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Morgana Gabrielle Forlin Dumke

Developing a Business Model for a German Direct Air Capture Company: a Case Study

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Bachelor Thesis submitted to the Course of Mechanical Industrial Engineering from Federal University of Santa Catarina to obtain the title of Graduate in Mechanical Engineering, with a license for Industrial Engineering.
Supervisor:: Profª. Caroline Rodrigues Vaz, Dra.

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The present study at the level of Graduate was evaluated and approved by the examination board composed of the following members:

Prof.(a) Caroline Rodrigues Vaz, Dr(a).
Institution Federal University of Santa Catarina

Prof.(a) Monica Cavalcanti de Sa Abreu, Dr(a).
Institution Federal University of Ceará

Prof.(a) Maurício Uriona Maldonado, Dr(a).
Institution Federal University of Santa Catarina

We certify that this is the **original and final version** of the bachelor thesis that was judged proper for obtaining the title of Graduate in Mechanical Engineering, with a license for Industrial Engineering.

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Profª. Caroline Rodrigues Vaz, Dra.
Supervisor:

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1 CONTEXTUALIZATION AND RESEARCH PROBLEM

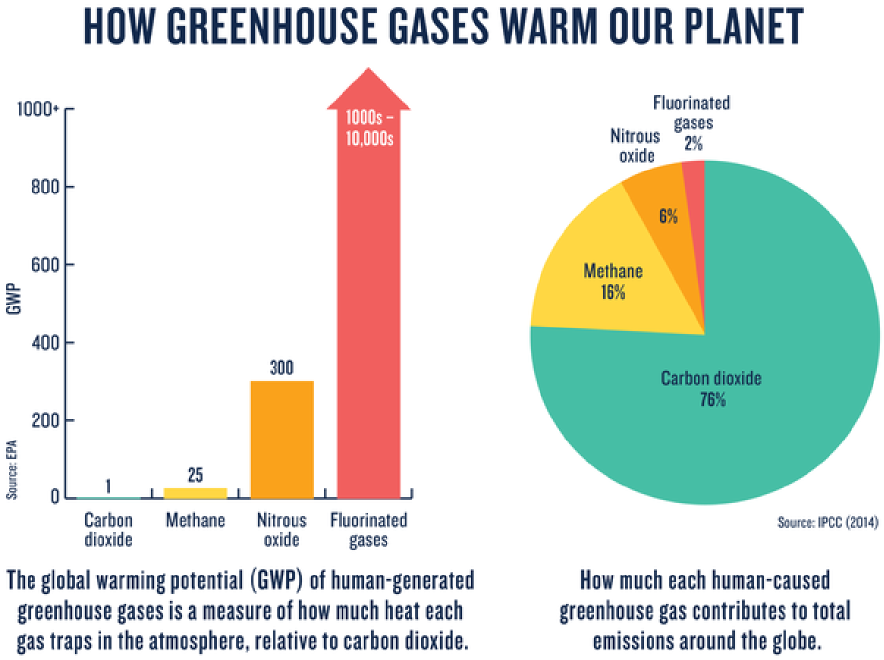
Climate change has consistently been a topic of debate worldwide as it severely alters our planet and impacts all aspects of our lives. It affects our health, the crops we grow, housing, safety and work. The changes are also seen in our environment, such as melting glaciers and ice sheets, sea level rise, more intense heat waves, average global temperature increase, droughts, wildfires, and extreme rainfall. According to the Intergovernmental Panel on Climate Change (IPCC, 2018), some of these changes are irreversible for at least the next hundreds to thousands of years.

The term climate change is used to reference the long-term shifts in temperatures and weather patterns on Earth. These changes can happen naturally due to the greenhouse effect, a phenomenon first observed by scientists in 1896, where gases in the atmosphere trap heat from the sun and naturally warm the planet. Since the 1800s, human activities have significantly intensified that effect, especially with the industrial revolutions and the exacerbated use of fossil fuels. As a result, we now face the challenges of global warming, where the higher concentrations of greenhouse gases - in particular carbon dioxide - causes extra heat to be trapped and ergo the rise of temperature worldwide. According to the IPCC report (2018), carbon dioxide accounts for approximately 65% of all greenhouse gas emissions, making it a significant contributor to climate change. The burning of fossil fuels, such as coal, natural gas, and oil, remains the primary source of carbon dioxide release into the atmosphere.

Addressing the challenges posed by climate change requires a concerted effort, and one of the most impactful approaches is to address the issue of carbon dioxide (CO_2). While efforts have been made globally to reduce CO_2 emissions by investing in renewable energies, greener technologies, and sustainable practices, these measures alone have proven insufficient. The planet continues to struggle with excessive carbon emissions that surpass by far the acceptable values. As a result, the concept of direct carbon capture (DAC) emerged as a new pathway toward decarbonizing the atmosphere. This innovative approach aims to directly remove CO_2 from the atmosphere, acknowledging the need to go beyond reduction efforts and actively remove carbon dioxide from the air.

Five major greenhouse gases contribute to global warming through the greenhouse effect: carbon dioxide, methane, nitrous oxide, fluorinated gases, and water vapor. Carbon dioxide (CO_2) is the primary driver of climate change, accounting for about 76% of all global human-caused emissions. Once released into the atmosphere, it remains encaptured for a long time, where after 100 years 40 percent still remains, 20 percent after 1,000 years, and 10 percent as long as 10,000 years later (DENCHAK, 2019). Methane (CH_4) accounts for approximately 16% of all emissions generated by humans and remains in the atmosphere for almost a decade less than CO_2, but it has a greater potential of impacting global warming in terms of the greenhouse effect. Nitrous oxide (N_2O) accounts for around 6% of human-caused greenhouse gas emissions worldwide and has an even higher greenhouse power than methane and carbon dioxide, remaining in the atmosphere for over a century. Fluorinated gasses (HFCs), which are 100% fabricated by human technology, have the capability of trapping a significantly higher amount of heat than any other source, and they also have the longest lifespan, remaining in the atmosphere for even tens of thousands of years, which is why one of the most important measures for combating climate change is to replace HFCs for less harmful options. Finally, water vapor is the most commonly found one, not directly related to human activities themselves, but rather as a consequence of the warming caused by the other emitted gasses. A comparison between the four human-generated greenhouse gasses can be seen in Figure 1.

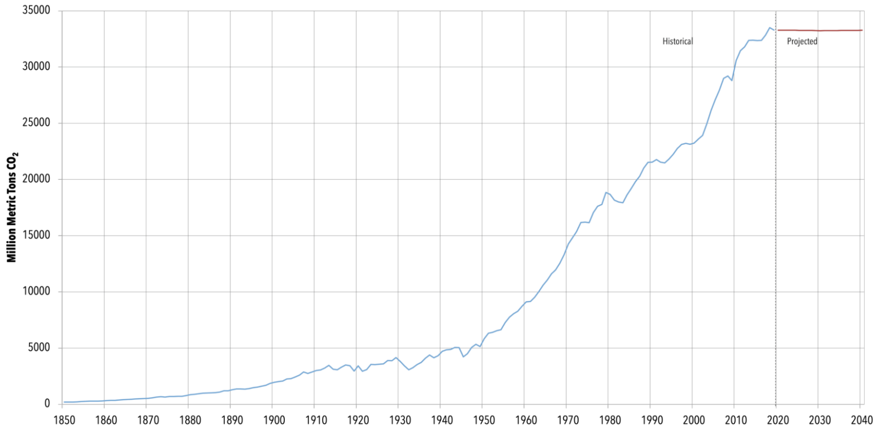
Figure 1 – Greenhouse gases GWP and contribution.



Source: (DENCHAK, 2019).

According to NASA (2023), the concentration of greenhouse gases in our atmosphere is around 419 parts per million, a considerably elevated number compared to the 200 to 280 parts per million that remained consistent for most of the past 800.000 years. The concentration grew exponentially in the past century due to human activities, as shown in Figure 2. The consequences of the greenhouse effect can also be seen through the 1,01 ℃ rise in global temperature since 1880, the 12,6% reduction rate of the Arctic Sea Ice extent per decade, the 427 billion metric tons of ice sheets lost per year since 2002, the 102.5 millimeters rise in sea level since 1993 and the 337 zettajoules ocean heat content increase since 1955.

Figure 2 – Global Carbon due tons, 1850–2040.



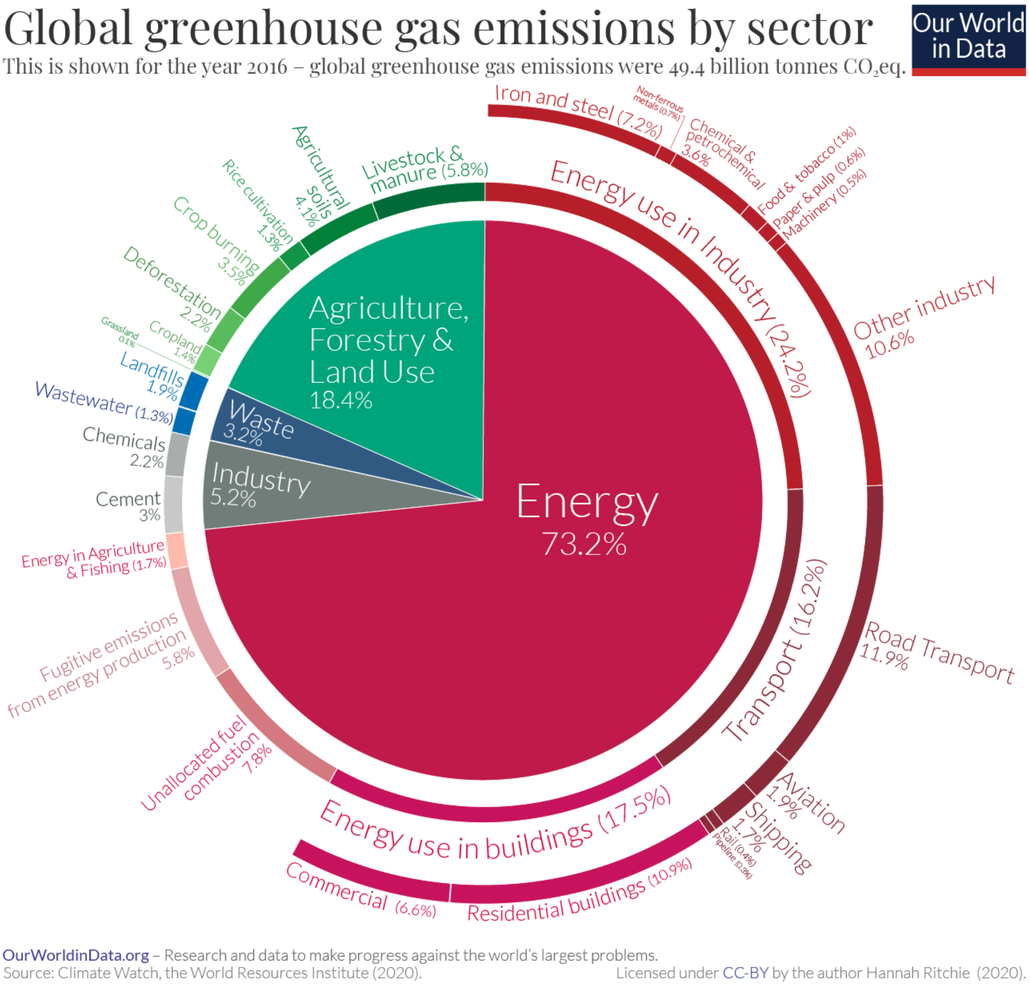
Source: Oak Ridge National Laboratory (2017); International Energy Agency (2020).

According to the Intergovernmental Panel on Climate Change (IPCC, 2018), 1983 to 2012 was likely the warmest 30-year period of the last 1,400 years. And all five of the years from 2014 to 2018 were the hottest on record globally. It is estimated that if the planet continues to warm at the current rate, global warming will reach 1.5 degrees Celsius above pre-industrial levels between 2030 and 2052 (DENCHAK, 2019). Besides the consequences for the planet presented before, there are also other phenomena that can be observed due to the greenhouse effect, such as extreme weather events, droughts and floods, alterations in ecosystems and natural habitats, spread of insects that carry diseases like dengue fever and Zika, intense heat waves, and reduction of crop yields.

In order to effectively reduce carbon emissions and fight climate change, it is important to understand what are the main sources of greenhouse gas emissions. Global greenhouse gas emissions can be classified according to the economic activity or sector that is leading to its generation. In Figure 3, the global greenhouse gas emissions are shown by sector.

Analyzing Figure 3, it is evident that global emissions are a summary of emissions from a range of sectors and their corresponding sub-sectors, but there are a few areas that require more attention, given their expressive emissions rates. Around 73,2% of emissions can be linked to energy use, being electricity and heat production as the largest contributors to global emissions, 18,4% to agriculture and land use, and the remaining 8% are related to industry (more specifically cement and chemicals) and

Figure 3 – Global greenhouse gas emissions by sector.



Global greenhouse gas emissions by sector

This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO_2eq.

OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Climate Watch, the World Resources Institute (2020). Licensed under CC-BY by the author Hannah Ritchie (2020).

Source: (RITCHIE; ROSER; ROSADO, 2020).

waste.

Since there is a variety of emission sources, there is no easy fix for climate change, and each sector comes with its specific problems and entanglements, requiring unique solutions and initiatives.

Climate change affects everyone all over the world. The urgency of the matter extrapolates national borders and requires international cooperation in order to find feasible solutions that will put us on the net-zero track.

On December 12 of 2015, the historic Paris Agreement was signed in Paris, during the UN Climate Change Conference (COP21), where world leaders from 194 Parties (193 States plus the European Union) signed the agreement which is a legally binding international treaty on climate change, which entered into force on 4 November 2016.

The Paris Agreement has the purpose of reducing greenhouse gas emissions worldwide and limiting the increase in global temperature in this century to 2 degrees

Celsius, and optimistically even 1.5 degrees compared to pre-industrial levels. Every country commits to reducing its emissions according to specific goals set for each country. Besides that, the Agreement proposes that developed nations should assist developing ones and that transparency is prioritized in the reports provided by the countries. The framework provided guides the global effort for decades to come, envisioning a net-zero emissions world, and corroborating with the achievement of the Sustainable Development Goals. The Paris Agreement works with five-year cycles where the Parties involved are expected to submit an updated national climate action plan (Nationally Determined Contribution, or NDC), where the actions taken to contribute to reducing greenhouse gas emissions and achieve the goals set by the Paris Agreement must be presented.

To achieve the 2 or 1.5 degrees Celsius goal, emissions must be reduced globally by 55% until 2030 and reach net zero by 2050. There is no general rule on how much each country has to cut emissions, and national plans vary from country to country, depending on the country's capabilities, level of development, and contribution to emissions over time.

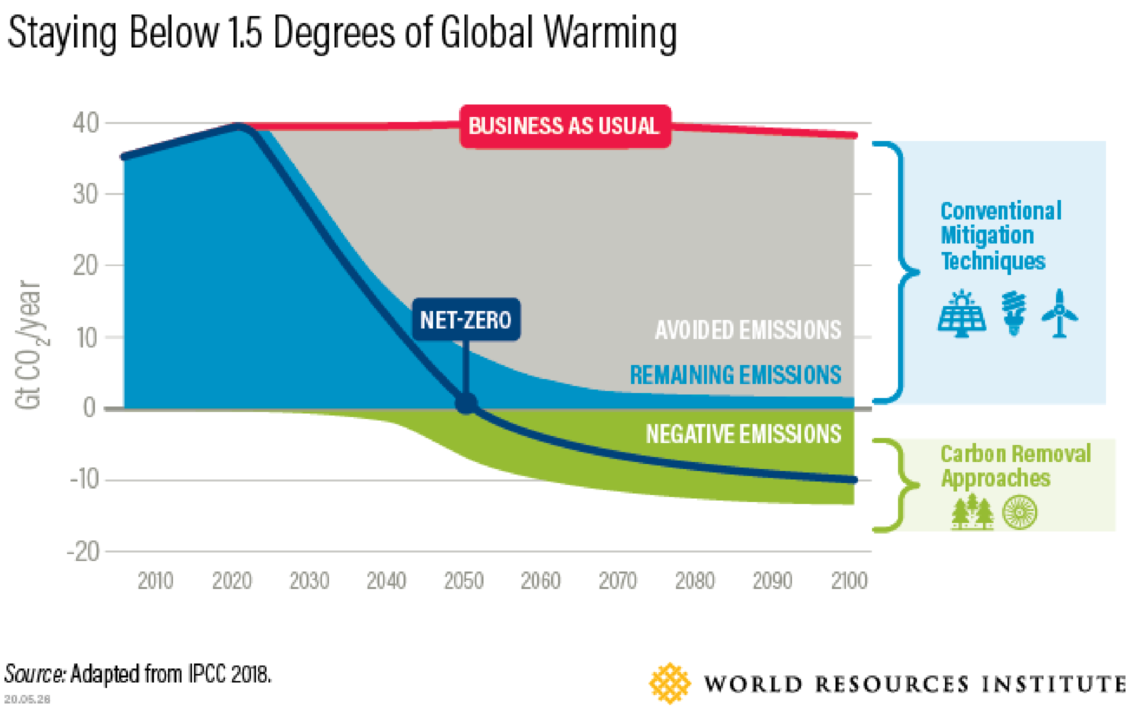
China, for example, committed to leveling off its carbon emissions no later than 2030. India set its sights on cutting emissions intensity by 33 to 35 percent below 2005 levels and generating 40 percent of its electricity from non–fossil fuel sources by 2030. The United States had committed to cutting overall greenhouse gas emissions by 26 to 28 percent below 2005 levels by 2025. U.S. initiatives to achieve the target include the Clean Power Plan and the tightening of automotive fuel economy standards to reduce transportation emissions (DENCHAK, 2019).

It must be considered that in order to achieve the goals set in the Paris Agreement, the world will need not only to reduce emissions but also to actively retrieve CO_2 from the atmosphere. Investing in renewables, improving energy efficiency, and avoiding deforestation are critical steps to reverse climate change, but they might not be enough, as exposed schematically in Figure 4.

As shown in Figure 4, the deployment of carbon removal is critical to achieving global emissions reduction targets by 2050. Globally, scientists predict that up to 10 $GtCO_2$ will need to be removed annually from the atmosphere by 2050, with an increased removal capacity of up to 20 $GtCO_2$ per year by 2100. (WORLD RESOURCES INSTITUTE, 2022).

Direct Air Capture (DAC) presents itself as one of the most promising solutions for fighting climate change. The technology is still in the early stages of development and requires extensive research to achieve the desirable state-of-the-art level of readiness. The main issue today with this type of technology is the cost. It is very expensive, and for that reason, difficult to become profitable and gather investment and support. For that reason, there is an urgency to delineate strategies and paths that will make this

Figure 4 – Achieving net-zero emissions in 2050.



Source: Adapted from IPCC 2018.
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Source: (WORLD RESOURCES INSTITUTE, 2022).

technology profitable and attractive for investors and possible clients, justifying the need for a well-structured business model.

