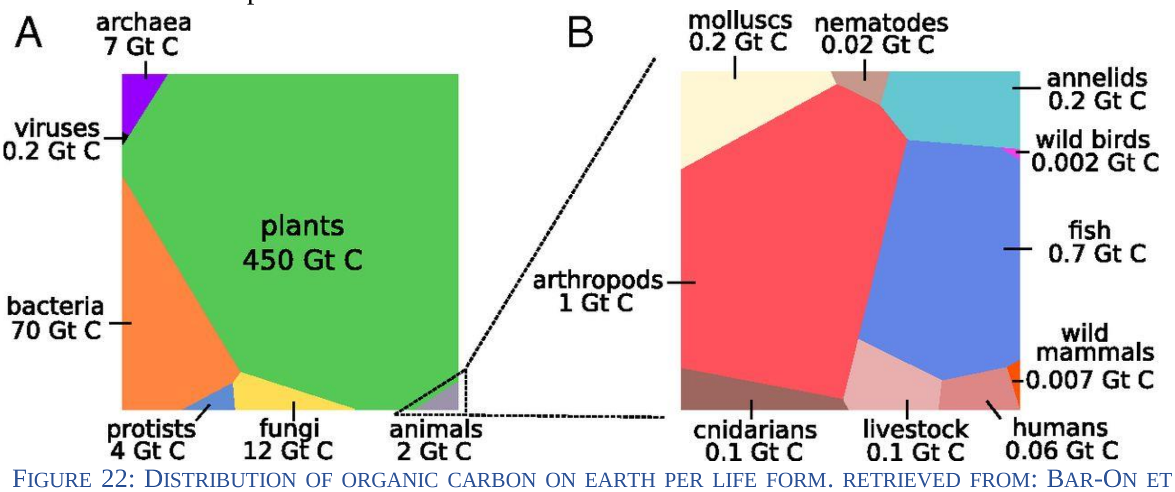

FIGURE 22: DISTRIBUTION OF ORGANIC CARBON ON EARTH PER LIFE FORM. RETRIEVED FROM: BAR-ON ET AL. (2018).

Appendix III – Technology Readiness Level

The way technologies are classified on their maturity is done by the 'Technology Readiness Level' scale. A score of 1 to 9 is provided to a technology. 1 meaning the subject is being studied, and 9 meaning a technology is commercially applied. Figure 23 shows a specified scale of the TRLs for CCS development. The stages of research, development and demonstration are universal for any technology (Kearns et al., 2021).

CATEGORY	TRL	DESCRIPTION
Demonstration	9	Normal commercial service
	8	Commercial demonstration, full-scale deployment in final form
	7	Sub-scale demonstration, fully functional prototype
Development	6	Fully integrated pilot tested in a relevant environment
	5	Sub-system validation in a relevant environment
	4	System validation in a laboratory environment
Research	3	Proof-of-concept tests, component level
	2	Formulation of the application
	1	Basic principles, observed, initial concept

FIGURE 23: TECHNOLOGY READINESS LEVEL SCALE FOR CCS DEVELOPMENT. RETRIEVED FROM KEARNS ET AL. (2021).

Appendix IV – Case-study

Shell's stakeholder matrix assessment results.

Stakeholder type/Question	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	Influence	Importance
Policy makers (EU, National, Regional)	1	1	1	1	1	0	1	1	1	0	5	3
Investors & financial institutions	1	1	0	0	1	0	1	1	0	1	3	3
Industry	0	0	1	1	1	1	1	0	1	1	3	4
Local public	0	1	1	1	1	1	0	1	1	0	4	3
Controlling organizations	0	1	1	1	1	0	0	0	0	0	4	0
Media	0	0	0	0	0	0	0	1	0	1	0	2
NGOs	1	1	0	0	0	0	0	1	0	1	2	2
Project teams	0	1	1	0	0	1	1	0	1	1	2	4
Technology suppliers	0	1	0	0	1	1	1	0	0	1	2	3
Suppliers and contractors	0	1	1	0	1	1	1	0	1	1	3	4

TABLE 11: SCORING OF SHELL'S STAKEHOLDERS THROUGH THE CHECKLIST METHOD BY ILINOVA ET AL. (2018).

Appendix V – Interview summaries

List of interviewees, including career affiliations, research classification and date of interview.

TABLE 12: EXPERT INTERVIEW RESPONDENTS.

Name	Affiliation	Classification	Date of interview
Marnix Brinkman	Nederlandse Emissie-authoriteit – Dutch emission authority.	Policymaker	28-06-2021
Bram Sommer	Porthos, Public affairs	Project development	6-07-2021
Pablo Vercruysse	Alco Energy	Project development	6-07-2021
Dominique Vrins	Ministerie van Infrastructuur en Waterstaat – Ministry of Infrastructure and Watermanagement	Policymaker	7-07-2021
Hennie Zirkzee	BiondOil – Chief Operating Officer	Project developer	12-07-2021
Herman van der Meyden	Shell – Manager governmental affairs	Project developer	22-07-2021
Sander van Egmond	Academic research, Greenpeace, TNO, Urgenda	n.a.	6-08-2021
Maarten Gnoth	Hinterland investment management	Institutional investor	18-08-2021
Dick Boddeus	Nationaal Groenfonds, Triodos, Rabobank	Institutional investor	30-08-2021

Marnix Brinkman

Marnix is advisor at the Nederlands Emissie-authoriteit (NEa), Dutch emission authority. He works in the department of 'energie voor vervoer' (Energy for transport), one of two branches of the 'Dutch Emission Authority'. The NEa is an independent part of the Dutch government that monitors the trade of CO_2 emission allowances.

With respect to BECCS, Marnix talks about the calculations for emissions for biofuels. In order to introduce a biofuel in the fuel-mix, it must adhere to a minimum percentage of emission reduction compared to the fossil alternative. The emissions are considered chain-wide, so go further than only emissions from exhausts. Emissions can surely be reduced by applying CCS and CCU.