The importance of a business model for novel technologies, specifically in the context of Direct Air Capture (DAC), cannot be overstated. A well-designed business model is crucial for DAC to become a viable and scalable solution for carbon dioxide removal. It enables the assessment of DAC's commercial viability by considering factors such as market demand, pricing models, and potential revenue streams. A robust business model helps define the value proposition of DAC, highlighting its unique benefits and positioning it competitively in the market. It guides the identification of target markets, facilitates market penetration strategies, and supports the development of partnerships and collaborations. Additionally, a well-crafted business model ensures efficient resource allocation, risk mitigation, and sustainable growth. By attracting investments and aligning with strategic goals, a strong business model paves the way for DAC technologies to make a significant impact in addressing climate change and achieving carbon neutrality goals.

Even though there are already direct air capture plants in operation or soon to be operating worldwide, we are still far from being able to commercialize them on a large scale. They are expensive and in need of refinement to achieve optimal performance. For that reason, it is important to develop more research on this topic in order to make it more accessible and ready to be commercialized on a larger scale. With this study, a company acting in the direct air capture business (DAC), we will call it Company X, will be analyzed and the main goal of this study is to answer the question: what would be an ideal business model for Company X to ensure the thriving of its technology in the current and future market?

1.1 OBJECTIVES

The sections bellow describe the general objective and the specific objectives of this study.

1.1.1 General Objective

Develop a business model for a German company specializing in direct air capture within the environmental technology sector.

1.1.2 Specific Objectives

1) Describing the processes involved with the main carbon capture technologies;
2) Understand the dynamics of the voluntary carbon market (VCM);
3) Develop a market analysis regarding direct air capture (DAC);
4) Determine the overall cost structure of a direct air capture module;
5) Delineate revenue pathways that would enable Company X to achieve profitability;
6) Propose a visual business model for Company X.

1.2 JUSTIFICATION

This study has the potential to positively influence multiple Sustainable Development Goals (SDGs), including "Affordable and Clean Energy," "Industry, Innovation and Infrastructure," "Sustainable Cities and Communities," and the crucial "Climate Action" goal. By focusing on a decarbonization technology, this study aims to make a significant contribution towards addressing climate change and its impacts.

While carbon capture technologies are already in operation in certain industries such as fertilizers, chemicals, and coal power plants, there is still a significant demand for carbon capture solutions that can be applied across various sectors. The primary challenges faced today revolve around the cost and efficiency of these technologies, with ongoing research focusing on addressing these aspects to achieve economic viability and improved effectiveness. In line with these objectives, this study aims to explore the adaptation of cooling towers, which are widely utilized in multiple industries, for carbon capture purposes without disrupting their core functions. Additionally, it seeks to identify strategies for achieving economic viability and market acceptance for this application. Moreover, Company X is conducting research on leveraging waste heat to enhance the cost-effectiveness and energy efficiency of their process.

With the potential of mitigating climate change, through the reduction of CO_2 in the atmosphere, we can start reversing global warming effects. Just reducing emissions is not enough, we have to think of ways to also remove the CO_2 that is already circulating in the atmosphere. Direct air capture (DAC) companies are pivotal in this matter, offering a solution that is both scalable and innovative. However, as a new technology, the path to sustainability and viability for these businesses is not yet clear. This study is highly relevant as it seeks to address this question, exploring how DAC companies can establish themselves, thrive, and contribute to a sustainable future.

1.3 RESEARCH DELIMITATION

This study was conducted over a period of 6 months, from from January 2023 to June 2023, resulting in findings and conclusions that are relevant to that specific timeframe. The research was conducted in Berlin, Germany, and expanding the study to other regions, particularly outside of Germany, may introduce variations in political, economic, and regulatory factors that could influence the outcomes and conclusions discussed in this study. Moreover, the business model presented in this study was built specifically for Company X and would likely require adjustments if applied to other companies, even those operating in the DAC industry within Germany.

The business model presented in this study encompasses some limitations that should be acknowledged. Firstly, the role of cooling towers and waste heat in the business model is relatively superficial and lacks in-depth exploration. While these aspects were in fact considered, their comprehensive analysis is not provided in this study. Additionally, the cost structure of the business model is not extensively disclosed and limited information is given, only an overview of the actual cost structure is provided, due to confidentiality reasons. Finally, the customer relationships and channels sections of the business model were combined, as they were very complementary of each other.

1.4 RESEARCH STRUCTURE

The study is divided into five chapters, each serving a specific purpose. The first chapter, the introduction, outlines the main objective of the study, along with specific objectives. It provides a justification for the study, establishes the scope and limitations of the research, and provides an overview of the landscape surrounding the topics of direct air capture.

The second chapter, the Literature Review, delves into the most pertinent concepts related to carbon capture, direct air capture (DAC), and business models. It provides a comprehensive analysis of existing literature on these topics, offering readers a solid foundation to comprehend the author's decisions and the rationale behind the final conclusions drawn in the study.

In the third chapter, Methodology, the author outlines the procedures undertaken to conduct the study. It clarifies the methods employed, including an explanation of ethical considerations, and the potential limitations of the study. This chapter provides an understanding of the research approach and ensures transparency in the methodology employed.

The fourth chapter presents the findings and analysis. The author systematically constructs the business model for Company X, following the proposed methodology and gradually developing a roadmap for the company. The results are visually summarized in a Canva, providing a concise representation of Company X's simplified business model. Additionally, the chapter includes a comprehensive assessment of risks and corresponding mitigation strategies.

In the final chapter, the author concludes the study by revisiting the most significant remarks drawn throughout the research. The chapter also elaborates on potential future advancements that can be derived from the study, providing valuable insights for further exploration and development in the field.

2 LITERATURE REVIEW

This literature review aims to provide the reader with a deep understanding of the fundamentals as well as the current state-of-the-art of research, theories, and perspectives on the subject, and to identify gaps or unresolved issues in the literature. A wide range of scholarly sources and research papers are examined to develop this literature review.

It will serve as a platform for contextualizing the study, highlighting existing research contributions, and identifying areas where further investigation is needed. The primary focus of this study revolves around comprehending the technological and political facets of carbon capture, with an emphasis on direct air capture (DAC). Furthermore, the examination of carbon markets and their functioning will demonstrate how carbon credits are traded. Finally, the study aims to explain the concept of a business model and its practical application within a DAC company. By the end of the literature review, the reader should have a good understanding of the most fundamental aspects of DAC, and will be able to comprehend how a business model can be build around it.

2.1 CARBON CAPTURE

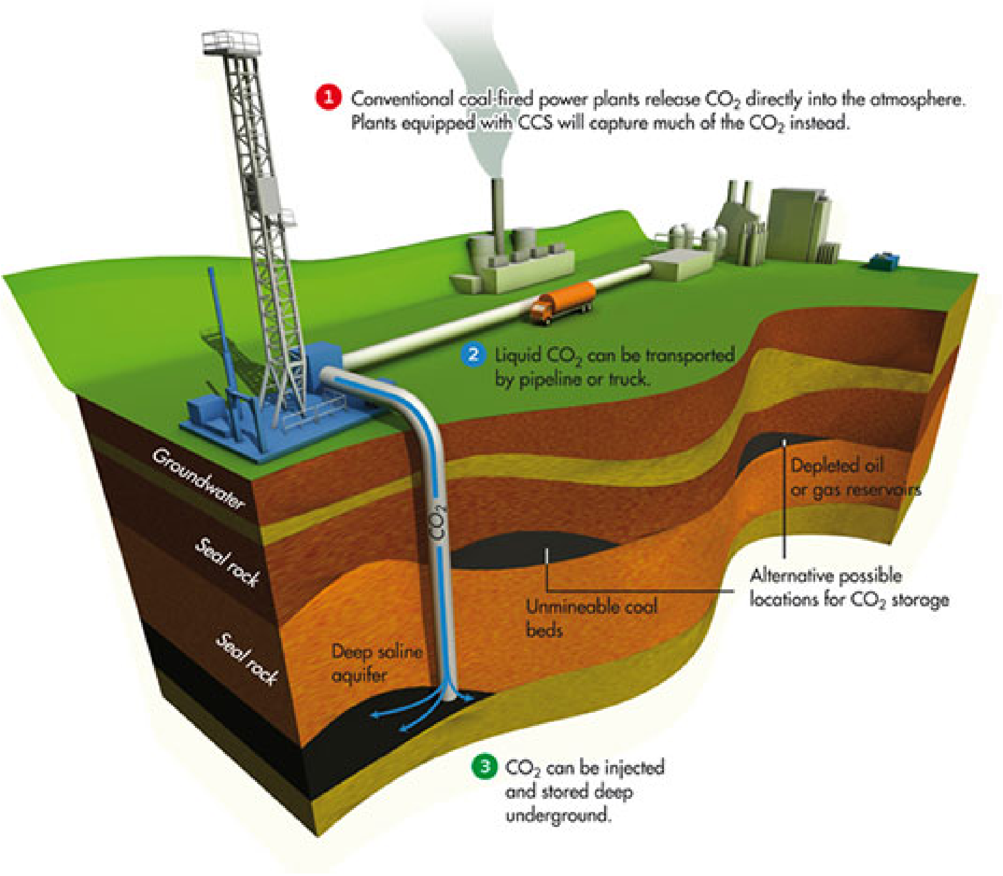
Two distinct areas of technologies must be considered when addressing carbon capture, those being Carbon Capture and Storage (CCS) and Carbon Dioxide Removal (CDR). CCS technologies aim at reducing the release of CO_2 emissions from a source; they capture large amounts of CO_2 from gas mixtures (in some cases retrieving 100% of the emitted CO_2) destined for the atmosphere. This solution is vital in applications where CO_2 emissions are unavoidable, like steel and cement production, manufacturing of chemicals, and fossil-fuel power generation. CDR technologies, on the other hand, direct their efforts at removing CO_2 already present in the air. If the technology results in net-negative emissions, by being powered by renewable energy and the captured CO_2 being permanently stored in the end, then it may be called a NET (Negative Emissions Technology) (ERANS et al., 2022).

There are six major technical approaches to remove and sequester CO_2: Coastal blue carbon, Terrestrial carbon removal and sequestration, Bioenergy with carbon capture and sequestrations (BECCS), Carbon mineralization, Geological sequestration, and Direct air capture (DAC) (OZKAN et al., 2022). CCS is also described since that technology was a precursor of the idea of capturing carbon dioxide.

2.1.1 Carbon Capture and Storage (CCS)

CCS focuses on reducing carbon emissions from the primary emitting sources. It prevents more CO_2 from being released (or at least part of it) but it does not tackle down the CO_2 that is already in the atmosphere. The process consists of three main steps: capturing the carbon dioxide emitted during power generation and industrial processes, transporting it, and then storing it deep underground. The process is schematized in Figure 8.

Figure 5 – Carbon Capture and Storage process.



Source: (INTERNATIONAL, 2015).

Some CCS facilities can capture up to 90% or 100% of the CO_2 produced, which is a game changer for climate change mitigation. Currently, industries like coal power plants, and steel or cement factories, known for being carbon-intensive, are already being pressured to invest in CCS technologies, so that there are fewer emissions and it is possible to achieve the CO_2 targets.

A variation of the CCS technology is the CCUS (carbon capture, utilization, and storage), where instead of being stored underground in the last phase of the process, the CO_2 is redirected to industries that rely on CO_2 for production. That is the case for enhanced oil recovery (EOR) for example, one of the main industries that incorporate CO_2 in their process, where the CO_2 is utilized with water for oil extraction, which simultaneously improves oil recovery and sequesters the CO_2 underground. There are also other industries that rely on CO_2, but not all of them provide permanent storage for CO_2, like soda carbonation where the CO_2 is soon released again into the air.

There are three available approaches to CCS (or CCUS): post-combustion carbon capture, pre-combustion carbon capture, and oxy-fuel combustion systems.

Post-combustion CO_2 removal refers to the process where carbon dioxide is separated from the exhaust of a combustion process after fossil fuels or other carbonaceous materials (such as biomass) are burned. It is commonly used in conventional natural gas and pulverized coal-fired (PC) power generation, on overall large-scale fossil fuel combustion devices like boilers, cement kilns, and industrial furnaces. Among the current technologies, the most effective method of CO_2 capture from the flue gas of a PC plant is by chemical reaction with an organic solvent such as monoethanolamine (MEA), belonging to a family of amine compounds. In a vessel called an absorber, the flue gas is “scrubbed” with an amine solution, typically capturing 85 to 90 percent of the CO_2. The CO_2-loaded solvent is then pumped to a second vessel, called a regenerator or stripper, where heat is applied in the form of steam to release the CO_2. The resulting stream of concentrated CO_2 is then compressed and piped to a storage site, while the depleted solvent is recycled back to the absorber (RUBIN et al., 2012). A similar technology can be used for post-combustion CO_2 carbon removal at a natural gas-fired boiler or combined cycle (NGCC) power plants, with the difference that the CO_2 concentration in the flue gas is more diluted and there are fewer impurities (clean flue gas stream), and in order to also achieve high capture efficiencies, amine-based systems are applied.

Pre-combustion CO_2 capture processes are more common in industrial facilities, being less developed for gas power plants, due to the higher cost. It involves a preliminary step where the fossil fuels or bioenergy are processed with steam and/or oxygen (partial oxidation or gasification) to produce syngas, a gaseous mixture of carbon monoxide (CO) and hydrogen. The carbon monoxide then reacts with more steam, yielding additional hydrogen and converting the CO to CO_2. The CO_2 can be separated from the high-pressure gas mixture, yielding raw syngas for combustion or chemical production (IEA, 2019). In the coal power plant using pre-combustion CCS, even though the fuel conversion steps involved are more elaborate and costly than in traditional coal combustion plants, CO_2 separation is much easier and cheaper because of the high operating pressure and high CO_2 concentration of this design (RUBIN et al., 2012).

Finally, in oxy-combustion (or oxyfuel) systems, instead of air, nearly pure oxygen is used to combust fuel, producing flue gas composed almost solely of CO_2 and water vapor (IEA, 2019). In this case, the result is a much more concentrated and pure stream of CO_2, which makes it easier and cheaper to capture. With this process, it is possible to avoid large amounts of nitrogen being present in the flue gas stream, only small amounts of pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NOx) can be found in the flue gas. The main advantage of this process is that instead of a costly post-combustion CO_2 capture system, it only requires an air separation unit (ASU) to generate the relatively pure oxygen needed for combustion, however, the ASU also increases the cost. It is also crucial for this process that the system is properly sealed to avoid air leakages into the flue gas to prevent the level of oxygen and nitrogen in the flu gas to scale up to undesirable levels. Currently, this process is mostly used for coal-fired power plants.

Once the carbon dioxide is captured using one of the aforementioned approaches (post-combustion, pre-combustion, or oxy-combustion), it is compressed and chilled into a fluid so that can be transported via pipelines (most usually), ships, trains, or other vehicles. Finally, CO_2 can be permanently stored in deep, underground geological formations, such as former oil and gas reservoirs, deep saline formations, and coal beds. Another possibility, as mentioned before, is directing the captured CO_2 to other industries that use carbon dioxide to produce their product.

2.1.2 Direct air capture (DAC)

Direct air capture (DAC) emerged as a technology capable of directly removing carbon dioxide from the atmosphere. Indeed, CO_2 is nearly evenly distributed around the globe at average concentrations of 405.5 parts per million and rising (ORGANIZATION, 2019). The working principle is to use chemicals capable of binding CO_2, thereby removing it from the air. The captured CO_2 can then be sold to industries that require carbon dioxide as an input, like enhanced oil refineries (EOR), conversion to fuels and chemicals, and carbonated drinks producers, or the CO_2 can be injected into underground permanent storage sites (DACCS).

Since CO_2 can be found anywhere in the world at similar concentrations, this technology does not rely on a specific location or emission source like CCS, the requirement for DAC plants is that they should be placed near a renewable energy source and with access to means of permanent storage or usage. For climate change mitigation, geological storage of carbon dioxide plays a more important role when compared to industrial use of CO_2, it is seen as a more reliable, sustainable, and long-term solution. However, since there is no revenue opportunity beyond public policy support, finding opportunities of utilizing CO_2 within other industries is a way of reducing the net cost of DAC technologies and still contribute to removing CO_2 from the atmosphere.

DAC is not the only solution available for directly removing CO_2 from the atmosphere. Reforestation, for example, is a much cheaper - and natural - way to decarbonize our planet. But when compared in terms of scalability and land use, one DAC unit can be 1.000 times more efficient than a tree, which means that the same amount of CO_2 captured by 200.000 trees can be done using 1.000 times less space, without even considering further technology improvements that can possibly optimize those numbers even more in the future, since this technology is still very new. Overall, compared to other types of carbon removal approaches, DAC has the advantages of using minimal amounts of space and being sited with flexibility, with the possibility of being built on marginal land or near geological storage sites to minimize the need for CO_2 pipelines (WORLD RESOURCES INSTITUTE, 2022).

Currently, there are 19 active DAC plants worldwide, capturing more than 0.01 Mt CO_2/year. As per our calculations, an estimated number of 1250 DAC plants with a capacity of 1 MtCO_2/year each would be required to remove 25 GtCO_2 by 2030, assuming a linear growth of carbon capture and storage from the capacity of 0.0385 Gt per year (Global CCS Institute, 2018) to a capacity of 20 Gt per year (National Academies of Sciences, 2018) in 2020 (OZKAN et al., 2022).

Direct air capture involves three major steps: capture, transport, and storage. In the first step, the air is sucked in by large fans and is directed towards a contacter, where the CO_2 will be trapped using a sorbent (that can be either liquid or solid) containing chemicals that react with CO_2, and the carbon-free air can pass through and return to the atmosphere. The sorbent then needs to be heated so that the CO_2 can be released, which is then regenerated and can start a new capture cycle. Finally, the CO_2 is transported and stored underground in geological formations or used in various products and applications within different industries (DACCS). The process is schematized in Figure 6.

Even though most of the DAC companies follow the path presented above, some companies study new approaches and innovate, especially when it comes to the contacter and sorbent material used.

The final destination can also vary. The advantage of opting for permanent underground sequestration is that the carbon dioxide is permanently stored, maximizing climate benefit, however, it relies on governmental subsidies since it does not directly generate profit. Industries like concrete and polymer manufactures that use CO_2 as an input can provide long-term sequestration (decades or centuries), with the advantage of generating a profit and reducing the cost involved with DAC. Other industries such as beverages and fuels however, only provide short-term sequestration, since the CO_2 is shortly released back into the atmosphere.

According to (GAMBHIR; TAVONI, 2019), there are essentially two processes by which the sorbents capture CO_2. The first is known as absorption, whereby the CO_2 dissolves into the absorption material. The second process is adsorption, whereby CO_2 molecules adhere to the surface of the adsorbent material. In both cases, at the end of the capturing phase, once the sorbent is saturated with CO_2, the CO_2 can then be released from the sorbent and move on to its final destination. GAMBHIR (2019) also elaborated on the characteristics of the different DACCS technologies, which differ according to the chemical sorbent used and chemical reaction type, thus having different

Figure 6 – CO_2 capture using DAC plant, storage, and reuse.