The systems show parties are accredited for emissions reduction through biofuels differ per country. In the Netherlands you are accredited on the amount of renewable energy that is produced whereas in Germany, the amount of CO_2 reduction is taken. If you combine this with CCS and CCU, this could really become interesting financially, Marnix mentions. In the Netherlands the Ministry (Economic affairs and Climate) is considering creating such a system where **emission reduction** is **rewarded**. Marnix predicts this is probably going to be operational around **2025**. Although climate-target metrics vary per country, calculations adhere to the same methodology.

The NEa's view on fossil and biogenic carbon is hard to answer. It consists of multiple components. Biofuels in particular are rewarded within the NEa's system, being biogenic of nature. When considering CCS, this still only considers biogenic CCS, not negative emissions. Renewable energy created is the indicator for emission reduction.

Sustainable Biomass criteria

To assess the sustainability of biomass sourcing, Marnix refers to the ISCC certification as a system for sustainability criteria. Monitoring is currently conducted by the ISCC, an auditor. In the future, NEA will be responsible for this from next year to have more transparency in these chains.

Biogenic emissions are accounted as neutral. They can be deducted from total emissions, CCU, is one of them. What negative emissions are explicitly is not clearly defined. The ISCC is the biggest certifier on what sustainable biofuel. This is then checked by third-party auditors, who check the calculations when a company claims to have produced a certain amount of emissions.

Strictness of the audits.

When a company wants to be certified, audits take place at least once a year. How strict these look at CO_2 calculations he does not know. Marnix refers to the Dutch *Biodiesel fraud* as an example where the auditor could have detected malpractices earlier. The NEa will receive these auditing tasks next year and Marnix foresees the NEa will be a lot stricter in controlling companies.

Scopes of emissions considered

The department where Marnix works, Energie voor Vervoer, is mainly focussed on scope 2 and partly 3. Depending on the fuel, the suppliers are obligated to reduce emissions by a small amount.

The NEa is the conductor of policy. Looking at energy for transport, NEa also looks at potential incentives for CCU. Right now, focus is primarily getting to reduction conform to targets, focussing on quantity of renewable energy (This is not a good stimulus to improve emission reduction, with regard to good biomass, bad biomass., a business case is lacking.

NEa does not have a statement on negative emissions. Negative emissions will be necessary when you want to achieve the goals set in Paris in 2015 according to Marnix. BECCS is currently the most techno-economic solution. Fossil emissions should be reduced with help of CCS. Marnix sees it as plausible that negative emissions will not be included in the ETS.

Lignocellulosic biomass

Marnix is optimistic on lignocellulosic biomass as well as people in his network because sustainable wood harvesting. Sustainably sourced biomass is possible and bad examples are scarce. Negative emissions are also found in bioethanol production. A plus is the purity of the stream and easily an extension to BECCS. The barrier with food-crops, but also woody biomass, are still extremely controversial in the Netherlands.

A multitude of parliament members are opposed to these kinds of biomass, also for fuel properties. They are in the end responsible for the adoption of use of biomass, making it harder for BECCS to become mainstream. Parliament members focus more on electrification, not taking into account the necessity of bioenergy and BECCS.

Universal emission accounting systems

Marnix sees this only as a possibility through the IPCC (United Nations), creating a universal carbon accounting system. The RED II is the method for the EU. Additional emissions should be included next to scope 1, which goes further than the IPCC's carbon-accounting method. It should be more far-reaching. *Double accounting* is the only barrier but should not be a big problem given the challenge climate-change poses. This does however not provide an equitable system.

Global perspective

With regard to the rise of 3rd world countries (India and China) that are currently still growing their fossil industries, not having achieved peak emissions, Marnix mentions the carbon border adjustment mechanism. Marnix positive about this development and the role for the EU to increase reach.

Bram Sommer

Bram Sommer is public affairs officer as a lobbyist. He works at an office that is about transport, agriculture. Bram is currently outsourced to Port of Rotterdam. He is part of the SOM-COM team: translated to 'communication and management of public space'.

Bram mentions the current state of affairs of the project, which is going to be operational in 2024, and has recently finished off the final contracts. In 2022 the shareholders will give a final investment decision, then the purchase of pipeline will be conducted.

Stakeholders

Bram identifies the following stakeholders: municipality of Rotterdam, Province of Zuid-Holland, companies in the port area that may experience negative effects from construction and operation, people living in the vicinity of the project and NGO's.

Field of work

Bram is primarily occupied with politicians: national and European. He focusses on law and policy. Last two years Bram has worked on the Dutch SDE++ policy. Bram is focussed on law-based problems, not public relations. The problems that Bram finds are all subsidy related. How is a subsidy going to fit into a particular project is what concerns him.

Perception of CCS

The fact that CCS is eligible for SDE++ is not received positively everywhere. In some circles, CCS is seen as a technology that keeps away subsidy for these technologies. Greenpeace has sent a letter to Dutch parliament that this should not take away money from other budgets. The letter[4] argues for a subsidy for solely renewable energies, also H_2.

Greenpeace diversifies towards Climate-neutral technologies: also, because Joris Thijssen, ex chair of the board of Greenpeace, who is now part of parliament.

CCS was eventually included into SDE++, also because it was included in the Dutch climate-accord. This was included because it was recognized that without CCS the climate-accord would be rather impossible to achieve. Therefore, a lot of friction to the inclusion of CCS in SDE++. Greenpeace's actions to turn perception the bad way was however not very effective.

[4] Letter derived from https://www.greenpeace.org/static/planet4-netherlands-stateless/2021/07/d21f0a26-210701-greenpeace-notitie-ccs.pdf

Last subsidy round of SDE++ Shell and Exxon received some bad publicity for receiving funding. This motivation is explained because of two aspects:

1. Public money to big dirty companies;
2. Money for companies that should be doing another technology instead of CCS.

Port of Rotterdam

The opinion on the duration of life cycle differs per party. Port of Rotterdam sees CCS as viable for the long-term, making it a technology that will supply neutral emissions for the port's future endeavours. In particular blue hydrogen, but also negative emissions are envisioned to be generated in the future through this infrastructure. This is in contrast to people that view CCS as a transition technology that is necessary to bridge the gap in emission reduction until renewables have become more abundant.