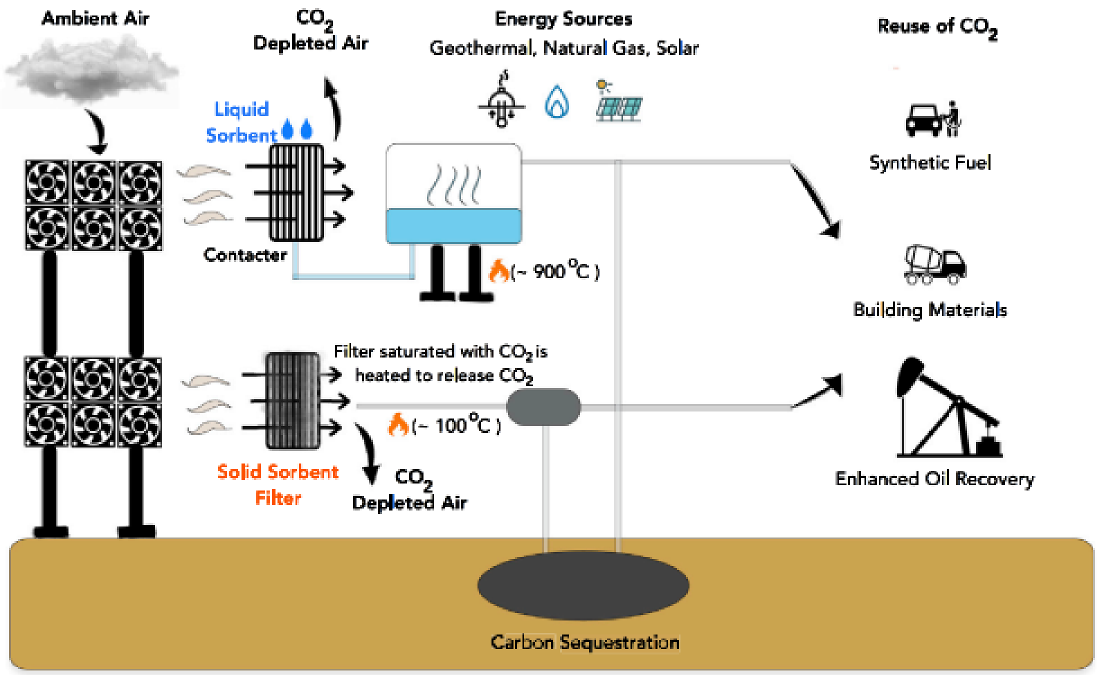


Figure 1. CO_2 captured from air using liquid and solid sorbent DAC plants, storage, and reuse
The ambient air is sucked in through large fans which is then treated with a chemical sorbent (Liquid or Solid) and heated to extract CO_2. This CO_2 is then either sequestrated or used in other industries as shown.

Source: (OZKAN et al., 2022, p.3).

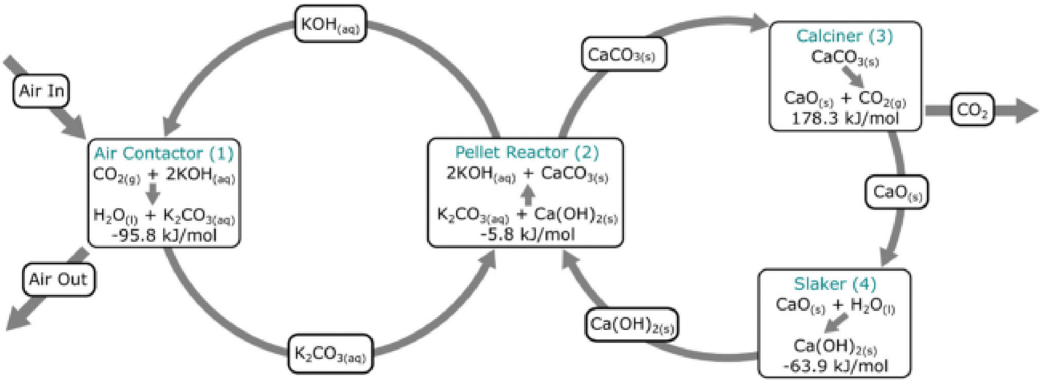
regeneration processes and energy requirements.

The sorbent material choice is a critical part of direct carbon capture technologies. The sorbent can be either liquid or solid, the second being the most common. Generally, solid sorbents have better kinetics, are less prone to volatilize into the atmosphere, and avoid heat losses from evaporating a liquid (SHI et al., 2020). Due to the low concentration of CO_2 in the atmosphere, it is much harder to capture the CO_2 directly from the air when compared to CCS technologies previously described, and special considerations must be made regarding the energy demand for the process.

Using a liquid sorbent, ambient air is placed in contact with a strong liquid base, such as potassium hydroxide or sodium hydroxide (NaOH), which dissolves the CO_2 (GAMBHIR; TAVONI, 2019). The removal of CO_2 from the base is done in a separated posterior process using a calcium hydroxide ($Ca(OH)_2$) solution, and the base can be regenerated and start a new cycle. The CO_2 is expunged in the form of $CaCO_3$, which will be directed to a calciner to react with oxygen (O_2) at very high temperatures, resulting in pure CO_2 and calcium oxide (CaO). The CaO can be combined with water to be reused, while CO_2 will receive its proper destination.

The process for solid sorbents is divided into two main phases, the first one being the adsorption of CO_2 and the second one being the separation of the CO_2 using relatively low-temperature heat (desorption phase), which will regenerate the sorbent. The process can be seen in Figure 7.

Figure 7 – Carbon Engineering DAC process. An aqueous alkali hydroxide solution is used for CO_2 capture from air in the contactor, which is subsequently contacted with Ca(OH)2 to form CaCO3 and regenerate the aqueous alkali hydroxide solution. CO_2 is produced in a second cycle, which also produces CaO, which is slaked to regenerate CaCO3.



Source: (ERANS et al., 2022, p.10).

For any of the methods proposed, to guarantee a significant amount of net CO_2 removal, the electricity and heat inputs must come from low-carbon sources, otherwise removing CO_2 would also imply releasing CO_2, which will counterbalance the positive effect of CO_2 capture. One analysis, for example, estimates that if a DACCS plant is operated with electricity generated by a gas power plant (without CCS), the gas combustion would return CO_2 equal to 70%–90% of that captured by the DACCS plant to the atmosphere (GAMBHIR; TAVONI, 2019).

Implementing DAC goes beyond the technology itself, the entire chain must be considered to ensure the effectiveness of the technology. In comparison with CCS, DACCS has a lower capture rate, since the concentration of CO_2 is much lower, and the technology is currently more expensive. Nevertheless, there are some advantages, one of them being the possibility of implementing it anywhere in the world, since it is not bounded to a specific industry or process, as long as a low-carbon energy input is provided, and a proper destination is designed.

2.1.3 Barriers to Deployment

In order to develop these technologies into a feasible, market-ready version, there are still a few challenges that must be overcome. The first and most significant challenge so far is related to the cost of implementing these solutions. The main issues related to the first challenge are the equipment costs and the energy required during the process. In addition to that, CO_2 capture technologies can negatively impact power and industrial plants' efficiencies, and increase their water use, besides other additional costs. Altogether, the additional costs that emerge with the technology implementation can ultimately turn CCS and DAC projects financially unviable.

A second relevant point is that there are a lot of uncertainties with these technologies since they are still under early development, requiring research and optimization in order to achieve a more efficient and cheaper version. Therefore, the financial returns of carbon capture projects involve more risks, which makes investment less appealing to possible investors, requiring refined risk mitigation strategies to incentivize investments in CCS and DAC development.

Another challenge is related to carbon dioxide transportation. Significant energy is required to compress and chill CO_2 and maintain high pressure and low temperatures throughout pipelines, and the pipelines themselves are expensive to build (VINCENT GONZALES ALAN KRUPNICK, 2020). The pipelines, which are the main transportation method for CO_2, must follow strict safety rules to avoid accidents like leakages and explosions, and they must be specially designed for this application, it is not possible to use existing oil and gas pipelines for example. On top of that, pipelines must be connected to appropriate storage destinations, which becomes harder and more expensive for larger distances between the source and storage.

The storage also encompasses a few challenges. There are available geologic storage possibilities for at least the next century, which mean there are no storage limitations in the short and medium term. Long-term storage is something that worries some researchers, but it is not the main focus for now. The primary issue is related to CO_2 leakage, especially considering the possibility of underground injection of CO_2 generating seismic activity. Studies on storage today are looking into ways of minimizing those risks and are considering above-ground carbon dioxide mineralization as an alternative to underground storage (VINCENT GONZALES ALAN KRUPNICK, 2020).

A final barrier is related to uncertainties in public support. As it is not a much profitable technology (at least not yet) it still relies heavily on government subsidies and public support. Nevertheless, this approach to climate change mitigation encompasses some debates and considerations, such as the benefit of mitigating CO_2 emissions, the implication that use of CCS and DAC prolongs the use of fossil fuels, the role of pipelines in impairing landscapes and fragmenting ecologically sensitive areas, the perceived and actual safety of transportation and storage of CO_2, the extent to which other climate solutions are implemented in addition to CCS (VINCENT GONZALES ALAN KRUPNICK, 2020). At this point, there is not a full comprehension as to how these technologies are seen by the public, and further research would be necessary to assess the public opinion, considerations, and reservations.

2.2 CARBON CREDITS AND CARBON OFFSETS

The Kyoto Protocol of 1997 and the Paris Agreement of 2015 were international accords that laid out international CO_2 emissions goals (CARBONCREDITS, 2023). The carbon emission trading system was formally established after the Kyoto Protocol of 1997, where the carbon credits and carbon offsets were officially born and started being applied by the countries that signed in the agreement. The agreement between the parties involved was that developed countries and transition economies would commit to pursuing lower emission levels when compared to their 1990 emissions.

Carbon credits and carbon offsets work as "permission slips" that are issued to offset unavoidable carbon emissions or to remove CO_2 from the atmosphere. While carbon credits usually represent a reduction in greenhouse gas emissions, carbon offsets go beyond and can also represent greenhouse gas removal. Besides that, carbon credits are transacted in the carbon compliance market, while carbon offsets transactions happen in the voluntary carbon market. Nevertheless, the terms are often used interchangeably. Purchasing one carbon credit or carbon offset is equivalent to removing one metric ton of greenhouse gases from the atmosphere.

Carbon credits are typically associated with cap-and-trade systems in which governments limit the carbon emissions that specific industries can release. Companies exceeding their allowances must buy new credits to increase their cap (HASHGRAPH, 2023). The number of credits issued every year changes depending on the emissions targets, which vary according to country and industry, for example. The tendency is that the limit - or cap - for emissions will slowly decrease over time, which will make the credits more scarce and consequently more expensive so that the emissions target can be achieved.

Overall, the carbon credit system works by using financial incentives to force businesses to reduce their emissions, which can be done either by rewarding those who manage to use fewer credits than they were given or by penalizing those who use more. This trading system aims to reduce overall emissions over time so that the goals stated in the Paris Agreement can be achieved.

With the creation of carbon credits and carbon offsets, a new market emerged, where CO_2 emissions were given a price and became a commodity.

With carbon credits, carbon revenue flows vertically from companies to regulators, though companies who end up with excess credits can sell them to other companies. Carbon offsets flow horizontally, trading carbon revenue between companies. When one company removes a unit of carbon from the atmosphere as part of its normal business activity, it can generate a carbon offset. Other companies can then purchase that carbon offset to reduce their own carbon footprint (CREDITS, 2023).

Companies that choose to enter the carbon emissions market, by innovating with technologies such as CCS or DAC for example, have the ability to generate offsets that can be purchased by other companies or individuals that wish to reduce their carbon footprint. The purchase of these offsets is not mandatory like for carbon credits, which is why the market for carbon offsets is the “Voluntary Carbon Market”.

According to Refinitiv, one of the world’s biggest providers of financial markets data and infrastructure, the carbon credits market was valued at US$261 billion in 2020, representing 10.3Gt CO_2 equivalent traded on the compliance markets for that year. The voluntary carbon market for offsets, even though smaller, is expected to grow in the following years. According to BCG (2023), the voluntary carbon market was valued at $2 billion in 2021 — four times its value in 2020 — and it is expected to reach between $10 billion and $40 billion by 2030.

2.2.1 The voluntary carbon market (VCM)

The voluntary carbon market refers to a system in which individuals, organizations, and companies can voluntarily offset their carbon emissions by purchasing carbon offsets. Purchasing carbon offsets means that the company is investing in projects that help reduce greenhouse gas emissions, which can be done by projects like planting trees, CCS technologies, renewable energy, energy efficiency improvements, and other projects that remove greenhouse gases from the atmosphere.

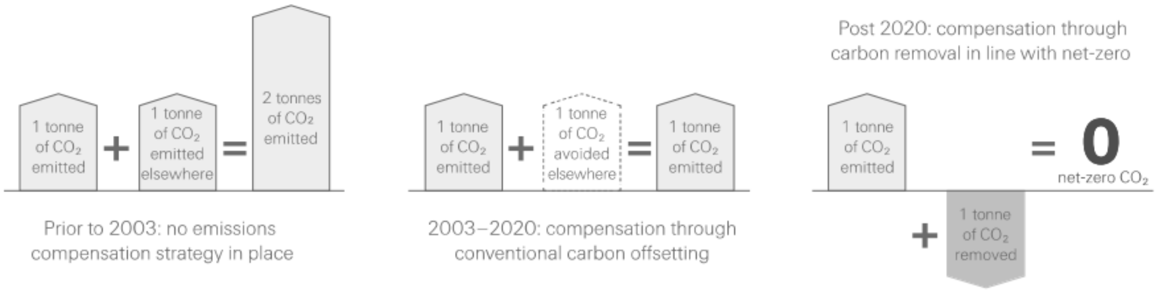
The voluntary carbon market operates parallel to the compliance carbon market. While the second one is regulated by government policies and mandatory emissions reduction targets, the VCM offers flexibility and wider participation for individuals and smaller organizations.

Carbon offset projects within the voluntary market are obliged to undergo a certification process to ensure their legitimacy and credibility. These projects are often verified by third-party standards and organizations such as the Verified Carbon Standard (VCS), Gold Standard, Climate Action Reserve (CAR), American Carbon Registry (ACR), Social Carbon, and Plan Vivo. Their standards and certifications provide assurance to buyers and participants in the voluntary carbon market that the projects they support are credible, transparent, and contribute to real emissions reductions and sustainable development.

The VCM has been questioned regarding the real effectiveness of the carbon offset projects. Many argue that by relying on carbon offsets, we might be masking the real problem, namely the large amounts of emissions, and reducing emissions should be the first priority. In theory, they serve as a compensating system for our tremendous greenhouse gas (GHG) emissions, but in practice, it only mitigates the problem and it is not a permanent solution. In Figure 8 a simple scheme is presented.

As shown in Figure 8, even though carbon offsets help balance out the emissions, they are only slowing down the rate of emissions, because fewer emissions are occurring, but they are not avoiding CO_2 from being released whatsoever neither are

Figure 8 – Carbon offsets vs carbon removal.



Source: (RE, 2020).

they reversing the already critical state of emissions. The amount being released is indeed smaller, but it is also still happening. The voluntary carbon market should then be seen as a supplementary measure, rather than a replacement to the efforts aimed at reducing emissions at their source.

There are not enough offsets for all of the CO_2 emissions, and not all of the proposed offset projects actually get executed. They often lead to greenwashing, where companies portray themselves as sustainable when they are actually doing the bare minimum. Companies accused of greenwashing either invest in non-verified credits, do not prioritize in-house emissions reductions, or double-count carbon credits (SMOOT, 2023). On the social side, they end up increasing the gap between the world's rich and poor, where the richer countries continue to emit as they wish while paying off poorer countries to offset their emissions.

This is where the difference between avoided emissions credits and carbon removal credits is important. When you buy an offset, you pay someone else to not emit carbon dioxide. If you've emitted one tonne of CO_2 and bought one tonne of offsets, less CO_2 is getting released, but your one tonne is still up in the atmosphere and will stay up there for a long time (FUND, 2022), as can be seen in 8.

When you buy a carbon removal credit, you pay someone to pull carbon dioxide out of the atmosphere and store it outside of the atmosphere on your behalf. If you have emitted one tonne of CO_2 and you have bought one tonne of carbon removal, you have broken even because the equivalent amount to your one tonne of CO_2 has been pulled back out of the atmosphere (FUND, 2022).

Investing in carbon capture technologies, that will actively remove carbon dioxide from the atmosphere, will place the investing company in a position where it is less likely to be accused of greenwashing. Opting for carbon removal credits instead of carbon offsets could potentially increase the legitimacy of the company's intentions, and the sustainability stamp becomes more genuine. According to McKinsey, the voluntary carbon credit market will reach $50 billion by 2030, which equals 15x growth compared to 2020 levels. In 2050, the market will be 100x the size of the 2020 market.

Carbon offsets are, of course, better than no offsets or initiatives, but they are not sufficient on their own and should not be seen as a solution in the long run. For meaningful changes to happen, a combination of actions is necessary, cutting emissions from the source is the top priority, in addition to then offsetting the remaining with effective programs like renewable energy, energy efficiency, carbon sequestration, and aviation offset.

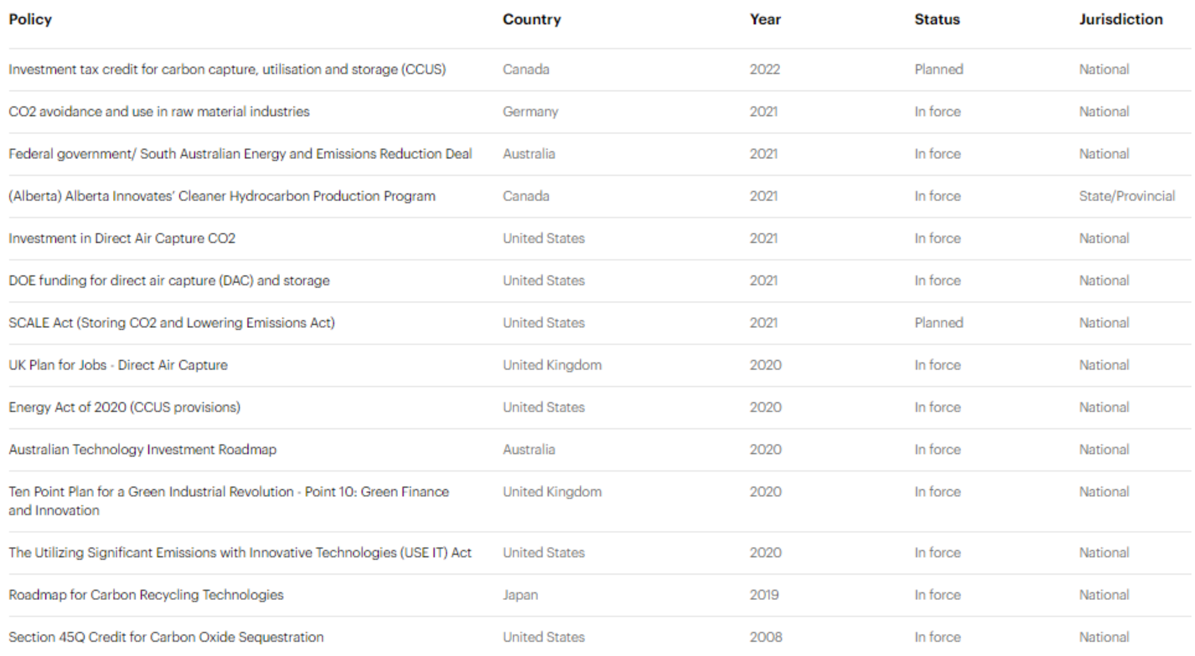
There is a trend today among customers within every industry to prioritize companies that corroborate with their ideals and that they see as ethical. It is a smart move for companies that intend to stay in the market for the long run to get ahead in the environmental issue, as it has become a competitive advantage.

Overall, the voluntary carbon market provides individuals and organizations with an avenue to voluntarily support climate action by offsetting their emissions and supporting projects that contribute to sustainable development and greenhouse gas reductions.

2.3 RELEVANT POLICIES AND MARKET MECHANISMS

DAC deployment is only feasible today if supported by shielding carbon policies. It is hard for DAC technologies to thrive on its own, which is why it needs supportive policies, especially at an early stage of development. In Figure 9, a summary of in-force and planned policies regarding DAC worldwide can be seen.

Figure 9 – Relevant policies regarding DAC.



Policy	Country	Year	Status	Jurisdiction
Investment tax credit for carbon capture, utilisation and storage (CCUS)	Canada	2022	Planned	National
CO2 avoidance and use in raw material industries	Germany	2021	In force	National
Federal government/ South Australian Energy and Emissions Reduction Deal	Australia	2021	In force	National
(Alberta) Alberta Innovates' Cleaner Hydrocarbon Production Program	Canada	2021	In force	State/Provincial
Investment in Direct Air Capture CO2	United States	2021	In force	National
DOE funding for direct air capture (DAC) and storage	United States	2021	In force	National
SCALE Act (Storing CO2 and Lowering Emissions Act)	United States	2021	Planned	National
UK Plan for Jobs - Direct Air Capture	United Kingdom	2020	In force	National
Energy Act of 2020 (CCUS provisions)	United States	2020	In force	National
Australian Technology Investment Roadmap	Australia	2020	In force	National
Ten Point Plan for a Green Industrial Revolution - Point 10: Green Finance and Innovation	United Kingdom	2020	In force	National
The Utilizing Significant Emissions with Innovative Technologies (USE IT) Act	United States	2020	In force	National
Roadmap for Carbon Recycling Technologies	Japan	2019	In force	National
Section 45Q Credit for Carbon Oxide Sequestration	United States	2008	In force	National

Source: (IEA, 2022).

Countries and regions that have taken an early lead in supporting DAC research, development, demonstration and deployment include the United States, the European Union, the United Kingdom, Canada and Japan (IEA, 2022).

Since every country has its own policies and strategy for carbon regulations, the success of this technology will rely heavily on where they are being developed. In the long run, international policies will be important to incentivize NET technologies, such as DAC, so that they don't have to be restrained to only a few countries or locations.

In order to determine which policies would be more effective in the thriving of DAC, current approaches in countries where these technologies have been successfully developed were analyzed. Some important elements include the emissions trading scheme, the carbon tax, the subsidies, the regulations, and tax incentives.

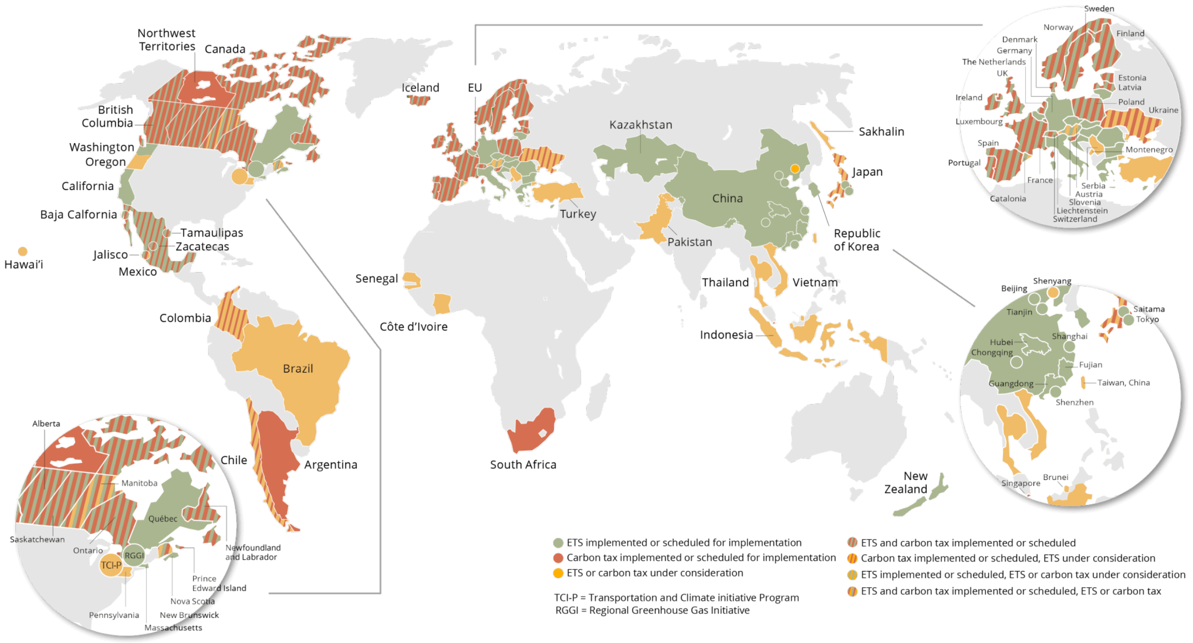
The emissions trading scheme (ETS), also known as the cap-and-trade system, is where we have the carbon credits system previously described. By creating supply and demand for emissions allowances, an ETS establishes a market price for greenhouse gas emissions. The cap helps ensure that the required emission reductions will take place to keep the emitters (in aggregate) within their pre-allocated carbon budget. (GROUP, 2023)

A carbon tax directly sets a price on carbon by defining a tax rate on greenhouse gas emissions or – more commonly – on the carbon content of fossil fuels (GROUP, 2023). As of 2021, 35 carbon tax programs have been implemented across the world (CLIMATE; SOLUTIONS, 2023), as can be seen in 10. A common practice is increasing taxes on carbon-intensive energy for example. While carbon taxes are more accurate in terms of cost, they do not guarantee a reduction in the amount of emissions and there are no goals or expected outcomes, as does the cap and trade system. On the other hand, with cap and trade, the pricing is more volatile.

The subsidy, in simple terms, allows for a reduction in risk and uncertainty associated with a new project, a reduction in costs, or some combination of the two, a significant aid for investors (VON STECHOW; WATSON; PRAETORIUS, 2011). Subsidies are especially needed at the beginning of the technology so that it can more easily enter the market. Still, it must the structured in a way that it doesn't harness other competing technologies or generate false impressions of the market structure. It must be constructed in a way that market inefficiencies are not simply being masked and that the subsidies can eventually be retrieved or reduced, and the technology may be able to thrive on its own.

With regulations, the adoption of certain technologies can be encouraged - or discouraged. CCS has been boosted through regulations in Canada and the United States, for example. Since July 2015, the Canadian government has limited new coal-fired generators to 420 tonnes of CO_2 per gigawatt hour of electricity, which contributed to the deployment of CCS.

Figure 10 – Carbon Pricing Implementation Globally



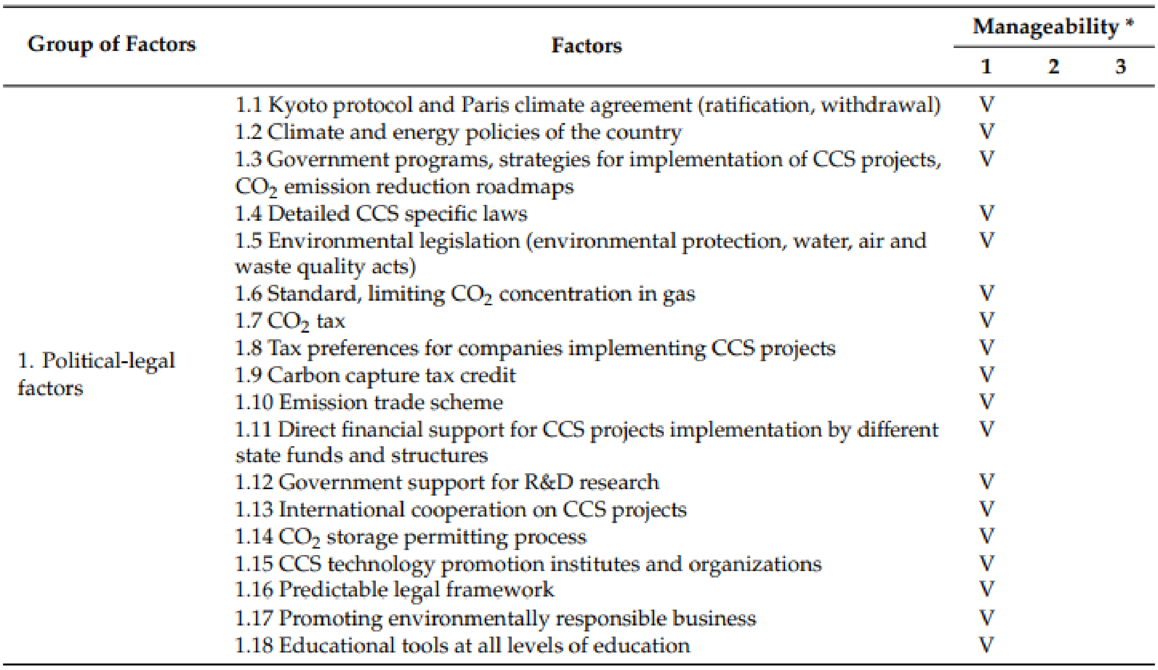
Source: (CLIMATE; SOLUTIONS, 2023).

Several other factors can also play a role in the CCS and DAC political and legal scenario. The study conducted by (ROMASHEVA; ILINOVA, 2019) proposed a checklist method to assess the maturity of countries' policy incentives and regulatory framework in the field of CCS technologies and projects deployment. A list of questions was elaborated related to numerous political-legal manageable factors, which are presented in Figure 11. The level of maturity of the country was then determined through a score derived from the answers to the questions. Seven relevant countries were evaluated in terms of CCS, those being the US, the UK, Australia, China, Germany, Canada, and Norway. The US acquired the highest score, followed by Canada and Australia. Even though such a study has not yet been developed specifically for DAC, most of the factors considered for CCS in the study would also be equally important for DAC, as these technologies share similar purposes.

When defining new policies and market strategies, some key elements must be considered by policymakers, so that CCS or DAC technologies can be successfully developed. Besides the factors pointed out, it is also important to consider social aspects like distributional impacts and competitiveness.

Lower-income households spend a larger share of their income on energy than higher-income households. As a result, a price on carbon that increases energy costs can have a greater impact on lower-income individuals. Directing a certain percentage of revenue from a carbon tax toward low-income households to compensate for

Figure 11 – Political-legal factors affecting the implementation and deployment of carbon capture and storage (CCS) projects



Group of Factors	Factors	Manageability *		
		1	2	3
1. Political-legal factors	1.1 Kyoto protocol and Paris climate agreement (ratification, withdrawal)	V		
	1.2 Climate and energy policies of the country	V		
	1.3 Government programs, strategies for implementation of CCS projects, CO_2 emission reduction roadmaps	V		
	1.4 Detailed CCS specific laws	V		
	1.5 Environmental legislation (environmental protection, water, air and waste quality acts)	V		
	1.6 Standard, limiting CO_2 concentration in gas	V		
	1.7 CO_2 tax	V		
	1.8 Tax preferences for companies implementing CCS projects	V		
	1.9 Carbon capture tax credit	V		
	1.10 Emission trade scheme	V		
	1.11 Direct financial support for CCS projects implementation by different state funds and structures	V		
	1.12 Government support for R&D research	V		
	1.13 International cooperation on CCS projects	V		
	1.14 CO_2 storage permitting process	V		
	1.15 CCS technology promotion institutes and organizations	V		
	1.16 Predictable legal framework	V		
	1.17 Promoting environmentally responsible business	V		
	1.18 Educational tools at all levels of education	V		

Source: (ROMASHEVA; ILINOVA, 2019, p.6).

increased energy costs can help ensure that the tax does not disproportionately affect the poor (CLIMATE; SOLUTIONS, 2023).

Without provisions protecting local production, a carbon price could put domestic energy-intensive, trade-exposed industries (EITEs), such as chemicals, cement/concrete, and steel, at a competitive disadvantage against international competitors that do not face an equivalent price (CLIMATE; SOLUTIONS, 2023). To avoid local producers being harnessed and prevent what is called "emissions leakage", where there would only be a shift in demand from one country to the other, the low-carbon policies plan must include provisions to avoid emissions leakage and encourage emission reductions.

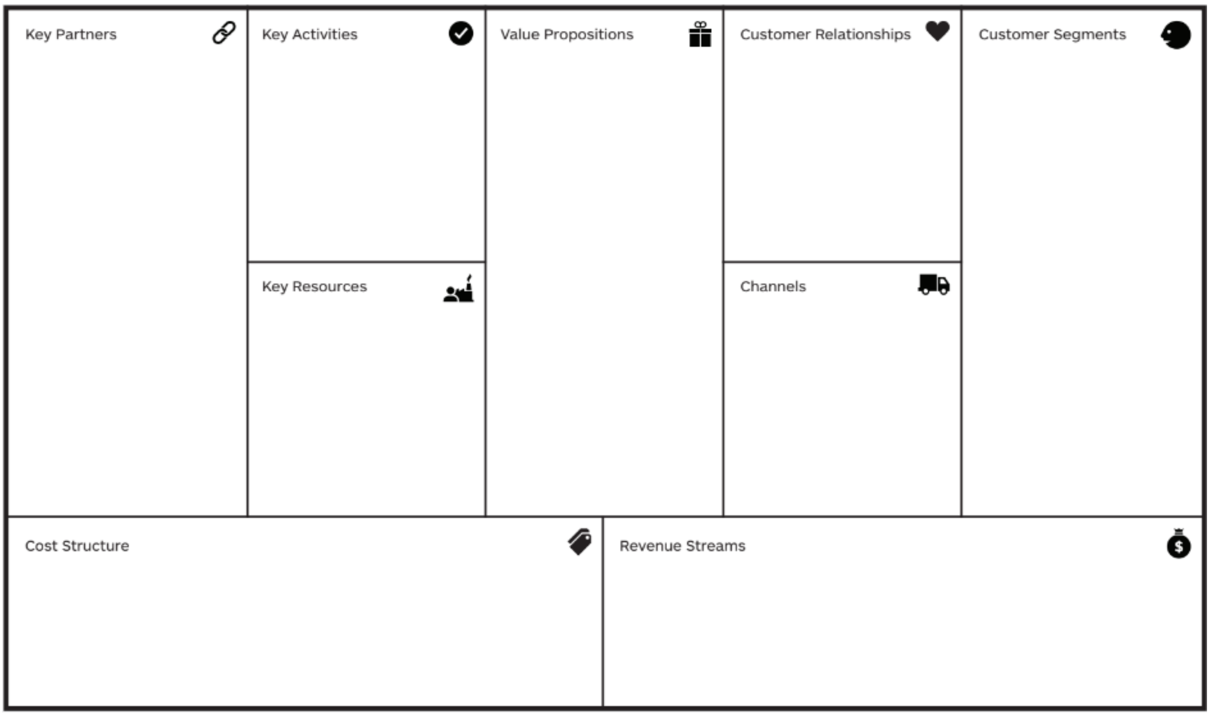
2.4 BUILDING A BUSINESS MODEL

After exploring carbon capture in detail, particularly direct air capture (DAC), and examining its technological and political aspects, as well as the dynamics of carbon markets, it is now crucial to dive into the final piece of the puzzle: understanding business models. This section focuses on explaining what a business model is and why it is crucial for any company aiming to stand out in the market. The concept and characteristics of a business model will be explored, highlighting its importance in helping companies become competitive in the market.

A business model describes an architecture for how a firm creates and delivers value to customers and the mechanisms employed to capture a share of that value. It's a matched set of elements encompassing the flows of costs, revenues, and profits (TEECE, 2018). It refers to the conceptual framework and plan that describes how a company creates, delivers, and captures value. Overall, it acts like a blueprint that tells how a company operates, differentiates itself from competitors, and ultimately achieves profitability and sustainable growth.

The elements of a business model must cover the three main areas of a business: desirability, viability, and feasibility, and can be described through 9 building blocks: Customer Segments, Value Propositions, Channels, Customer Relationships, Revenue Streams, Key Resources, Key Activities, Key Partnerships, and Cost Structure (AG, 2019). Different authors can change slightly the elements composing a business model, but overall it fits within the categories mentioned. In Figure 12, an example of what a framework for a Canva Business Model would look like.

Figure 12 – Example of Business Model framework.

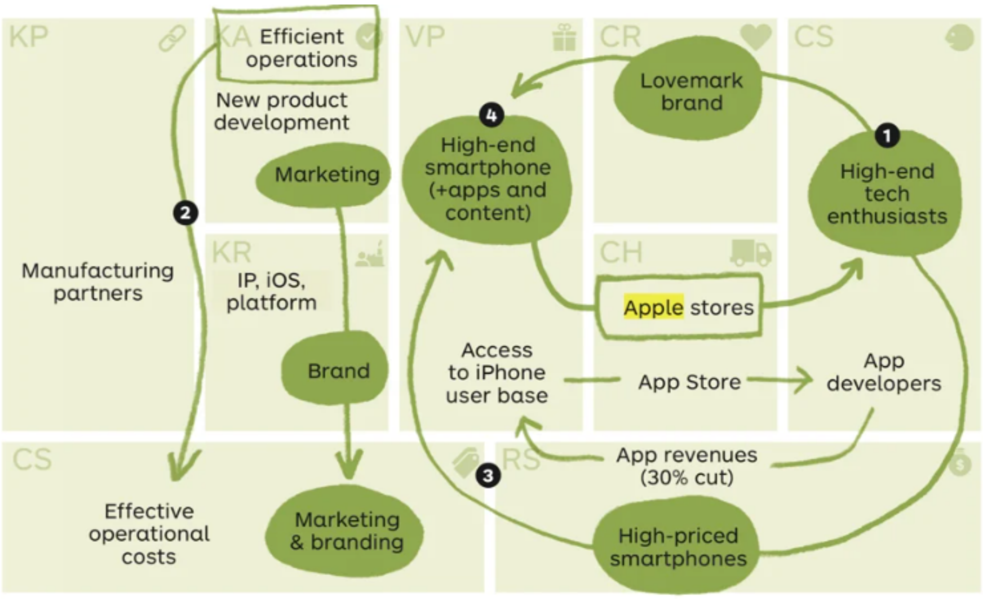


Source: (AG, 2019).

Depending on the field of the company, the business model can change drastically. Each company or industry will have a different business model that fits them better. Take as an example the business model applied at Apple, shown in Figure 13.

Apple, a global front-runner in the smartphone industry, has achieved remarkable success. While there are other companies with comparable or even superior quality,

Figure 13 – Business Model for Apple.