Negative emissions

2050 is a year where negative emissions have started to develop according to Bram. The infrastructure in the Port of Rotterdam that is currently available can also be used for transport of CO_2 with regard to usage for fuel purposes -like E-fuels. By 'retrofitting' and the use of old infrastructure, perception may change from 'a necessary evil' to a 'necessary good.'

Accessibility Porthos

Porthos is an open-access network based on supply and demand. Every company was able to apply, four have emerged as final participants and right now capacity is full. How to expand this capacity is currently the question internally since storage potential is limited to around 37 Mt CO_2. Whether it is possible to expand to another open gas-field is something all initiators (Gasunie, EBN, Havenbedrijf) are working out as of now. Porthos is also doing a pilot CO_2 -distribution project for the ministry of Economic Affairs and Climate for the destination of CCU. This concerns the seasonal demand for CO_2 by the horticulture in the accompanying Westland.

Exploitability of knowledge

Whether the information and experience from Porthos are exploitable for other future cases Bram thinks is likely. Internationally there are a lot of questions on Porthos. Bram personally also receives a lot of questions on the SDE++ subsidy scheme since they only can apply for EU subsidy. Bram identifies a big discrepancy in budget potential for CCS from EU subsidies.

Public perception on CCS

Port of Rotterdam does not measure public acceptance of Porthos. Brams's personal opinion is that the public perception is not positive. The upside is that CCS is part of the climate-accord, so it is set to develop further.

Bram identifies that only sporadically politicians talk about their opposition on CCS when it appears in the news again. His opinion is that extended negative coverage does not succeed because CCS gets clouded together with issues related to renewable energy technologies that are inherently controversial in their own ways. In Dutch politics, there is very little opposition found in the trajectory of CCS. Bram explains that the decision to do CCS offshore is already a big upgrade for public perception compared to storage on land.

Incentivising CCS

The SDE++ subsidy only partly finances renewable energy project. Profits are still allowed to be made and entail 4-5% on investment. This is however partly on public money, so perception public perception is important to consider. Considering the ETS price is rising, Bram sees that making CCS as a profitable, logical investment option. Bram does not worry about the future financial incentive.

Guidehouse is an organization that shows options on alternatives for CCS, showing that Porthos' sourcing of CO_2 is best. application of CCS currently the best way to operate is. If the next two years subsidy will be provided in the next SDE++ rounds, Bram is very confident Porthos will have economic stability.

Legal risk

Porthos has not received any financial claim form external parties. Bram mentions that the project has been rather lucky with the availability of an unused existing pipeline to A pipeline is created over land to the Noordzee. The trajectory of which was already through industrial areas, so not hindering any towns and cities. This is considered quite fortunate considering the small risk CO_2 leakage.

In addition, depleted oil and gas are often not completely depleted. This may result in potential claims from the administrators of these gas fields claiming to lose potential income due to remaining natural gas.

Competition with alternative technologies

Bram acknowledges the danger of inter-project legal problems when comparing a hypothetical off-shore wind park and off-shore CCS. The fact that Porthos is likely to expand its oil-field usage implies a battle for sea area. Horticulture is also demanding more CO_2, being in competition with CCS. Same for electricity grids, which need to be adjusted in cooperation with the grid provider because CCS demands a lot of energy.

European cooperation

Bram mentions the potential idea for a more holistic European approach to energy transition. In Netherlands and Norway and others are in the advantageous position for CCS. Other countries lack the spatial possibility of gas and oil fields. If a trans-border CCS network could be deployed, the business case would improve significantly. To fit this idea the largest restrictions would be foreign policy, regulating CO_2 quantities and responsibilities for storage.

Pablo Vercruysse

Pablo Vercruysse is director of technology, quality and environment for Alco energy in Rotterdam and Alco biofuel in Ghent, both biorefineries and producing bioethanol, green CO_2, protein-rich animal feed, electricity and other by-products. He has a past in quality and assurance and operations management.

Alco and the destination of CO_2

CCS and BECCS are on the agenda for Alco. Alco is currently working with Porthos and Athos. The Ethanol plant is a great source of biogenic CO_2.

The production process for bio-ethanol utilizes 2/3 of the maize for the product and an additional rest-stream that is protein rich animal feed. All CO_2 from fermentation of maize is captured and is sent to Rotterdam (CCU). Alco also generates its own energy; however, natural gas is used for this process and not energy from biomass. These are Alco's sources of CO_2 for potential CCS and CCU.

Incentives

About financial barriers and incentives, Pablo tells that in the Netherlands there is at the moment talk going on about a CO_2 tax. In addition, the ETS provides all companies a % of emission rights for free declining. Fossil CO_2 emission rights need to be paid. In the past they were 5 euros, but currently already 50 euro per ton CO_2. Pablo sees this rise to 100 in the future.

Pablo says that the EU claims to be best kid in class considering green energy, but still pose too many restrictions for green technology to occur. The government needs to incentivise capture of CO2, more important for fossil, but more expensive CO_2.

Also CCS is very expensive to operate but however does generate ETS, but there are no ETS compensations other specific CCS compensations available from government. Both Belgium and the Netherlands have no incentive for CCU.

BECCS and CCS

Capture of CO_2 to a 99% pure compound from bio-ethanol production. The capture of fossil CO_2 is post-combustion and has low purity. Biogenic CO_2 does not need to be purified.

Pablo mentions that other potential sources of biogenic emissions are a large % of waste processing and biogas. Both processes do not supply a pure source CO_2.

Coming years, a large price difference shall emerge for fossil CO_2. If paying for emission rights is cheaper than CCS operations, emitting is the go-to. This determines the business-case heavily.

Inclusiveness of CCS

When asked about why Alco did not connect itself to Porthos he answers that they were very willing to, but since there were only limited reservations available, they lost a spot to bigger companies like Shell. Pablo confirms that ‘Inclusiveness for CCS is restricted’.

Subsequently, the capture, purification, liquification and transport of CO_2 are a costly problem for smaller producers like Alco.

CCU

Apart from CCU for horticulture, E-fuels are a on the radar in Ghent. These are however new concepts, and still heavily depend on subsidies to develop. The cost-price for E-fuel is equal to bio-methanol. In Ghent, Alco is developing this e-fuel project.

CCU with chemicals is not yet in ETS, so only costs occur + the payment for Emission rights. Chemicals are also very energy intensive and have lower margins than fossil fuel production. It means upgrading carbon to useful products. CCU for chemicals is not a business case.

In Ghent, CO_2 is purified for use in soft drinks, having to comply to NVWA standards. This demands very specific product composition, which adds more costs to the purification process.

Currently: fossil CO_2 capture and CCS is relevant to ETS. Alco does recommend capturing CO_2 for bioethanol production. Other CCU application is researched by Alco, but currently does not consist a business case other than horticulture.

Competition

Hydrogen is a resource necessary for a lot of chemicals and specific biofuel production. This inflicts competition between these different products. Hydrogen is bound to consuming a lot of energy, and considering that electricity to be green, creating a larger demand for renewable energy.

Talking about e-fuels. Demand for green electricity is also too high. 2030 shall be a moment when this imbalance is more stabilized. LCA is necessary to determine what option is most clean.

Synergies

Bioethanol from maize is not a complete problem solver, but it does give a useful protein by-product. This may become a great substitute for unsustainable soy for feed use. Soy-import is avoided. 2nd gen ethanol from waste streams is desired but does not give the valuable protein by-product.

The EU does have a protein deficiency. This problem is viewed from an energy perspective, only looking at the energy value of product, also from by-product. This is completely irrelevant for protein for animal-feed. The LCA for bioethanol is only focussed on energy, does not include waste streams.

Environmental agencies do not highlight the omission of soy imports. The Protein and energy sections of the EC do not communicate.

Reputational risk

Public perception from Alco's operations: Bioethanol CO_2 capture perception is limited and depends on the level of knowledge of a person. The regular man in the street is not aware of the production process of ethanol. Environmental agencies are however stigmatizing the use of a food-source, but from a LCA -perspective, are exaggerating the food-waste story. CO_2 abatement is 99% compared to fossil fuel, which is important information to share to people who are unaware.

The fact that a food-resource is used is often inflated also by politicians. Some people do not comprehend the overall outputs form this process, not even biogenic CO_2.

Demand for biogenic CO_2

Demand for bio-CO2 is high by horticulture, but supply is very limited. This is not necessarily because of climate goals, but purification costs. The biggest demand for biogenic CO_2 comes from the chemical industry. Recent years more than before due to more subsidy by governments to invest in such a resource. Bioethanol refineries have had some incentives for development, otherwise they would not have been built.

Rotterdam already has pipeline infrastructure that can be used for transport of liquid CO_2. Impurities are primarily NO_x. Depending on the final use, CO_2 needs processing anyway since applications demand specific compositions of CO_2 gasses (They are not 100% pure).

Alco sees the first sign of bio CO2 gaining value. Horticulture preferences Bio CO2 to fossil. In some years this is going to be a problem, given the limited amount of bio-CO2 available and the growing demand from industry.

Only Bioethanol is currently used for CO_2 capture and usage. 2nd generation bioethanol is currently not an option. Lack of investment, restriction on biomass sourcing are main barriers for uptake of 2nd gen bioethanol production.

Seasonality of demand

The demand for CO_2 is both seasonal for soft-drinks and for horticulture. Additionally, storage of CO_2 is limited. Other than crops, demand varies for CO_2 also based on

Technological innovation

The pace for technological innovation on chemicals is very hight. Choices for right technologies are super important, also with respect to new ground-breaking technologies.

Minimum mixing requirements

Minimum amounts of biofuel are currently required for road transport. Premiums are provided for this. This is currently mandatory, because voluntary mixing did not occur. Pablo emphasizes that mixing biogenic CO_2 will never be initiated by companies: it is expensive, thus hard measures are needed to push through higher.

Dominque Vrins

Dominique Vrins works at the Dutch ministry of ‘infrastructure and transport’ on sustainable transport. She focusses on inland shipping, aviation and road transport. She works out questions around sustainable biomass and energy reduction. This ministry handles the questions surrounding sustainable biomass and energy reduction. All terms and conditions are in the RED II guide emission accounting and is used by this ministry. The ministry is the conductor of policy, not the creator.

Biofuels

Future demand of biomass shall increase; hence biomass shall also be in higher demand.

Public perception

The government has to deal with the public perception. If the government does not manage public perception, scepticism. The chains including agricultural and feed crops are currently starting to be **phased out** by the Dutch senate, although the climate-accord allows for moderate use of these biomass resources.

Minique mentions a bio-diesel fraud case where biodiesel was incorrectly and insufficiently accounted in the books and illegal certification. The bio-diesel fraud case is very important: Used Cooking Oils for biodiesel emit way less than fossil diesel.

The NEa does the audits for biofuel producers together with ILT (Investigation bureau of transport and physical environment) on chain-wide sustainable fuel.

Accountability producers

The auditing for biodiesel fraud was too limited. Only the books could be checked but could not check the full chain operations. Recently a law passed where this was adjusted.

Biofuels can be identified by special isotope tests where the C14 carbon atom is detected. Instead of regular fossil C12.

Emission certificates are likely to become applied chain-wide to improve overall sustainability and transparency.

Waste stream potential

The Netherlands has large waste-stream production, but the system of value is missing. This is a large opportunity according to Minique since streams are often only valued on energy content.

Sustainable biofuel bottlenecks

The largest bottleneck for biofuel uptake Minique considers to be the ceiling of 65% mixing potential with fossil fuels. Another is the sufficient sustainable biomass supply. It is very hard to determine whether biomass is sustainably viable. Also, to which industry it goes is a question. When upping the percentage in the mix, biofuel needs to be upgraded more, incurring more costs. If this is not necessary, upping this percentage is not performed without any mandate.

RED II accounting rules are being implemented as of now and will demand a certain percentage of % e-fuels in some fuels in 2030. The development however is not going fast according to Minique: there is little sector interest due to additional liquification and transport steps of CO_2.

Biofuel potential

Transport sectors like inland maritime transport must reduce 60% emissions with use of flue gas desulphurization and aviation is under ETS, the national target is being adjusted. The ETS for Road-transport is becoming relevant in 2025. Expansion ETS to road transport. Emissions are viewed as 0 at the exhaust. From the REDII.