Source: (AG, 2019).

Apple still dominates the market, which can be partially attributed to its business model. This model incorporates strategic "moats" that create significant barriers for potential competitors, making it difficult for them to surpass Apple's market position.

Using visual tools like Canva to display the business model offers decision-makers a convenient way to visualize the company's strategy. With a single image, one can easily see the overall essence of the company. This visual representation allows for a comprehensive view of the company's big picture, making it easier to communicate and understand the strategic components that drive its operations.

In the context of Company X, it is crucial to consider sustainable business models as another important concept. Historically, most business model types have not prioritized vital sustainability issues that have significant societal and environmental impacts on both humans and nature. However, business models are now facing increasing pressure to transform into a more sustainable economic system in order to achieve the sustainability goals of companies.

Sustainable business models can be defined as business models that incorporate pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and hold a long-term perspective (GEISSDOERFER; VLADIMIROVA; EVANS, 2018). Sustainable business models hold significant potential to integrate the principles of sustainability into the value proposition, value creation, and value capture activities of businesses, enabling them to align with and pursue sustainability goals effectively (NOSRATABADI et al., 2019).

Internationalization, along with the urge to keep up with sustainable development goals, has made worldwide competition among firms more complex, with conventional business models struggling to find appropriate solutions (NOSRATABADI et al., 2019). In this context, the alternative concept of the sustainable business model has brought a competitive advantage to organizations through empowering the conventional business models to meet sustainable development goals while maintaining productivity and profitability (NOSRATABADI et al., 2019).

Having a holistic view on the presented approaches reveals that designing sustainable value creation, sustainable value delivering, and sustainable B2B partnerships are other solutions that have emerged in the literature for developing a sustainable business model (NOSRATABADI et al., 2019). Four main approaches have emerged in the literature for designing a sustainable business model: designing a sustainable value proposition, designing sustainable value creation, designing sustainable value delivering, and generating sustainable partnership networks for creating and delivering such sustainable value which can meet the social, environmental, and economic benefits at the same time (NOSRATABADI et al., 2019). The same conclusions were also expressed by (GEISSDOERFER; VLADIMIROVA; EVANS, 2018).

Finally, another concept that could be relevant for Company X is the sustainable business innovation model, where besides the sustainable aspect being considered, the novelty of the company is also taken into account. In this particular case, the "sustainable start-ups model" would be relevant for Company X, where a new organization with a sustainable business model is created (GEISSDOERFER; VLADIMIROVA; EVANS, 2018).

For the purpose of this study, the company will focus on the Canva business model, as it is simple and convenient, especially considering the novelty of this technology. Nonetheless, for future development and when the technology reaches more mature levels, other business models should be explored, in particular sustainable business innovation models.

To begin building the business model, it is important to analyze each of the components shown in Figure 12. For starters, the first field that must be addressed is the Value Proposition, which is where the company describes the assortment of products and services that create value for a specific customer segment (AG, 2019), stating what it is that makes their business stand out from the competition and attract customers, making them unique.

The Customer Segments field identifies the categories of individuals or organizations that a company intends to target and serve. Categorizing and segmenting customers based on their similarities and needs allows for a focused approach, so that the company can select the right customer segments to prioritize and which segments to exclude. By understanding the specific requirements of each segment, the company can direct its strategies to effectively conquer the desired customers. Aligned with

Customer Segments, is the fields of Customer Relationships and Channels. The first one determines the type of relationship the company will build with its customer segments, including for example the ways through which the company acquires and retain customers. Customer Relationships involves understanding customer needs, providing support, addressing inquiries, and building trust and loyalty over time. The Channels on the other hand, refers to the means through which a company communicates, interacts, and delivers its Value Proposition to customers. This includes responsibilities such as raising awareness among customers about a company's products and services; assisting customers in evaluating a company's Value Proposition; delivering a Value Proposition to customers; and providing post-purchase customer support (AG, 2019).

Cost Structure and Revenue Streams compose the viability side of the business model. The Revenue Streams Building Block refers to the sources of income a company generates from its different Customer Segments. Each Customer Segment will most likely a different value they are willing to pay for. In order for the company to effectively satisfy its customers needs, it is important to address each segment individually, and plan their revenue streams accordingly. These Revenue Streams may employ various pricing mechanisms, including fixed list prices, bargaining, auctions, market-dependent pricing, volume-dependent pricing, or yield management (AG, 2019). The Cost Structure outlines the complete range of expenses associated with operating a business model. It represents a complete analysis of all aspects of the business, including value creation, customer relationships, and revenue generation. By understanding the Cost Structure, a company can properly allocate resources, optimize its operations, and make informed decisions to achieve cost efficiency and profitability.

The Partnerships topic if an extremely relevant field when it comes to DAC. This field comprehends all of the players such as suppliers and partners that allow the business model to succeed. Companies may establish alliances and collaborations in order to optimize operations, mitigate risks, and access critical resources. By investing in strategic partnerships, companies can leverage the strengths of their partners, enter new markets, and create synergies that can improve their overall value proposition.

The Key Resources field refers to assets required to sustain the business model. They can vary from physical, financial, intellectual, or human. Together, the key resources enable a company to deliver its value proposition, meet customer demands, and achieve its business objectives in a competitive marketplace. Complementing the Key Resources are the Key Activities, which describe the essential actions and processes a company must do to guarantee a successful operation. They can vary deeply from one company to the other, an can include items such as product design and development, manufacturing or service delivery, marketing and sales, customer support, supply chain management, research and development, and administrative tasks. Key activities may also involve strategic activities such as partnerships and collaborations, regulatory compliance, quality assurance, and continuous improvement. As for the others field explored, the key activities must lead the company in the direction of delivering the value proposition to its customers.

The main purpose behind the literature review conducted in this study was first to allow the reader into the current state of knowledge and research regarding the many aspects of carbon capture and, more specifically, Direct Air Capture (DAC). Through a comprehensive examination of technological aspects, political considerations, and carbon markets, a holistic view of the DAC landscape was presented, shedding light on the intricacies and opportunities inherent in this field. Furthermore, the review explored the concept of a business model, its purpose in developing a business, and its key components. Moving forward, this literature review serves as a solid foundation for the subsequent phases of the research, where further discussions, discoveries, and conclusions will contribute to the development of an effective business model for a successful DAC company.

3 METHODOLOGY

To ensure the credibility of this study and achieve the proposed objectives, it is necessary to determine the proper methodology. In this chapter, the methodological procedures utilized during the development of the study were explained, starting with the definition and classification of the scientific methodology applied, followed by the data collection, data analysis, ethical considerations, and limitations.

3.1 CLASSIFICATION OF THE STUDY

This study adopted a qualitative approach based on a single case study. The purpose is to develop a business model for a company developing a direct air capture technology (DAC) applied to industrial cooling towers as a means to decarbonize the atmosphere. For confidentiality, the company's name and the participants' titles were changed. Company X is currently developing its first prototype, which should be launched between 2023 and 2024. The company in question is one of the front-runners in developing direct air capture products, more specifically retrofitting cooling towers, and has agreed to share relevant data regarding the product and its ramifications.

In this study, the main sources of information will be the data provided by the company, the data collected by the author while observing the company and taking notes, and a thorough literature review. Company X has also granted access to all of the transcriptions of previous relevant meetings and product discussions that can contribute to the study.

Within qualitative methods, the action-research case study was chosen, as it combines theoretical investigation with practical action. The author was directly inserted into the daily routine of the company and was given the freedom to express opinions and participate in discussions. This approach values the active participation of the people involved, recognizing that they have relevant knowledge and experiences to contribute to the research. Instead of simply observing and analyzing the situation, researchers engage directly in action, seeking effective transformation. Considering that the subject of this study is a technology new to the market and that requires extensive research and development to achieve a competitive market-ready solution, a participatory action research case study allowed the parts involved to trace a path toward building knowledge regarding direct air capture and instigate further investigation to improve this technology.

3.2 DATA COLLECTION

In conducting the literature review, the primary sources of data comprised online articles and research publications. Additionally, to gather firsthand information about company X, the author engaged in a 6-month period of observation, starting from January 2023 to June 2023. This involved direct interaction with the company, conducting interviews with key stakeholders, and reviewing pertinent company documents, including transcripts of internal and external interactions.

The company has established a systematically organized knowledge base that effectively facilitates document navigation. Google Drive and Notion are the two most used tools in the company, ensuring efficient internal organization of relevant documents. This approach simplifies the access and retrieval of information, allowing the author to easily locate the necessary data.

The data collection process encompassed a wide range of aspects related to the company's operations. It involved examining the company's internal documents and conducting observations to gain insights into various areas. Key areas of focus included understanding the company's existing partnerships, previous and potential future investments, revenue generation strategies, targeted customer segments, competitive landscape, prototype costs and projected expenses, as well as risk assessment and mitigation approaches. In addition to the company-specific data, the author also conducted extensive literature reviews and online research to gather information on topics such as direct and indirect competitors, the voluntary carbon market, regulations, and political considerations. This comprehensive data collection approach ensured a well-rounded and informed analysis of the company's current state and its broader industry context.

Throughout the duration of the author's involvement with the company, active participation in meetings and discussions provided an intimate understanding of every facet, encompassing both the business and product aspects. This hands-on approach facilitated the development of a comprehensive and holistic perspective of the company as a cohesive entity.

As for the information gathered through articles and scientific research, the author analyzed over 80 external sources and used 48 of them to justify the decisions and conclusions throughout the study, including articles and online sources.

3.3 DATA ANALYSIS

Once all the data is collected, the author can classify and analyze the gathered information. The first step was to outline a plan on what topics were to be covered in the results in the discussion section. During the literature review, the last topic was about how to build a business model, which helped draw a plan as to what should be included in the business model of company X.

The first topic to be developed is a dive-in into the company and its technology, where an overview of the company was provided along with technical information about the ongoing and future products. The second step was to develop a market analysis, where other competing technologies were analyzed, especially in terms of competing in the voluntary carbon market for selling carbon credits, other DAC companies were studied, focusing on their technology and business models, then a customer analysis, and finally we had a look on relevant regulations. For the market analysis, both information obtained externally through research and internally by analyzing the company's documents were applied.

In the section "Building a business model", all of the relevant elements of a business model, outlined during the literature review, were analyzed in the context of Company X. For each topic inside this section, data obtained from the literature review, the data collection inside the company, and the market analysis were analyzed and interpreted by the author. Using multiple sources allowed for a triangulation of the qualitative data, ensuring the validity and reliability of the findings.

Finally, in the last topic, the author formulated a visual comprehensive business model for Company X, incorporating insights from the literature review, as well as the author's own findings and conclusions described during the section "Building a Business Model for Company X".

3.4 ETHICAL CONSIDERATIONS

The sensitive data regarding the development of the technology will not be presented, being used only for the author's full comprehension of the technology. The author will be signing a non-disclosure to ensure Company X confidentiality.

3.5 LIMITATIONS

Case studies have several limitations that must be considered. Firstly, the findings of a case study, in this case, Company X, may not be applicable to all DAC companies, as every DAC company has its own particularities. This limits the ability to make the claims considered in this study universal conclusions. For one, Company X is situated in Germany, which has its own set of laws and regulations, and incentives, that most likely cannot be extrapolated to other countries without careful consideration.

Secondly, as case studies rely heavily on qualitative data, which can be subjective and prone to interpretation biases, it is open for interpretation, requiring an extra caution in analyzing the data to ensure objectivity.

Thirdly, the researcher's presence and involvement in the case study can introduce biases or influence the outcomes. The researcher's presence and involvement in the study can introduce their own perspectives, assumptions, and prior knowledge, possibly influencing data collection and analysis, putting at risk the validity and reliability of the study.

In relation to the technical aspect of Company X, certain technical aspects of the prototype have not been extensively discussed in this study. Specifically, the company has conducted a thorough analysis of cooling towers, which holds significant importance both technically and from a business perspective. However, it should be acknowledged that this study does not delve into a detailed examination of the company's activities related to cooling tower retrofitting. At present, the company has not initiated the retrofitting of cooling towers, indicating that this aspect of their business remains in the research stage. They are to be considered for business purposes but not in extensive detail.

Furthermore, there may also be challenges in accessing certain information or obtaining complete data, either due to confidentiality reasons or lack of documentation, which can impact the comprehensiveness of the study. These limitations often lead to uncertainties and constraints, which must be carefully acknowledged by the author, as they might lead to gaps in the study.

Lastly, this case studies are was conducted during a 6-month time frame of observations, which limits the ability to capture long-term effects or changes over time. The findings of this study may not be representative of the case's dynamics outside the studied time frame and must be revised in case of future development.

All of the above-mentioned limitations must be considered while conducting a case study in order to ensure transparency and validity in the chosen approach and interpretation of the results.

4 RESULTS AND DISCUSSION

The Results and Discussion chapter of this thesis provides a comprehensive analysis and interpretation of the collected data, focusing on its application in structuring the business model of Company X. This chapter aims to highlight the findings and provide a deeper understanding of the research question and proposed objectives. Additionally, the implications of these results will be discussed in relation to the existing literature and theoretical framework. By the conclusion of this chapter, a clear understanding of the envisioned business model for Company X will be attained, along with a comprehensive rationale for the decisions made.

4.1 STUDY ENVIRONMENT

Founded in 2021 by two sustainability-driven engineers, Company X embarked on its mission to decarbonize the atmosphere with passion. With an initial fundraising effort that attracted three venture capitals and seven individual investors (five angel investors and the two founders), amounting to a total of 1.35 million euros, the company managed to assemble a small dedicated team. Company X then organized itself into three main areas: chemical and process, mechanical, and business. Despite its modest size, the company fostered a high level of integration among these areas from the beginning, promoting effective communication and synergy across the different domains.

Since then the company has grown, and currently counts with over 7 permanent employees and 5 intern positions. The company is running entirely on investments and grants, with the first profits expected to be generated in 2025, once the first modules can be installed. The company intends to reach a price-point of 532 €/t by 2025, before realizing 106-161 €/t in 2030.

The upcoming market-ready modules represent a significant milestone, with an anticipated capture capacity of 62.5 tons of CO_2 per year. Looking ahead to 2024, Company X plans to install 8 modules, resulting in a combined capture capacity of 500 tons of CO_2 annually. Recent progress has been made as the company successfully constructed the initial prototype, enabling comprehensive testing and experimentation to identify areas for optimization and refinement, but the planned module predicted to be launched in 2024 is still in its early stages of development.

Elaborating on the technology, the upcoming product is a modular capture unit capable of capturing CO_2 directly from the air. Company X uses a low-temperature, Vacuum Temperature Swing Adsorption (VTSA) process, using an amine-based solid sorbent, placed on a structured bed from additive manufacturing. One of the biggest advantages of solid sorbents is the lower temperatures in the process (80 to 120 $^\circ$C), which are easier to achieve in a smaller-scale company, plus their stability under moisture in the air.

The process occurs in two main stages, adsorption, and desorption. In the first phase, adsorption, the sorbent passes through a contactor, where the surface area where the sorbent is in contact with air must be maximized. With the contactor in place, an airflow must be provided to force the air to go through the contactor, where the CO_2 will be pulled from the airflow by the sorbent until the sorbent is fully saturated.

Once enough CO_2 is embedded in the sorbent, the second phase, desorption, can begin. The desorption requires higher temperatures to occur, in the range of 95°C to 100°C, and the process must happen under vacuum, as the presence of air can damage the sorbent when going through elevated temperatures. To enhance the performance of the sorbent, a steam injection can be added to the process, which will increase overall efficiency (humidity-enhanced sorption of CO_2 (OZKAN et al., 2022)). After the desorption is finished, the regenerated sorbent can begin another cycle.

There are two major paths in the process, one involving air and one involving water. In the air path, air released from the cooling tower is channeled into the capture system and split between several identical modularized units. Each unit is equipped with capture reactors fitted with 3D-printed porous support for optimal volume/surface ratio and minimized pressure drop. The reactor surface is embedded with the sorbent, promoting the capture of CO_2 from the flowing air. When the sorbent becomes saturated, the chamber is depressurized by the vacuum pump, producing a pure CO_2 stream. In the water path, hot water is diverted from the cooling tower (40 - 60 °C) input, and high-temperature water is generated using a heat pump (100 °C). To improve CO_2 desorption during the vacuuming phase, the high-temperature water is leveraged to heat up the reactor. The reactor is then cooled down using the cold water output from the heat pump.

The captured CO_2 can then be processed and transported to its final destination, which can be permanent storage or utilization in other industries, such as carbonated drinks, cement, and chemical industries.

The airflow is provided by a cooling tower, which must be retrofitted so that the module can be integrated into the process. Currently, the first prototype capable of capturing CO_2 has been successfully developed and it is undergoing tests and optimizations. The airflow is temporarily provided by a fan, while the retrofitting of cooling towers composes the next phase for the company.

One big advantage of the company's X product is the dimension. The current version is sized as 2m x 2m x 1.5m, and the next version is planned to be even smaller, with 1.5m x 1.5m x 1.5m, considering future optimizations.

The initial concept was to focus solely on leveraging cooling towers, so that the carbon dioxide present in the air passing through the cooling tower could be captured, but new possibilities aroused during research and development. Waste heat integration is being explored as an alternative path, so that the business can expand beyond cooling towers. With this approach, any industry generating sufficient amounts of waste heat could then be a possible consumer of the product. A considerable portion of the energy required by the process is used for heating water for the system, and leveraging waste heat could reduce the requirement for heat, lowering the overall cost. Nonetheless, those are future improvements that still need to be properly researched, as right now the focus of the company is to develop the prototype predicted to be ready in 2024.

4.2 DIRECT AIR CAPTURE MARKET ANALYSIS

In the context of direct air capture (DAC), two markets require analysis. Firstly, there is the broader market encompassing all carbon dioxide removal technologies (CDR). Subsequently, our attention shifts to the specific market of DAC technologies. While carbon capture and storage (CCS) technologies were examined during the literature review to comprehend the carbon capture ecosystem as precursors to DAC, we will not delve into them extensively. Our primary focus will be on CDR and DAC, with CCS technologies only addressed when relevant.

The analysis of the direct air capture market encompasses both financial and environmental considerations. It necessitates understanding the monetary potential and profitability of the technology, as well as the current and future capacity for CO_2 capture. Within this framework, two primary aspects will be assessed: the economic aspect, predominantly evaluated through carbon offsets and the voluntary carbon market, and the environmental aspect, involving the examination of atmospheric CO_2 concentrations and overall emissions. These factors will be taken into account when analyzing various products and technologies, customers, suppliers, competitors, and regulations.

As of 2022, the real voluntary carbon market is valued at around $2 billion, while the compliance carbon market is valued at $899 billion (NEUFELD, 2023). Despite the compliance market being more significant, the voluntary market has grown over five times what it was 3 years before, and it is expected to grow even further.

According to a 2020 report by the World Bank, carbon prices on the VCM start at less than US$1/ton CO_2e and increase to US$119/ton CO_2e. And the prices for almost half of the emissions are at less than US$10/t$CO_2$e (CARBONCREDITS, 2023). In 2021, a total of 493 MtCO_2e were traded in the VCM.