Sustainability criterium is 65% less emissions with regard to fossil fuel. At the moment CCS and CCU is not a business case. In 2025, more interest is likely to emerge. In Germany this is more relevant, because that is the modus operandi on emission targets, and not production of renewables.

The Dutch government calculates climate targets focussing on percentage of renewable energy produced. 60-65% CO_2 reduction is necessary, CCS not relevant, but in Germany it is.

Alco is creating ethanol from food and feed crops, experiencing push-back. Interest is very low in such chains. I&W shares the thought that biofuel (food crops) can be sustainable. Minique hopes that the market will join this vision.

Hennie Zirkzee

Hennie Zirkzee is a chemical engineer, academic and currently Chief Operating Officer at BiondOil. He has worked in American and Dutch chemical industry. Focus was on R&D, plant management and bio-based and bio-refinery projects. The company Biondoil can be seen as a technology brokerage, connecting the investor with the developer. Additionally, BiondOil is project-developing itself. All in all, a spider in the web. A 2nd generation Bioethanol plant is currently under development and is planned to be operational in 2025.

CCS and CCU

CCS is on the agenda for BiondOil. Next steps for are finding a partners: Porthos, Athos for future collaboration.

A 2nd gen bio-ethanol plant emits biogenic CO_2. Can we upgrade from the product how it is? Liquification of CO_2 brings utility to food products and horticulture. Fuel is also an option. Of course, H_2 is needed for methanol and other fuels. Other CCU for chemicals and other materials is possible but is in a lower TRL. Looking at costs and risks is very ETS-related. Certificates are related market with bioCO_2.

Negative emissions

Hennie does not accept the term negative emissions. He says it is an administrative problem that incorporates the problem of permanency.

Hennie does believe in emission reduction up till zero, as this is the best thing possible. Active human regulation of atmospheric CO_2 is far-fetched because of the variation in the short carbon cycle.

BiondOil future vision

Energy cell concept: In situ CO_2 capture inside the system: combustion and capture in car. Eventually dropping off CO_2 and tanking for ethanol at a tank station. The tank station stores the CO_2 to be later transported and used for e-fuel. It is still very much a concept: The TRL of the energy cell is 3-4. CO_2 module is being designed, then utilized in a ship. Hennie says this will take about 10 years to become operational and is more of side-project.

Hennie points out that EV's are bound to serve road transport in urban areas. For rural areas, fuels like the energy cell technology shall become more important.

CCU for Biondoil is in the pipeline for multiple innovations but is totally dependent on future demand.

Synergies

Synergies for biofuel production can most easily be found in alcoholic biofuel processes. Hennie describes this as fermentation coupled to thermo catalytic processes.

Biomass fraud

Every biomass system is fraud sensitive. Audits and reviews, improving traceability are keys to enhance legitimacy for developers.

A measure to combat biomass fraud is to use technologies like remote sensing and block-chain systems. This transition must be sector driven and is not possible for individual parties. Reputational value is only generated when this whole stuff is put into place and operational. The fact that we are talking in hypotheticals means this is still far in the future.

Reputational gain/loss

Biondoil's potential reputational gain for use of biogenic products will only be received when operational and is currently not measurable, says Hennie. When only displayed on 'powerpoint slides', a project does not say much about its future operationality.

Green NGOs are in Hennie's eyes too focussed on everything wrong with renewable technologies. Every technology has its shortcoming, and biomass is particularly viewed as negative. The sourcing of biomass should only be by-product of processed wood. All NGOs are against biomass and should be given no reason to address unsustainable practices.

This means that if a biorefinery is caught on something illegal or unprocedural, a project may lose subsidy very fast. If this risk is not managed, the people have no project. How to combat this? Instead of combustion Hennie proposed to cascade, upgrade the wood pellets. A counter argument is to cascade in first option. Extract lignine, having cellulose and hemicellulose.

Demand for net-neutral product

Demand for ethanol comes primarily from Shell and AtJ producers. Creating a circular strategy is based on the aggregate demand for a product, assuring economic viability as top priority for the customer.

Business-case criteria and finance

Whether there is a business case for CO_2, fossil and biogenic, taking in mind the vast capex of infrastructure, Hennie answers reluctantly. BiondOil does not see itself as ideologically far on the spectrum on green innovations: first criterium is to be financially viable by looking at all revenue streams.

Biorefineries are 100 millions of euros, partly loans from banks and part equity. The risk ought to be reduced, often by assuring contracts on bio-resources for 5-10 years, but also on the supply side for Ethanol. Only then, the black box, also known as the plant, is discussed regarding finance. Proven technologies are assessed, looking at existing cases of operation. A scenario is needed where trust is gained through existing technologies. First, basic risk is defined, then the business case.

A vicious circle can be acknowledged: By lack of cases and information trust is lacking. Cases are lacking because lack of investment. Subsidy is a big variable in the development of biorefineries. Collateralization on behalf of the government is a possible criterium for reliance.

Herman van der Meyden

Herman van der Meyden is a manager for Shell in the Porthos project. He concerns himself with government relations and energy transition. He communicates with NGOs, environmental agencies, government and sector parties and describes himself as a lobbyist. He has a background in engineering and political science and is now three years in his current function. Experienced in CCS, Porthos manager.

Shell and BECCS

Herman confirms Shell is experimenting BECCS and is developing two BECCS cases:

1) Shell's aspiration for BECCS via biofuel production: biogenic CO_2 emissions from biodiesel production: HEFA (hydro-processed esters and fatty-acids) and HVO (hydrotreated vegetable oils) plants in Rotterdam, generating negative emissions. Currently Shell has requested subsidy for this project and a final investment decision is almost made.

Herman says that Shell has a patented technological innovation of capture with higher capture efficiency.

2) There is also a chicken manure combustion facility for energy. There is currently a demonstration in Moerdijk which is planned to be expanded. 1t per day pilot factory. +60t demonstration

HVO, HEFA are Jet-fuel, diesels and naphtha's. The by-product CO_2 is not pure and needs to be concentrated with additional steps: O_2 driven processes.

Fossil or biogenic, CO_2 is CO_2 says Herman. Oxyfuel combustion creates purer CO_2 stream. Concrete projects are on the agenda. O2-driven capture processes result in pure CO_2. Gasifier plant for residue refinery Pernis, pure CO_2 that is sold to Westland. Capture from biofuel installation utilizes this capture and upgrade technologies. This stream will be used for Porthos in the future.

Shell is historically largely immersed in CCS. The technology is ready, the business case and social acceptance are the current question marks. Nederland, Canada QUEST, Mexico.

CCU and Shell

Expansion of **CCU** is limited to policy. The use of CO_2 for horticulture does not count as emission reduction. There is no real stimulus for doing CCU. Back in the day when shell started doing it, 2005-2008 it was into the system, after that no more in ETS compensation.

In cooperation with government, this resulted in the CCU pilot, Horticulture Nederland. OCAP and Herman carried the case for CCU and CCS and combining it, making it profitable for all parties. This is still a pending project (Horticulture).

Cement is one other application for Shell. Shell is currently using CO_2 for batteries. Moerdijk Combia buys CO_2 to put in carbonates. All processes re very high energy penalty according to Herman. To make use of CO_2 a lot of energy is needed, opposite of combustion. This is not always included in PowerPoints.

Future Business-model Shell

The future of Shell's BM: Which technology will Shell turn to? All things mentioned are in the mix: Large-scale electrification, Hydrogen, CCU, E-fuels and Biofuels. Shell will likely be a electricity company in the future. Offshore wind projects have recently been awarded prizes (Mayflower) of 1 GW becoming a nice capable source energy. Biofuels too: 2^{nd} gen biofuels, waste-stream feedstock, Hydrogen, CCS + natural gas, hard to decarbonize sectors, aviation, maritime and steel production.

Concluding: people should not forget how much energy is consumed, and what changes are needed to capture this discrepancy to a fully sustainable system.

Legal risk

On the milieudefensie case:

Cases are part of a collective pressure from society like *Follow this* (Mark van Baal), increasing pressure. The specific decision by the court is not helpful for Shell in Herman's opinion. On the one hand, these cases will provide more communication to move faster. To create movement is very useful. The way how this decision is motivated is not in line with Herman's view on business. ''It only offer targets instead of HOW''. The overall pressure does help.

Shell does experience no real pushback for the choice to do it an sich, but the fact that Shell receives public funds for it creates a lot of pushback, especially by receiving subsidy for CCS and wind parks, are clean investments but are still not received well according to Herman.

After an 8 o'clock news meeting, an NGO is seen to be the cause of global warming, concluding that they should all just pay for it themselves, restricting funds for other (real) sustainable alternatives. Shell does also create offshore wind. The main thing for investments is a profit. This is the main driver. In the end, politicians gathered behind it, so it is accepted to an extent.

Ambition of Shell

Is Shell doing everything it can do? Since Herman is working at Shell, 2006, he would have said no, but right now, for Shell Nederland yes. Permit procurement, SDE++, EU subsidies, Infrastructure, electricity grid are the restricting variables, not Shell. Herman agrees that the pace of the transition is too slow. We also must accept all available alternatives. The power line through Schiermonnikoog, has recently lost its innocence. You can always find something to pull a technology down and inflate the negatives in a way it is not fair. Herman ends with saying it IS POSSIBLE to achieve the climate goals: Offshore wind, CCS potential. Both politically and socially the willingness to transition is increasing.

Sander van Egmond

Sander van Egmond has a wide background: he has a PhD related to CCS, worked at Greenpeace and Urgenda. He is now Freelance consultant and works primarily on geo-thermal heating projects.

Biomass transparency

Sander highlights the issue on clarity of sustainable biomass. He hears a lot of voices saying opposite things on the sustainability of biomass: wood is whether sustainable trim-wood or production forest wood. He mentions that the decomposition analysis is lacking on which source of wood comes from where. The areas of cultivation are calculated, but do not distinguish trim wood or production forest. This difference is important because one produces biomass ten-fold per area. For sustainable wood-sourcing a lot of area is necessary and transparency on biomass type is very unclear as of now.

Sander asks for transparent calculations to be developed: farmers address fundamental problems in the current way biomass is cultivated.

Effectiveness of BECCS

The notion of a CO_2 budget is also one Sander disputes. The question is if you really have 15 years like the IPCC mentions. And what happens if you leave the forests be? Don't they capture more carbon? Both perceptions, but also calculation on the real effectiveness of BECCS are disputed by Sander.

Competition with other technologies

Sander highlights a potential J-curve for prices around biomass: increased demand would eventually result in a price-increase over time. Prices for Wind and PV however are steadily declining, whereas biomass has more unknown price forecasts. The Technical aspects of biomass are about money, prices are not going down. This is also the case for CCS and nuclear energy. Developments around renewables are so fast that the use of BECCS and CCS can be considered debatable.

Also, battery development is going very fast. Hence, CCS with electricity production is a station passed. All renewables are superior. Sander acknowledges there will be exceptions, but he sees biomass *and* CCS as a far-fetched solution to combat emissions.

Legitimate CCS chains

Steel and cement are then better options. CCS is super expensive according to CCS is necessary until growth of CCS curves is not comparable to alternatives.

The feedstocks for CCS are wide, as well as different capture methods, infinite chains. All to the electricity sector. E-fuels are only for aviation going to be valuable, the rest can be electrified. The places where a difference can be made are limited. Emphasis is on economic aspects. Nuclear is also more expensive. Nuclear energy is also not on the short term available. And on what term can CCS play a role?

Past strategy

Sander mentions that in the past, unintelligently, CCS was coupled to the building of new coal factories, labelling it grey coal. The case of Barendrecht was initially developing according to plan. It went wrong with NGO interference in the national discussion, partly because of coal. If this was with steel, Sander predicts nothing would have happened. Sander predicts the same would happen for Biomass, there are certain applications for biomass (industrial application from waste streams like manure) than the social acceptance is a lot higher.

Claims against Public and Private organizations

The legal decision recently made in the case of Milieudefensie against Shell is very important (*Interview – Sander van Egmond)*. Although there will appeal to the court's decision a couple of times, this will in the end be very decisive and saying. Even when there will be appeal twice before Shell will comply,

Van Egmond talks about the weirdness of going to court as a club like Urgenda and Milieudefensie. Both ''Shell and the Dutch government can calculate, but in the end the emission targets are not sufficient. If you say you support the Paris accord, one should act towards it. Shell still spends 90% of budget in fossil investment. '' Shell is not the worst multinational, but if you invest 90% in fossil projects you are still going the wrong way.