On one side the VCM is growing rapidly, as more companies are increasingly investing in carbon dioxide removal approaches. Displaying the carbon-neutral stamp has become attractive to consumers, that are consistently prioritizing companies that corroborate with their personal values. On the other hand, the prices of carbon offsets are very competitive, as most CDR projects can achieve the US$10/t$CO_2$e margin, making it difficult for technologies such as DAC that have a higher price to infiltrate without governmental assistance.

Shifting to the environmental sphere of this analysis, according to the IPCC (Intergovernmental Panel on Climate Change), we'll need to remove 10 billion tons (or gigatons) of CO_2 from the atmosphere by 2050. We have removed around 0,01% so far (CDR, 2023), which means that CDR technologies have to increase significantly.

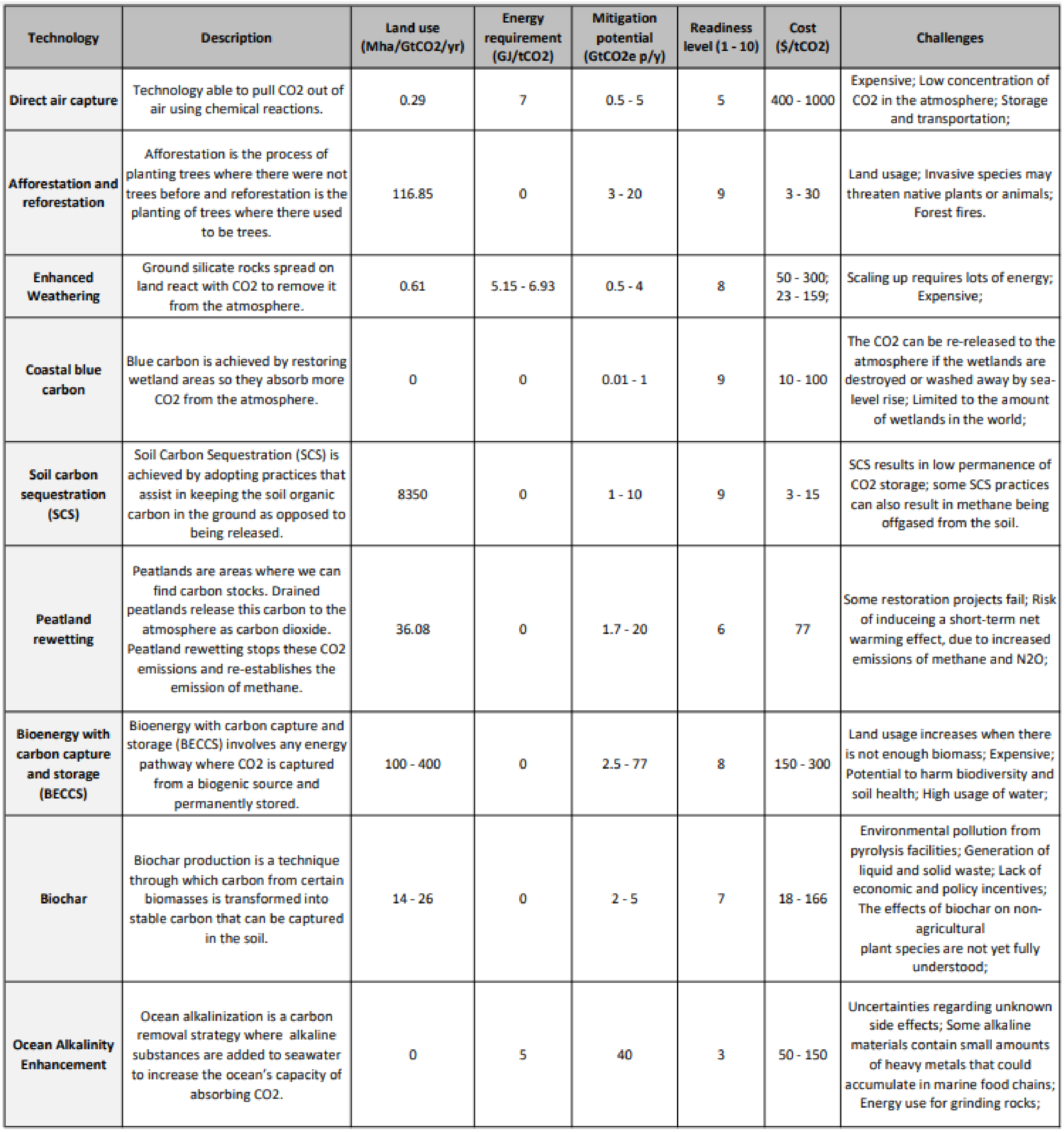
The atmospheric CO_2 concentration at present stands at approximately 421 ppm or 3,237 $GtCO_2$. To limit the temperature increase to under 2°C by the end of the century, a yearly capture and removal of 20 $GtCO_2$ would be necessary (OZKAN et al., 2022). Currently, the global carbon dioxide capture and storage rate is 0.0385 $GtCO_2$ per year, including a DAC capacity of 9,000 tCO_2 per year (OZKAN et al., 2022). If these rates persist, it would take over 20 thousand years to achieve the goals outlined in the Paris Agreement, underscoring the pressing need to take immediate action in mitigating climate change.

When it comes to DAC, there are currently nineteen DAC facilities active worldwide, capturing almost 0.01 Mt of CO_2/year, and a 1 Mt CO_2/year capture plant is in advanced development in the United States. In the Net Zero Emissions by 2050 scenario, direct air capture is scaled up to capture almost 60 $MtCO_2$/year by 2030 (IEA, 2022). Plans for a total of eleven DAC facilities are now in advanced development. If all of these planned projects were to go ahead, DAC deployment would reach around 5.5 $MtCO_2$ by 2030; this is more than 700 times today‘s capture rate, but less than 10% of the level of deployment needed to get on track with the Net Zero Scenario (IEA, 2022).

4.2.1 Products analysis

There are currently a few products available in the market that can actively remove CO_2 from the atmosphere. These technologies are known as carbon dioxide removal (CDR) technologies. That assortment of products includes targeted afforestation and reforestation, enhanced weathering, coastal blue carbon, soil carbon sequestration, peatland rewetting, direct air capture (DAC), and bioenergy with carbon capture and storage (BECCS), amongst others. A comparison between the most relevant methods is shown in Figure 14.

Figure 14 – Comparison between current CDR technologies.



Technology	Description	Land use (Mha/GtCO2/yr)	Energy requirement (GJ/tCO2)	Mitigation potential (GtCO2e p/y)	Readiness level (1 - 10)	Cost ($/tCO2)	Challenges
Direct air capture	Technology able to pull CO2 out of air using chemical reactions.	0.29	7	0.5 - 5	5	400 - 1000	Expensive; Low concentration of CO2 in the atmosphere; Storage and transportation;
Afforestation and reforestation	Afforestation is the process of planting trees where there were not trees before and reforestation is the planting of trees where there used to be trees.	116.85	0	3 - 20	9	3 - 30	Land usage; Invasive species may threaten native plants or animals; Forest fires.
Enhanced Weathering	Ground silicate rocks spread on land react with CO2 to remove it from the atmosphere.	0.61	5.15 - 6.93	0.5 - 4	8	50 - 300; 23 - 159;	Scaling up requires lots of energy; Expensive;
Coastal blue carbon	Blue carbon is achieved by restoring wetland areas so they absorb more CO2 from the atmosphere.	0	0	0.01 - 1	9	10 - 100	The CO2 can be re-released to the atmosphere if the wetlands are destroyed or washed away by sea-level rise; Limited to the amount of wetlands in the world;
Soil carbon sequestration (SCS)	Soil Carbon Sequestration (SCS) is achieved by adopting practices that assist in keeping the soil organic carbon in the ground as opposed to being released.	8350	0	1 - 10	9	3 - 15	SCS results in low permanence of CO2 storage; some SCS practices can also result in methane being offgased from the soil.
Peatland rewetting	Peatlands are areas where we can find carbon stocks. Drained peatlands release this carbon to the atmosphere as carbon dioxide. Peatland rewetting stops these CO2 emissions and re-establishes the emission of methane.	36.08	0	1.7 - 20	6	77	Some restoration projects fail; Risk of induceing a short-term net warming effect, due to increased emissions of methane and N2O;
Bioenergy with carbon capture and storage (BECCS)	Bioenergy with carbon capture and storage (BECCS) involves any energy pathway where CO2 is captured from a biogenic source and permanently stored.	100 - 400	0	2.5 - 77	8	150 - 300	Land usage increases when there is not enough biomass; Expensive; Potential to harm biodiversity and soil health; High usage of water;
Biochar	Biochar production is a technique through which carbon from certain biomasses is transformed into stable carbon that can be captured in the soil.	14 - 26	0	2 - 5	7	18 - 166	Environmental pollution from pyrolysis facilities; Generation of liquid and solid waste; Lack of economic and policy incentives; The effects of biochar on non-agricultural plant species are not yet fully understood;
Ocean Alkalinity Enhancement	Ocean alkalinization is a carbon removal strategy where alkaline substances are added to seawater to increase the ocean's capacity of absorbing CO2.	0	5	40	3	50 - 150	Uncertainties regarding unknown side effects; Some alkaline materials contain small amounts of heavy metals that could accumulate in marine food chains; Energy use for grinding rocks;

Source: Author, adapted from: (JOHN SANCHEZ; PISCIOTTA, 2023); (SOCIETY; ENGINEERING, 2018); (IPCC, 2018); (MCQUEEN et al., 2020); (GÜNTHER et al., 2020); (TANNEBERGER et al., 2020); (BUTLER, 2023); ((NWE), 2020); (FERN, 2022); (VENTURES, 2023).

4.2.1.1 Afforestation and refforestation

Afforestation and reforestation have a crucial role in carbon capture, as they establish or re-establishing forest areas. Trees absorb CO_2 from the atmosphere while they grow, as part of their natural cycle, and store it in living biomass, dead organic matter, and soils. The net uptake of CO_2 that a forest can capture reduces over time, as the trees mature, and when these levels go below desired values for carbon capture, and at this point, forest products can be harvested and converted into long-lived wood products, or used for bioenergy and biochar, and a new cycle can begin with the introduction of more trees where the old ones once were.

This approach has a maximum readiness level, as it is a simple method that is already extensively practiced throughout the world. On the downside, it requires an extensive amount of land and if not done properly, it might threaten native species of trees and animals, if the trees are introduced in regions that are very different from their natural habitat. Being a nature-based solution, it has little room for improvement, relying mostly on forest management for some optimization.

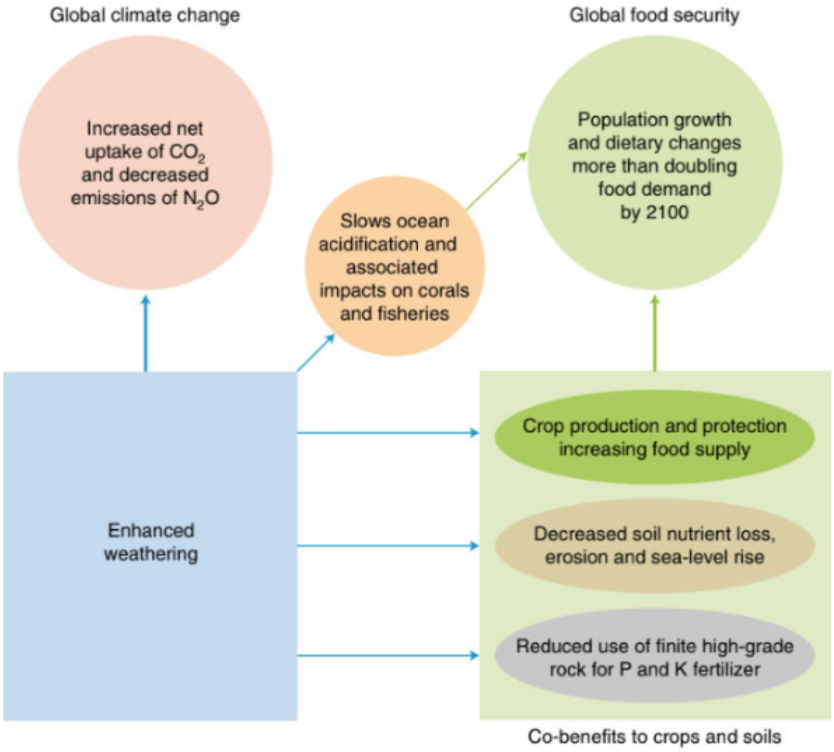
4.2.1.2 Enhanced Weathering (EW)

Enhanced weathering is the chemical breakdown of rocks - weathering - and is an important but very slow part of the carbon cycle that ultimately leads to CO_2 being locked up in carbonates on the ocean floor (TAYLOR et al., 2016). It is a natural process where rocks are eroded over long periods of time, sequestering CO_2 from the atmosphere.

The natural process begins with rain, usually slightly acidic. The acidic rain reacts with the rocks and soils it lands on, gradually breaking them down into minute rock grains and forming bicarbonate in the process. Eventually, this bicarbonate washes into the oceans, where the carbon is stored in dissolve form for hundreds of thousands of years or locked up on the sea floor (BEERLING; LONG, 2018).

Enhanced weathering is about scaling up this natural process. It involves pulverizing silicate rocks such as basalt to bypass the slow weathering action. The resulting powder, with a high reactive surface area, is then spread on large areas of agricultural land where plant roots and microbes in the soil speed up the chemical reactions (BEERLING; LONG, 2018). Some of the benefits that can be achieved with enhanced weathering are shown in Figure 15.

Figure 15 – Enhanced weathering benefits.



Source: (BEERLING; LONG, 2018).

The downside of this method is related to the energy requirement and the cost. Scaling up this technology would imply even more energy requirements. It receives a level of readiness 4 because even tho it is very advanced, it still has room for improvement.

4.2.1.3 Blue carbon

Blue carbon is simply the term for carbon captured by the world's ocean and coastal ecosystems. These coastal systems, though much smaller in size than the planet's forests, sequester this carbon at a much faster rate, and can continue to do so for millions of years (NOAA, 2023).

One method of slowing climate change impacts is to incorporate coastal wetlands into the carbon market through the buying and selling of carbon offsets. This approach creates a financial incentive for restoration and conservation projects by helping to alleviate federal and state carbon taxes aimed at discouraging the use of fossil fuels. When there is less pollution to tax, the process benefits not only the environment but also the financial well-being of the community doing the restoration (NOAA, 2023).

This method is more about protecting and restoring existing wetland ecosystems, which is already being done in multiple places in the world. For that reason, a level of readiness of five was attributed to this method. The main difficulty with this approach is that it is narrowed to the wetland areas in the world, which are limited, and it depends on maintaining these areas protected. Once they are destroyed, the CO_2 is released into the atmosphere.

4.2.1.4 Soil carbon sequestration (SCS)

Soil carbon sequestration is the process of removing CO_2 from the atmosphere by changing land management practices in such a way as to increase the carbon content of soil (SOCIETY; ENGINEERING, 2018).

Soil carbon sequestration is ready for implementation and many of the practices are already well known by farmers and land managers, requiring no additional machinery or infrastructure in most of the cases (SMITH; FRIEDMANN, et al., 2017). For that reason, SCS was accredited with a level of readiness equal to 5. The techniques used comprehends accurate management over crops (improved varieties and their rotation, use of ‘cover crops’, perennial cropping systems, agricultural biotechnology); nutrients (optimised fertiliser type, application rate, timing, precision application); water(including drainage of waterlogged mineral soils); vegetation(improved grass varieties, deep rooting grasses, increased productivity, and nutrient management); animals(stocking density, improved grazing management, improved animal feed production); and fire (SOCIETY; ENGINEERING, 2018).

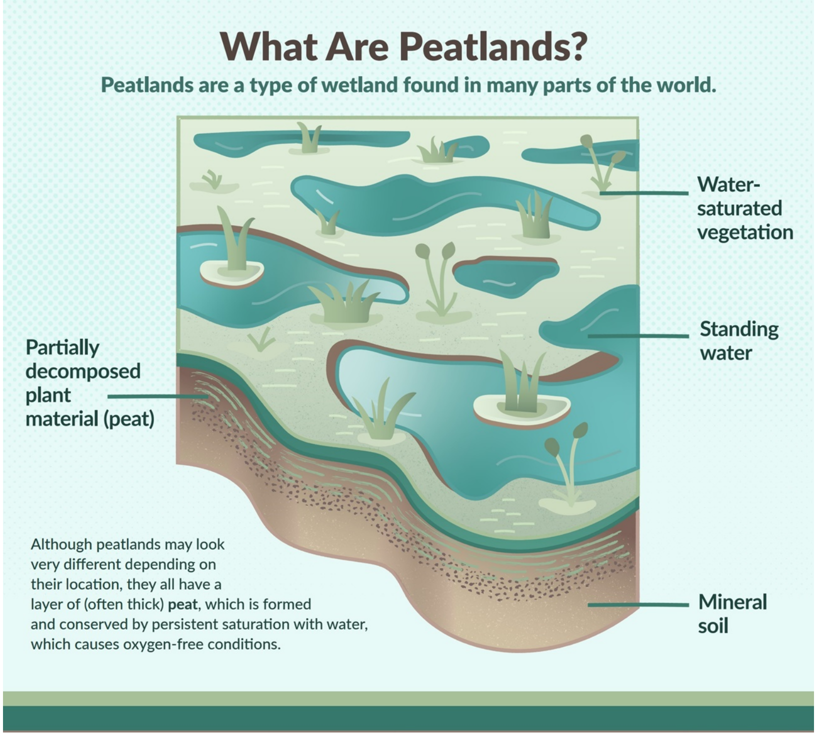
Even though SCS presents a considerable mitigation potential, with a conservative upper bound of 6,9 $GtCO_2/y$, increasing the potential after reaching that point is unlikely, as the soil becomes saturated with carbon, and the practices must be maintained otherwise the situation could be reversed. The cost presented is very conservative for this approach because using SCS could actually generate revenue, since the soil becomes healthier and better for crops.

Also important to consider, is that the land requirement for SCS is big, but it does not change the current use of the land, on the contrary, it improves the soil quality. This means that this approach could potentially be applied to any land without interfering with its ongoing activities.

4.2.1.5 Peatland Reweting

Peatlands are a unique ecosystem formed from organic matter accumulation in the presence of a high water table (BUTLER, 2023). They occur in every climatic zone and continent and cover 4.23 million km2, which corresponds to 2.84% of the Earth’s terrestrial surface (XU et al., 2018). Even though they cover only about 3% of the world’s land surface area, they contain close to 500 Gt of carbon within themselves, double the amount of the biomass of the entire world’s forests combined.

Figure 16 – Understanding the peatland ecosystem.



Source: (PETER EDWARDS, 2022).

When peatlands are drained, the carbon present in the organic matter dries and oxidizes, being then released to the atmosphere as CO_2 and contributing to global emissions. Scientists estimate that 15% of global peatlands have been drained for land development and agriculture, resulting in significant greenhouse gas emissions (PETER EDWARDS, 2022). The emissions from draining peatlands amount to a total of 5% of all human emissions.

Restoring natural water flow and saturating peatland through a process commonly referred to as “rewetting” can reduce greenhouse gas emissions, slow subsidence and reduce the risk of wildfire (BUTLER, 2023).