The legal case of Urgenda against the Dutch government was defended by the argument of BECCS in the future. The Judge described that as doing a mortgage on two technologies that are currently not even a reality. The fact that we are only now doing CCS, and not earlier is very weird. Deadline setting and later pushing away is detrimental to achieving climate targets.

Time perspective

The fact that fossil investment projects are often for decades, also not being in the picture of the Paris picture. The lag between initiation and operationality is not to be neglected.

Perception of CCS

The perception of CCS per stakeholder differently. In academia views on CCS also differ. Some academics though are against CCS. The biggest difference is in the perception of urgence to act. Another one is belief in technology versus behaviour. NGOs look at it as a communal change whereas organizations view it as the task of technology to reduce emissions.

The behavioural patterns for emissions reductions are broader than sheer direct energy use: ''going to the gym, bringing your kids, riding a bike that could have been driven outside, in an air-conditioned room, because you eat too much'', is a display of a system that is not efficient. In the end, the production industries are not primarily accountable for emissions considering the larger picture, hence CCS is not the universal key to emission reduction (*Interview – Sander van Egmond)*.

Bottlenecks sustainable systemic change

Sander does not see uptake of sustainable lifestyle being restricted by money. It is less about expensive cars, but more about the systems that people incorporate in their live: why go frisbeeing in France when there is a park a street away.

You have to keep an eye out for workers fossil industries which are in danger of disappearing.

The biggest restrictions to backing of sustainable technologies are community support and the hands to put in the labour.

Competitive demand CO_2

Competitive position CO_2: biogenic and fossil. CCS is technology for large installations. In which of those do I see biomass? Industries like steel and chemicals.

CCS

Another disadvantage CCS is that it needs to run full scale all the time, making it even more expensive, so CCS with electricity is no option. Sourcing may change in the future when sourcing from South America will stop.

Technical potential

Technical potential for CCS on the North Sea is a lot. The financing of Porthos to become total is almost finished, but Sander is still sceptical it will be completed. This is a very unlikely constraint.

Subsidies

When asked about a separate subsidy for both CCS and renewables or separate, Sander says it does not matter. He remembers a conversation with Diederik Samson. He said: in the end it all comes from one budget: taxes. On the other hand, CCS should not push out other technologies. It is more a administrative, temporary problem according to Sander.

Maarten Gnoth

Maarten has worked extensively in the Dutch energy sector, particularly on biomass trade and sourcing. He works at Perpetual Next, an investment fund for sustainable technologies. He works more as a freelancer, also attending congresses. Maarten has worked on the ROAD CCS project (Engie and Uniper) and has frequent contact with people from Drax.

A possible transition pathway

For electricity biomass is a transition fuel. Industry has more attraction for biomass use. Transport is also very limited in solutions. Industry, built environment, resources that are captured in a product. Not an energy carrier but a product.

In an ideal world if all technologies are exploited, BECCS may be very well suited to generate negative emissions. In the media, the press has two school of thought around BECCS:

1) BECCS is the reason to keep biomass alive: a way to parry the short cycle loop;
2) It is not the cheapest form of CCS.

In theory it should not matter where CO_2 is captured. Why should it be captured from the most efficient high concentration source? BECCS is twice as expensive as Coal CCS, so why invest in that? Cost-efficiency is forgotten sometimes. Instead, the low-hanging fruit can more easily be captured in contrast. Maarten does see BECCS have a future potential role.

Downsides of Biomass cultivation

Biomass has a bad image. Co-firing is one option that is unsustainable. There are some chains that cannot be continued to produce anymore. Replacing existing forests with production forrest, cutting wood from High Conservation Value forests (HCVFs), which is bad for biodiversity, large-scale wood for reduction of total carbon stock.

In the Netherlands, all NGOs are against the use of biomass, especially co-firing with coal. However, during the recent ‘Fit for 55’ webinar Frans Timmermans mentions we cannot go without biomass.

What you do want is professional forest management (good for increase carbon stock and protection biodiversity) with sufficient forestry certificates. Those certificates, with a black-list of companies and audits, are not water-tight, but are against these excess cases and ban those. Current certification is already covering a lot.

Biomass price and sourcing

For biomass there is no market principle: The more you buy, the price stays the same. Sourcing needs to be done from other continents or otherwise, local sources must be utilized. This is also possible but has only limited demand.

BECCS biggest barrier is also the biomass feedstock volume. If you want to do BECCS, this desirably comes from a large plant, no matter the output. For such a BECCS plant, this implies a demand 4-7 Mt wood pellets per year. For BECCS, only coal co-firing in Rotterdam would be fitting, but these are being out phased. There are almost no installations ready for BECCS deployment and it is unlikely to be installed for a 10MW plant. This means that a lot of biomasses will be needed and is this in a sustainable way available.

BECCS could be applied in, EU, North America, Canada, Malaysia, Singapore. Some large-scale plants 0.5 to 1 Mt per year supply necessary applying shipment transport. These are the most likely working BECCS scenarios.

Maarten is for the local sourcing and processing of biomass in order to avoid excessive sourcing and transport costs. It should be determined whether you want to source more wood from overseas instead of locally and produce on smaller scale. Europe shall then have a problem, but other places could apply this strategy. It will not matter in the long-run, emissions are global and emission reduction could take place anywhere.

Centralized vs Decentralized

Maarten's opinion is to produce BECCS in a more decentralized fashion for Europe, applying BECCS in other countries.

When designing a new energy system…

For the design of an energy system these questions are important:

1) Scale of operations: large or smaller?
2) Valorization of energy? Heat, electricity, steam?
3) Locally? Near the end user?
4) Transport distance of resources?

For feasible European BECCS you need a centralized large facility, which implies more pipelines and long-distance biomass sourcing, defeating the purpose of potential negative emissions.