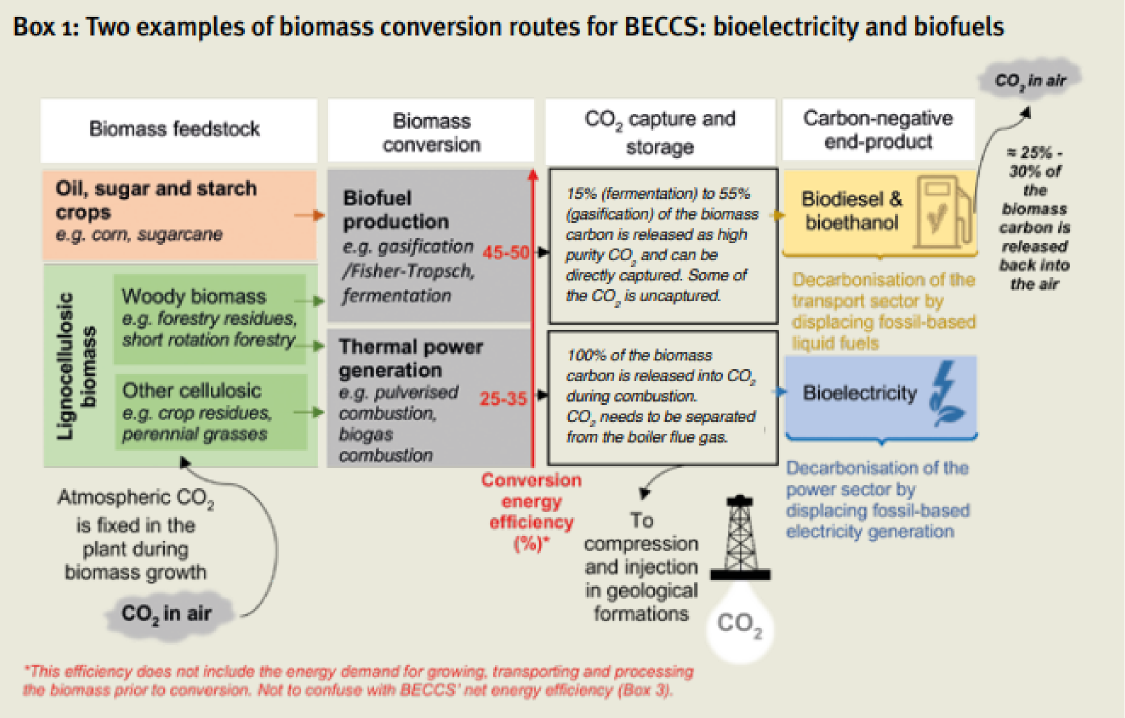
To estimate the land use for peatland rewetting, given the scarce amount of studies in the area, the study of (TANNEBERGER et al., 2020) was used. In the study, the maximum and minimum of tCO_2e per ha and year were given, from which an average can be derived. It was estimated that around 27,715 tCO_2e are emitted on average in temperate latitudes, which would mean that for 1 $GtCO_2e$, an area of 36,08 Mha would be required. It must be considered that the values given for the peatland rewetting, the precision is smaller when compared to the other methods, due to the lack of studies.

The level of readiness for this method was four, considering that more studies are required to understand better the process, as some projects have failed in the past and the consequent emissions of methane and NO_2 are still not fully comprehended.

4.2.1.6 Bioenergy with Carbon Capture and Storage (BECCS)

BECCS is a process in which biomass is combusted in an oxygen-depleted atmosphere, the waste gases are used to produce energy through a turbine system, the solid waste is recollected, and the waste CO_2 is captured and stored (JOHN SANCHEZ; PISCIOTTA, 2023). A schematic of BECCS is shown in Figure 17.

Figure 17 – The BECCS chain.



Source: (FAJARDY et al., 2019, p.2).

In a BECCS chain, CO_2 from the atmosphere is absorbed via photosynthesis into the biomass of plant materials. It is then burned or converted in power plants, industrial facilities or bio-refineries equipped with technologies that capture the CO_2, preventing the gas from returning to the atmosphere (FAJARDY et al., 2019). In order to provide permanent storage, the CO_2 that was captured is injected in deep geological formations.

For BECCS and afforestation/reforestation, land use is one of the biggest issues, as they require a finite resource that is arable land, and end up competing with other uses such as food production and livestock. In addition, there is a considerable amount of water that is used in the process.

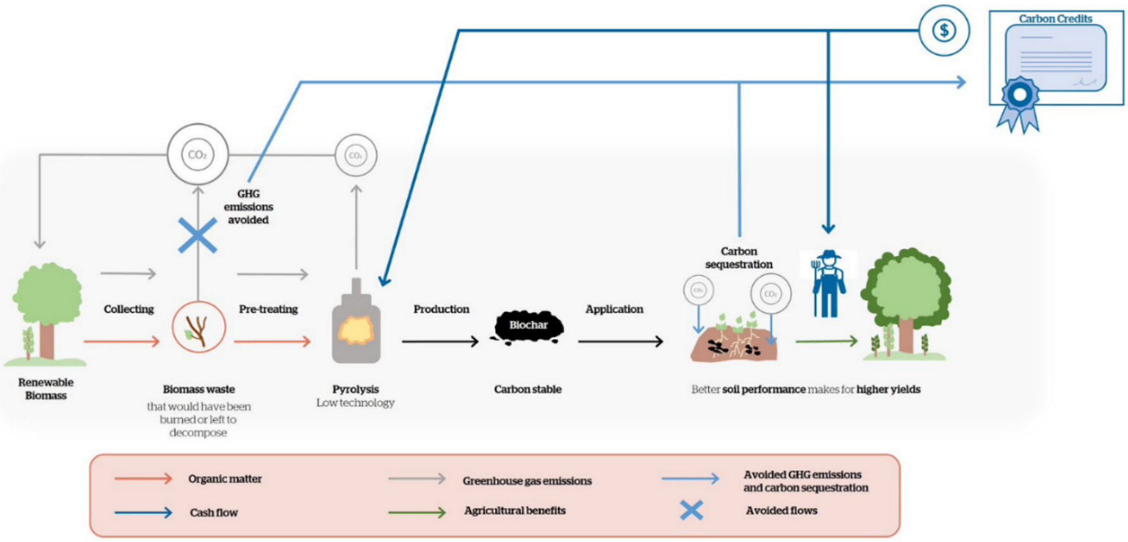
Only around 2Mt of biogenic CO_2 are currently captured per year, mainly in bioethanol applications (IEA, P., 2022). BECCS has the advantage of being the only

CDR technique able to also provide energy. On the other hand, massively deploying BECCS would imply in exorbitant land use. If we wanted to achieve the 1.5℃ target, CO_2 removal by BECCS would have to reach 0-22.5Gt of CO_2 per year by 2100, which would require between 0.4 and 1.2 billion hectares of land, corresponding to 25% to 80% of current global cropland (FAJARDY et al., 2019).

4.2.1.7 Biochar

Biochar, the solid product of biomass pyrolysis, is a charcoal-like carbon-rich material which can be prepared from various organic waste feed stock, such as agricultural wastes and municipal sewage sludge (WANG, J.; WANG, S., 2019). During the pyrolysis process, the organic material are burned in a container with very little oxygen, converting it into biochar, a stable form of carbon that can't easily escape into the atmosphere (SPEARS, 2018), an overview of the process is presented in Figure 18.

Figure 18 – Cycle of biochar.



Source: (STÉPHANIE BOMBAIL GECICA YOGO, 2022, p.4).

If the feedstocks that were used as an input for biochar were left to decompose naturally, it would imply in in CO_2 being released into the atmosphere and contributing to gas emissions. With this approach, the feedstock can be transformed into a structure that doesn't react with oxygen, therefore reducing CO_2 from the atmosphere.

When added to soil, biochar has the ability to store carbon, and to retain nutrients and water due to its porous physical structure. It helps restore soil fertility and reduces water runoff (STÉPHANIE BOMBAIL GECICA YOGO, 2022). The improved soil fertility also stimulates the growth of plants, which consume carbon dioxide (SPEARS, 2018).

Another benefit of this technique is the generation of energy or heat generation that happens during the process, which can captured and repurposed.

Biochar requires land firstly to grow the biomass feedstock and secondly for spreading. Biochar can also be produced from waste biomass, eliminating the need for additional land, and giving value to waste materials, although again there is competition for use of this waste from various GGR methods (SOCIETY; ENGINEERING, 2018).

4.2.1.8 Ocean Alkalinity Enhancement

Ocean Alkalinity Enhancement (OAE), refers to the mechanism of increasing the oceans' capacity of absorbing CO_2 by adding alkaline substances - mostly lime (CaO or $Ca(OH)_2$) - to seawater.

The costs per ton of CO_2 usually range from \$50 to \$100, but for methods that produce hydrogen as a byproduct, that cost can be reduced to as low as 3\$ per ton.

The primary resource requirement for ocean alkalinity is a source of calcium or magnesium minerals to provide that alkalinity. A natural source is limestone, mostly composed of calcium carbonate, which covers around 10% of the earth's surface, but it would need to be extracted and converted to lime for direct addition (SOCIETY; ENGINEERING, 2018). Besides the minerals required, there is also a significant amount of energy that must be considered relative to the processing of limestone (mining and grinding) and the production of lime through calcination.

Theoretically, the upper limit of CO_2 capture for this technology is bigger than all the other techniques combined and could reach up to 3800 $GtCO_2$ captured by 2100. On the downside, there are far too many uncertainties with this approach. There aren't enough studies that can provide a concrete assessment of how the ocean's ecosystems will respond, and what are the possible long-term complications. For this reason, the level of readiness for this technology is only two. Even though technically it could be applied today, it cannot be done in a responsible way, as there is no way of predicting for sure the consequences.

The technologies to extract, process, and transport minerals are all mature, but research on ocean alkalinization remains mostly at the level of theoretical work and laboratory experiments, with a few coastal experiments in development. Much research remains to be done to assess the efficacy and side effects of various approaches (UNIVERSITY, 2020).

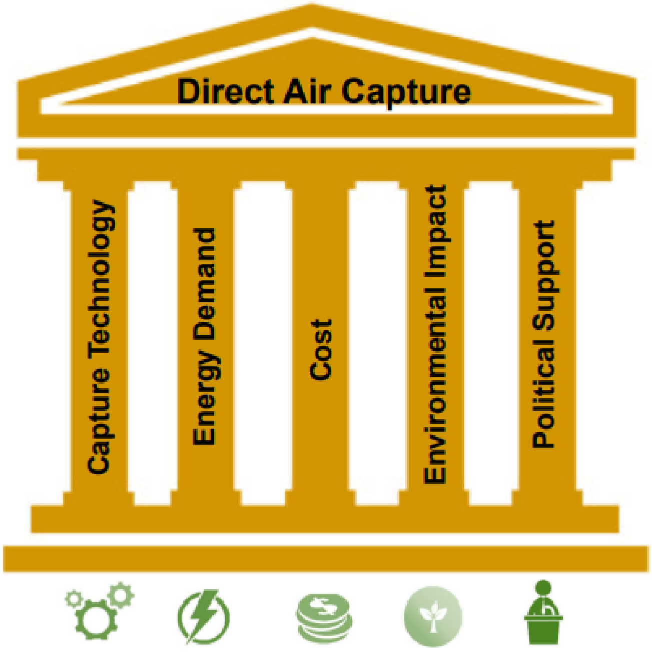
4.2.1.9 Direct air capture (DAC)

The last range of products that must be considered is direct air capture itself. As was explored during the literature review, there are 19 DAC plants in operation worldwide today, using different technologies to remove CO_2 from the atmosphere. They differ from one another, especially in terms of the sorbent used (liquid or solid for example), and the method through which they are capturing CO_2, which can be done by either creating a module that will capture CO_2 by itself or retrofitting existing structures to accommodate this function. Regardless of the approach chosen, these technologies share some similarities such as the high cost, the high energy requirement, low requirement for land use, and modularity.

The readiness level of DAC is the lowest amongst the technologies considered in Figure 14. This is mainly because the technology is still relatively new. The elevated cost of the technology prevents it from being able to thrive on its own, thus more optimizations are necessary for properly deploying DAC at an acceptable level.

Figure 19 illustrates the five fundamental pillars of Direct Air Capture (DAC): capture technology, electrical and thermal energy demand, cost, environmental impact, and political support. Achieving a well-balanced integration of these technology pillars is crucial for the effective and successful deployment of DAC.

Figure 19 – The five pillars of direct air capture.



Source: (OZKAN et al., 2022).

Furthermore, direct air capture (DAC) technology can assist in addressing emissions that are difficult to avoid and emissions originating from distributed sources. These include annual emissions from concrete manufacturing, transportation, the iron-steel industry, and wildfires.

Even though DAC is the focus of this study, and will be explored in detail during the case study, it was necessary to understand the other approaches that can compete with DAC in the voluntary carbon market. DAC falls short on the cost and energy use, but if those barriers can be surpassed, DAC has the potential of thriving in this market, especially due to its low land requirement and flexibility, as it can easily be applied almost anywhere.

4.2.2 Competitors analysis

When evaluating competitors, CCS technologies will not be included since they do not directly compete with DAC. CCS primarily targets carbon-intensive companies that would otherwise produce significant amounts of CO_2, whereas DAC can be employed by any company seeking to reduce its carbon footprint and achieve carbon neutrality. For companies with high carbon intensity, replacing CCS with DAC is neither a viable nor cost-effective option. It should be noted, however, that companies utilizing CCS technologies may also adopt DAC, but solely as a supplementary technology rather than a replacement for CCS.

As indirect competitors, other CDR technologies can be considered. While a company will never have to choose between DAC and CCS, it might be the case where it will be able to choose between different offsetting projects, which could be DAC or any other CDR technology.

Company X faces direct competition from other companies engaged in DAC projects. Currently, the most notable competitors in the DAC space include Climeworks, Carbon Engineering, and Global Thermostat, with numerous smaller companies also entering the field. Each of these competitors employs unique operational strategies and revenue generation methods, all of which will be thoroughly examined in this section.

The overall process of direct air capture includes three main stages. In the first stage, the air passes through a contactor, where the CO_2 will be entrapped using a sorbent, which can be either solid or liquid, that will chemically react with the CO_2 and remove it from the air. In the second step, the CO_2 must be separated from the sorbent using heat, a process usually known as desorption. In the third and final step, the CO_2 is transported to its final destination, which can be either permanent storage or utilization in other processes and products.

Multiple aspects of the process can vary among different companies. Variations may arise in how air is transported through the contactor, either naturally or through the use of mechanisms such as fans. Additionally, companies have the flexibility to select from a range of sorbents, encompassing choices within both liquid and solid categories. The contactor itself can adopt diverse shapes and sizes. The ultimate destination of the captured CO_2 can also differ based on the company's partnerships and geographical location. Furthermore, the overall cost can fluctuate depending on factors such as the construction methodology, resource allocation, and other related considerations. In Appendix A, the author analyzed current competitors in the DAC industry, evaluating the technologies used, mitigation potential, cost, business model, and served market of each of those companies.

Climeworks profits come from people and companies paying them to remove CO_2 on their names, choosing between a variety of plans available. The overall price paid is 1250 €/tCO_2 removed. The captured CO_2 is then stored deep underground by their partner Carbfix, in Iceland.

Figure 20 – Climeworks' plant Orca, the world's largest direct air capture and storage plant that permanently removes CO_2 from the air.

Source: Climeworks, 2023.

Company X's technology is very similar to the one from Climeworks. In Climeworks' approach, a fan pulls in the air towards a collector, where CO_2 chemically binds with a solid sorbent, and the CO_2 free air leaves the system. Once the sorbent is fully saturated with CO_2, the collector closes, stopping more air from coming in, and the system is heated up to 100°C, so that the CO_2 can release from the sorbent. Using Carbfix's method, water is infused in the system, mixing with the CO_2, and is then pumped deep underground, where it will mineralize and be stored for thousands of years. The process results in the production of gaseous CO_2 at 1 bar with a purity level of >99.8%. Depending on the ambient conditions, in particular relative humidity, the current Climeworks process can also extract H_2O from the air as a byproduct. (BEUTTLER; CHARLES; WURZBACHER, 2019).

Climeworks' CO_2 collector module has the capability to capture approximately 500 tons of CO_2 annually. This achievement is comparable to the CO_2 absorption capacity of approximately 20,000 trees, highlighting the remarkable efficiency of Climeworks' current approach, particularly in terms of land utilization. In terms of energy consumption, Climeworks addresses a significant concern associated with DAC by exclusively utilizing renewable energy sources, energy-from-waste, or other waste heat to power their plants. Another crucial aspect is the estimation of the company's carbon footprint. Currently, the grey emissions from a Climeworks plant amount to less than 10% of the captured carbon dioxide when renewable electricity is employed, and the company has set a target of further reducing this percentage to 4%.

To guarantee the veracity of the generated carbon credits, the data regarding the removed carbon dioxide must be quantified, verified and properly reported. For this purpose, Climeworks uses MRV, monitoring, reporting, and verification. This is a "full-chain methodology", which covers two main aspects: DAC, and storage through permanent underground mineralization. The verification process is conducted in partnership with the company DNV, an independent expert in assurance and risk management. Receiving the certification means that the company is removing the CO_2 following an approved methodology and are working within the stated standards. The methodology developed by Climeworks and Carbfix, verified and approved by DNV, is publicly available on Climeworks' website.

Climeworks plans to be in the Megaton capacity by 2030, and Gigaton capacity by 2050.

The Canadian company Carbon Engineering (CE) is one of the world leaders when it comes to DAC technology. The air contactor was designed inspired by cooling towers. The process starts when a big fan pulls air that passes through a surface containing a potassium hydroxide solution. This non-toxic solution chemically binds with the CO_2, removing it from the air and trapping them in the liquid solution as a carbonate salt.

Following capture, the trapped CO_2 undergoes a sequence of chemical reactions to concentrate and purify it, enabling it to transform into a gas form suitable for utilization or storage. The entire process is made in a circular way, so that in the end the chemicals are regenerated and can begin new cycle, and the captured CO_2 is ready to be transported to its final destination.

Some differences between CE and the other pioneers are 1) Carbon Engineering uses natural gas to power its capture units, instead of focusing of renewable energy, and 2) they use liquid alkali metal oxide sorbents, which require heat at around $800\circ C$ to be regenerated.

Global Thermostat (GT) uses waste heat from industry, wind power, and natural gas for heat and electricity generation. Different from the other two leaders, the plants are not for commercial use and the company assumes a research-oriented direction rather than business oriented.

There have been controversies surrounding GT, especially related to the final destination of the captured CO_2. The company seems to be directing most of its resources towards sucking CO_2 out of the air and refining this process, but the concerns about where the CO_2 goes afterward seem to be a future problem for the company.

Their focus is developing a carbon capture device that other companies will want to buy.

Global Thermostat's strategy is comparable to the one used by Microsoft when it first started — developing an operating system that could be sold to computer companies to use in their own products. This strategy differs much from the one used by CE and Climeworks, where the company makes itself present from beginning to end, all the way from capture to storage or utilization.