Competition for CO_2

The demand for CO_2 will depend on the carbon pricing. Carbon prices in april 2021 were 50 euros per ton of CO_2. This is a price for many technologies to go break even, Maarten says. Subsequently, with this cash flow, business will receive finance from investors.

It is important how investors see this carbon price: is it going up? Can we rely on this carbon market, or should we go for risk avoidance? The Carbon price varies a lot per country. If it stays at a stable 50 euros, there is a business case for CCS. Below that, not so much in Maarten's opinion

Maarten identifies a potential competition for CO_2 in places where it is heavily used as a commodity, like soft drinks in Asia.

Finance and risk of renewable energy technologies

Risk of BECCS and CCS. Wind on and offshore is currently manageable risk for institutional investors atm. Retirement funds, institutional investors. PV, PPA long-term warranty.

Biomass is ad hoc (Here and now dependent). Harder to finance. BECCS individual were bound to a lot of subsidies. Back then, it was not yet a proven technology, and the inherent partner companies ENGIE were not able to provide these funds. Banks, but also institutional investors will be last to invest. Maybe BECCS in a portfolio is an option, but a solo project to get investment is too early.

Risk-assessment tools for renewable energy projects

A risk profile is constructed on all relevant variables. For a wind park there are permits, contracts for electricity and maintenance that are considered in final risk. The overall risk-profile is a lot higher for biomass processing compared to wind parks.

Biomass risk varies heavily per chain and conversion method. There only some generic chain cases considered for risk assessment, the rest is its own niche of risk.

Investors want 10 years to set a price for 10 years, but this is not possible for Biomass. Biomass has a pay-back time of over 10 years. In addition, maintenance, fire hazard, mechanical failures add up to the total picture.

Retrofitting old infrastructure

CCS is very fit for the North-sea and the east coast of the US. Logistically, a reverse system can be created from old gas infra, hence, this is a nice impulse. Other countries have better incentives, but the North Sea is very useful. This 'reverse system' should be applied as much as possible before storing in saline aquifers.

Dick Boddeus

Dick is investment manager at the Nationaal Groenfonds (Dutch National Green fund). He has also worked for Rabobank and Triodos bank. He is responsible for the sections Sustainable Economy, Energy and Circular Economy and Nature and Landscape. From m September 1st, Dick is responsible for the front-office of the Groenfonds

Green Fund

The Groenfonds is a semi-public, semi-private organizations in line with the ministry of Agriculture, Nature and food-quality. It provides loans for a variation of project: from PV, wind, geo-thermal heating, biomass and biofuel projects.

Only last 5 years, the Groenfonds has started funding renewables. Only waste-product biomass is invested in. This will in the end fund itself, because it is lucrative produce.

Loan requests for CCS and BECCS

Groenfonds looks at every request, but for CCS and BECCS projects, the fund is rather small: about 70 million euros to be loaned in total. ''If a request for a project in general is more than 50 (CAPEX) mil, eyebrows are raised here'', Dick says, showing that Groenfonds cannot finance CCS and BECCS in totality. It can however provide subordinate loans. If a project needs 100, and the bank is not willing to fund completely equity is needed to complement to the amount that is still necessary.

The Groenfonds supplies loans to projects based on the stability of future cash flows. Debt payment happens in the following order: First the senior fund or bank receives their money, then the Groenfonds and then the equity holders in form of dividends.

Biomass

Sustainable biomass is essential for BECCS. The Groenfonds perspective is focused on nature conservation and biodiversity. Biomass financing is being financed because it is considered a rest-stream from nature.

It is lucrative to value waste streams of wood given there is a semi-constant flow of biomass from nature. Additionally. cascading for other uses is an option. The biomass project is often limited to some **constraints**: biomass from limited range (**100km**). It must also contain the same value, meaning consistent composition and features.

Biomass is a **transition resource**. Electricity and heat are not likely options, but industry is (chemicals). Is this is sourced in the vicinity of a plant, use of biomass is allowed. Groenfonds is quite pragmatic: the funding is often for (smaller) technological upgrades for biomass. Bio-LNG from waste supermarket products, produced by Nordsol, is one application that is funded by the Groenfonds. Its CO_2 then is sold to horticulture.

Groenfonds is financer, and there is SDE subsidy coupled to it: it compensates price changes, predictability. The government warrants as collateral.

Risk assessment biomass

Some risks for giving out loans are technical risks, Dick tells. It can be divided in three forms, relating to biomass.

- *Input*: Is a feedstock available for the long-term, is it sustainable and price-constant?
- *Throughput*: Are installations dependable? Risk that is pretty good quantifiable. Assessment is done by an external agency.
- *Output*: Technical risk that is constructed by engineer opinions. Procurement of product set in a contract for time and price.

Social acceptance

Currently biomass is under a lot of scrutiny: is it really sustainable or not? Public opinion is very hard to assess. Some indicators of lesser risk are when politics give green light and whether permits have been provided.

Dick tells that in a recent case a biomass installation was just financed, then the highest court made a say about the Nitrogen that was associated with production, which is currently ruining the business case. Stability is key for risk-assessment. You want to be able to predict for everything. If a specific part has a lifetime of X years, you can save up for that early. Financers will vanish when this kind of news comes out.

Interest-rate in setting loans

What happens in the market? Final interest is constituted out of three factors: cost of funding (Market interest); handling costs, risk of storage. All become higher when the risk becomes higher.

Good loan distributor knows something has a stable cash-flow or suitable collateral.

Risk for other renewables: PV, geo-thermal wells

Groenfonds has made a ordinance per sector. PV is pretty straightforward: A roof with southeast sun you can calculate X output easily: low risk. A geothermal well is a lot harder to predict depth of drilling, capacity etc. The technique needs to be proven in some way. TRL **7** is minimally required for investment. Lower than that, equity is needed.

Potential value of CO_2

Dick is not able to see CO_2 gaining value in the future. Groenfond does look at the future, but financing concerns the now. Groenfonds is too small to really invest in such large projects, but they fund how they can.

Production of bio-LNG by Nordsol, is a business case for Shell, who acquired the company recently. Sales of bio-LNG by-product CO_2 to horticulture is extra. This gives value to the CO_2 but is not the determining factor. It is also a fraction of profit compared to the Bio-LNG.