Recently, GT has partnered up with Tokyo Gas, Japan's largest provider of city gas, which committed to investing in GT's technology as it is pursuing net-zero goals, and wants to implement the technology to use the captured CO_2 in its low-carbon synthetic fuels.

Global Thermostat was definitely one of the leading companies in developing direct air capture, but it has fallen behind when compared to the previous two, especially considering some scandals that happen in 2021 where the company was not delivering the results promised. Since it assumed new directions, it appears to be getting back on track.

The company Noya, from San Francisco, USA, showed the most technological proximity with Company X among all the competitors listed, due to the focus at the beginning of the company being on retrofitting cooling towers, the same as Company X. However, after the US stated The Inflation Reduction Act in 2022, where the incentive for companies capturing at least 1,000 metric tons of CO_2 per year went from $50 per metric ton to $180 per metric ton, Noya opted to take on a faster path, exchanging the cooling towers for a fan, so that the module could be easily applied next to CO_2 injection wells.

The overall carbon capture process is not fully publicly displayed, what is know is that they use activated carbon monolith to serve as scaffolding for their sorbent, which chemically binds with CO_2 and removes it from the air.

The company CarbonCapture from Los Angeles, USA, emerged in 2019 as a strong competitor and is aiming at 5 $GtCO_2$ by 2030, with the first 10.000 tCO_2 to be captured between 2023 and 2024. This company shows an innovative approach to this technology, focusing on having a modular product (container-sized modules), which allows them to have rapid deployment and a gradual scaling of possible sites, not being necessary to have one gigantic plant in the short term. Besides that, the company takes care of the entire process to the customer, creating a unique customer journey where they only have to worry about the end product they desire. Finally, and more interesting of all, CarbonCapture is investing in creating a hardware platform capable of accommodating multiple types of solid sorbents, including amines, MOFs, hybrid solutions, and other novel materials. This last fact makes CarbonCapture stand out because they have the possibility of not only testing different sorbents but are also ready to absorb new sorbents that might emerge, which adds a new level of flexibility to their process.

The company Heirloom, from San Francisco, USA is leveraging limestone to capture CO_2. Making up 4% of the Earth's surface and costing as little as \$10 a ton, limestone is more abundant, far less expensive, and easier to source than custom engineered materials. They are innovating by investing in a technology that not many are using. They focus on both permanent storage and concrete fabrication as a final destination for the captured CO_2, and partnered up with the company CarbonCure for manufacturing concrete with embedded CO_2. They have a bold goal of permanently removing 1 billion tons of CO_2 from the atmosphere by 2035.

Analyzing the major players today in the DAC industry, the features that seem to be important in the product are having a modular design, scalable, with low energy demand, and big capture capacity. On the business side, having good partnerships is a must, and offering the lowest possible price. The consensus seems to be achieving the below 100\$/tCO_2 mark, but most companies are aiming at achieving this goal by 2030 at the earliest.

Finding a reliable verification process for carbon offsets within the context of DAC companies presents a significant challenge. Unlike traditional carbon offset projects that often involve tangible activities such as reforestation or renewable energy installations, DAC operates in a more complex and technologically advanced domain. The uniqueness of DAC processes and the limited precedents make it difficult to establish standardized methodologies for accurately quantifying and verifying the CO_2 removal achieved. Ensuring the integrity and credibility of carbon offset claims becomes crucial, as it involves verifying the actual amount of CO_2 captured and the permanence of the storage methods used. Developing robust and transparent verification mechanisms specific to DAC technologies requires collaboration among scientific experts, industry stakeholders, and regulatory bodies to establish standards that can provide accuracy and effectiveness of the carbon offset claims. Climeworks seems to be ahead in this aspect, but the other companies must chase the same goal if they wish to become competitive in the game.

While the direct air capture (DAC) market has seen a substantial influx of players, there is still plenty of room for participation from various entities. Most DAC companies emerged after 2019, indicating that the technologies are still in the developmental phase and have yet to reach a mature go-to-market level. Even if all the announced DAC projects mentioned earlier come to completion, there would still be a significant amount of CO_2 left to be captured. The main challenge lies in securing sufficient funds and investments to support the scaling and deployment of DAC technologies. Additionally, defining a viable and sustainable business model is crucial for DAC companies to ensure long-term viability. As the industry continues to evolve, addressing these funding and business model challenges will be fundamental to enable the full potential of DAC and maximize its contribution to global carbon dioxide reduction efforts.

4.2.3 Customers analysis

As was shown during the competitor analysis, a direct air capture company can have a wide range of clients, depending on their business model and the solutions they offer. The most common tracks among DAC companies are selling carbon offsets, selling the captured CO_2 to utilization companies, selling the device itself to other companies, and partnering up with storage companies to provide a full capturing cycle.

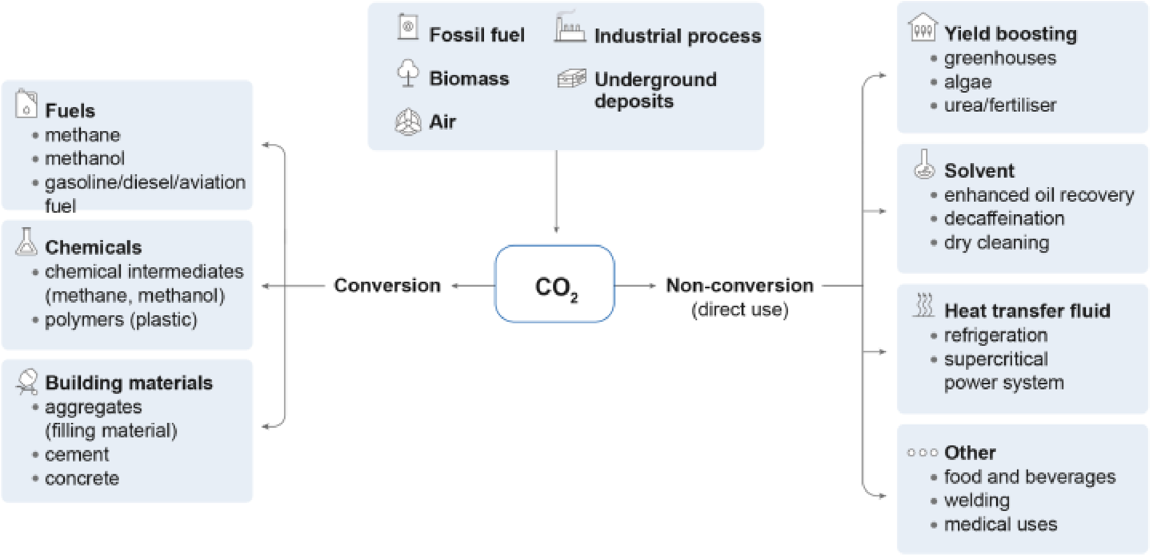
Selling carbon offsets often involves reaching out to verification companies and marketplaces. Carbon offset companies, which are specialized in carbon offsetting may seek partnerships with direct carbon capture companies to expand their range of solutions available to their clients. These companies typically offer emissions-offsetting services to individuals and organizations looking to neutralize their carbon emissions, and direct carbon capture can be an effective option for this.

Targeting companies such as energy and utility, companies operating power plants, renewable energy facilities, or industrial installations may seek direct carbon capture services to reduce their CO_2 emissions. These companies may be looking to comply with environmental regulations, improve their carbon footprint, or align their operations with sustainability goals. The same applies to companies within the industrial sector, across various segments, such as steel, cement, petrochemicals, chemicals, and more, which can benefit from direct carbon capture to reduce their emissions. Industries that are significant CO_2 emitters are increasingly showing interest in carbon capture and storage solutions to mitigate their environmental impact.

Another very relevant field worth mentioning is the transportation sector. Transportation companies, such as airlines, shipping operators, and logistics companies, often have elevated emissions and may seek direct carbon capture solutions as part of their efforts to reduce them. Direct air capture can be a viable option for offsetting the emissions generated by their operations. An industrial breakdown on CO_2 emissions was previously shown in 3.

On the utilization side, carbon dioxide can be used as an input for a variety of industries. One of its primary uses is in the carbonation of beverages, such as carbonated water, soft drinks, and beer. The food industry utilizes CO_2 for cryogenic freezing and chilling, as well as for extending the product longevity of packaged foods by displacing oxygen. It is embedded in fire extinguishers, especially when water-based suppression systems are not suitable, such as server rooms, electrical installations, and chemical storage areas. It plays a role in enhanced oil recovery, where it is injected into oil reservoirs to increase oil flow. It serves as a chemical feedstock for the production of compounds like urea and methanol. In agriculture, CO_2 is supplied to greenhouses to enhance plant growth and consequently improve the yields, through efficient photosynthesis. It is used in polymer production, where CO_2 serves as a raw material and helps to mitigate the environmental impact of plastics, in a process called carbon dioxide utilization or CO_2 conversion. It can serve as a chemical solvent when in the Supercritical CO_2 state, offering advantages such as low toxicity and easy removal after use. Finally, CO_2 supports algae cultivation for the production of biofuels and valuable by-products. These diverse applications highlight the versatility and potential for utilizing CO_2 as an input in various industries and processes. An overview of CO_2 uses can be seen on Figure 21.

Figure 21 – Possible pathways for using CO_2.



Source: (IEA, P., 2019).

Governments and regulatory agencies can also be a not-so-obvious possible range of clients. They may be interested in implementing carbon reduction policies, achieving climate goals, or implementing emissions offset programs. Regulatory agencies may also look into carbon capture solutions to enforce emissions limits and encourage regulatory compliance.

It is important to note that each client may have specific needs and different regulatory requirements. A direct carbon capture company needs to direct its solutions and business strategies to meet the demands of each client, providing customized and effective solutions for CO_2 emissions reduction.

4.2.4 Regulations

DAC companies are subject to various regulations and obligations depending on the jurisdiction in which they operate. These regulations are designed to ensure environmental sustainability, safety, and compliance with legal requirements. Some of the key regulations that DAC companies may need to comply with are related to the environment, carbon markets, intellectual property, and financial and business. For this study, only regulations applied in Germany will be considered, as this is the country where the company is established and also where is targeting its first customers. Within Germany, some key regulations include the Federal Emission Control Act (Bundes-Immissionsschutzgesetz, BImSchG); the Renewable Energy Act (Erneuerbare-Energien-Gesetz, EEG); the Waste Management and Recycling Regulations; the Energy Efficiency Regulations; the Carbon Pricing Mechanisms; and Climate Change Policies.

Environmental regulations must be considered regardless in pretty much every country, as every country has its own set of rules that must be followed. DAC companies are often required to obtain permits and comply with environmental regulations governing air emissions, waste management, and land use. These regulations aim to minimize the environmental impact of the DAC process and ensure that captured CO_2 is safely stored or utilized. The Federal Emission Control Act, in Germany, also fits in this category, as it sets out provisions and requirements for preventing or minimizing emissions from various industrial activities and installations. DAC facilities may need to adhere to these regulations to ensure their operations meet the necessary environmental standards.

The Renewable Energy Act (Erneuerbare-Energien-Gesetz, EEG) is a legislation that was introduced in Germany for the first time in 2000, with its main goal being to promote the development and expansion of renewable energy sources, increasing Germany's share of renewable. It is relevant in the context of DAC because most DAC companies are focusing on powering their systems primarily - if not exclusively - with renewable sources, thus the necessity to understand how their operations align with the objectives and incentives outlined in this act. Align with this act, it's also the energy efficiency regulations, which in Germany are design to reduce energy consumption and promote sustainable practices. Compliance with these regulations is important for companies, industries, and individuals to contribute to a more sustainable and energy-efficient future. As DAC is very energy intensive, it will most likely need to assess and optimize their energy usage to comply with these regulations.

Waste management and recycling regulations are also very strong in Germany. These regulations focus on waste prevention, recycling targets, waste separation, and proper disposal. DAC companies are not an exception to those rules, and must adhere to waste management and recycling regulations to ensure proper handling, storage, and disposal of waste materials generated during operations.

A very important regulation that must be carefully handled for a DAC company is the intellectual property regulations. Company X is currently investing in developing novel technologies, and this includes learning how to protect that knowledge. This includes securing patents, trademarks, and copyrights to protect their intellectual property rights.

Regarding the carbon markets, since DAC companies will most likely participate in the voluntary carbon markets by selling carbon credits, there are regulation that must be followed to ensure transparency, accuracy, and credibility in the measurement, reporting, and verification of carbon removal and emissions reduction activities. In Germany, carbon market regulations are directly linked to the European Union Emissions Trading System (EU ETS). As a member state of the European Union, Germany is subjected to the regulations enforced by the EU for carbon emissions trading.

Company X is also suggested to general regulations regarding health, safety and finances, as all other industries within Germany. These regulations cover aspects such as equipment safety, hazardous material handling, and emergency response protocols, on the health and safety side, and general business regulations such as tax laws, employment regulations, and financial reporting requirements on the finances side.

Overall, it is essential for DAC companies to look into the specific regulations in motion at their location and industry, as regulations can change drastically between countries and regions. For every aspect of the business, it is recommended to consult with experts that can advise the company as to which regulations are in motion and how can the company ensure that is covering all legal basis required for its operations.

4.3 BUILDING A BUSINESS MODEL FOR COMPANY X

A business model is a framework or plan that describes how a company creates, delivers, and captures value. It defines the core aspects of a business, including its target customers, value proposition, revenue streams, cost structure, key activities, resources, and partnerships. A business model outlines how a company will offer its products or services and how it will sustain its operations in a competitive market. Having a well-structured and effective business model can be the difference between succeeding or failing in the market, being crucial for guiding strategic decisions, attracting investors, and driving the long-term success of a business.

After analyzing multiple competitors and studying the market of direct air capture, a business model can be built for company X. The factors that will be considered in the process are value proposition; customer Segments; revenue streams; cost structure; competitive advantage; customer acquisition and retention; partnerships; scalability and growth potential; key resources and activities; and risk assessment and mitigation. Each of these topics will be explored individually, and in the end combined in a Canva Business Model, providing a visual overview of the whole business.

4.3.1 Value Proposition

Company X's value proposition is to develop a low-cost and innovative direct air capture module, leveraging cooling towers and waste heat.

Through a thorough analysis of the primary competitors, company X can identify the key areas where it can differentiate itself and offer a distinctive product to the market. This examination allows company X to pinpoint its unique strengths and attributes that set it apart from the competition, enabling it to stand out in the marketplace.

Two analysis must be conducted here. First, related to other CDR technologies, and second related to other DAC companies.

During the products analysis, the key aspects of the most relevant CDR technologies were explored. DAC falls short in terms of cost and electricity use when compared to most of the other solutions. On the other hand, it is the one using the least amount of land and has the advantage of geographical flexibility. The deployment of Direct Air Capture (DAC) is feasible in various locations since the concentration of CO_2 is relatively consistent across different areas. Besides that, the majority of the DAC companies are focusing on having a modular, scalable device. This means that it is not constricted to one specific size, and can be easily adapted depending on the customer request. Lastly, most DAC companies have implemented mechanisms that enable convenient tracking of the amount of CO_2 captured. This feature simplifies the reporting and certification process, ensuring transparency and accountability of the captured CO_2.

Compared to other DAC companies, company X uniqueness includes the next-gen reactor design currently under development, and the cooling towers retrofitting approach, which will lead to a complete patent family, ensuring that the business is legally protected on the long run. The focus on IP development, even though making company X differentiate from others, also implies in a need for strategic investors, that can provide the legal support and guidance.

The technology itself differs on various points from other DAC companies. For one, utilizing waste heat and airflow from cooling towers can lower the cost of the capturing process, as the company is re-purposing underutilized streams. Essentially, cooling towers worldwide are operating to remove heat from a process or a building, and use large amounts of ambient air to do so. Based on an internal Techno-Economic Analysis (TEA), along with experimental results developed by the company, company X's team is able to precisely quantify the potential of such streams.

Heat represents the majority of the running costs of a DAC system, as shown previously in the section "COMPANY X'S PRODUCT", and by using high temperature heat-pumps the waste heat of cooling towers can be leveraged and bring down the costs significantly with a non-invasive retrofit. Retrofitting the cooling tower to re-purpose its fan is technically more tricky, and represents less representative cost reductions compared to the waste heat, which is why this will only be implemented at later stages.

Another significant advantage is being highly accessible and geographically flexible. It was mentioned before that this is already an advantage when compared to other CDR technologies, but it is also a differential when compared to some DAC companies. Theoretically it should be possible to deploy DAC anywhere, but many competitors, such as Climeworks, are focusing on building their plants in remote areas, due to storage availability. However, this often leads to significant challenges in terms of construction and maintenance, resulting in consistently rising prices, particularly in recent years due to supply chain issues and rising transportation costs. To exemplify, Climeworks' Orca plant in Iceland encountered substantial expenses in its capital expenditure (CAPEX) related to extensive groundwork, including site preparation, obtaining permits, establishing foundations, and facilitating the necessary infrastructure such as water and electricity supply. These expenses are not necessary with company X's approach, considering that sites are already approved and ready for industrial applications.

Another advantage to highlight is the access to utilization customers and carbon hubs. Building decentralized DAC systems often presents the challenge of establishing proper CO_2 logistics, which can lead to increased costs and a larger carbon footprint. That's why many competitors opt for sites with available CO_2 storage, to mitigate these logistical challenges. By targeting industrial cooling towers, company X can easily find CO_2 consumers in the surrounding of their installation, a lot of industrial processes requiring CO_2 as feedstock for their process.

On the technical side, company X is developing a structured bed reactor of low complexity and high durability, while also investing on improving pure sorbent energy requirements. The most wide spread approach in DAC today uses packed beds of resin pellets, which present several drawbacks such as damaging equipment, pellet reorganization impeding CO_2 passage, and a complex and sub optimal assembly process for reactor construction. However, this approach still has the advantage of being the only technology with a scalable supply chain.

Finally, it is worth mentioning that according to internal analysis conducted by company X, it was concluded that the DAC industry as a whole has to grow by a factor of around 600,000 in the coming two decades, a market with room for many players to succeed together. Even though it is important to stand out and become competitive in the market, this market is big enough to accommodate multiple players.

4.3.2 Revenue Streams

Company X set two phases for generating revenue, with a total of three paths for profiting. Two of the paths will be applied during phase one, while the third path will only begin in phase two.

The first phase, called Go-to-market (2023-2025), consists of selling CO_2 to utilization companies and selling future carbon removal credits. During the go-to market phase, company X will sell their carbon capture devices to customers that are using CO_2 as a feedstock for their products or services. In parallel to the utilization companies strategy, future carbon removal credits will be offered to companies with a net-zero target, those buyers are typically companies like Stripe, Shopify, Microsoft or Airbus.

When engaging in direct selling with a customer, it is necessary to engage in negotiations and formalize a carbon removal purchase agreement. To maximize the support received, the agreement should include three main commercial elements: (1) it should be for multiple years, (2) it should include an upfront payment, and (3) the credit pricing should cover the supplier's entire cost to complete the carbon removal. This structure helps suppliers meet the needs of investors, who will typically only finance a project with a strong revenue stream for a large portion of the facility's lifetime (FUND, 2022).

During the utilization phase, the units will be sold directly to customers. They will operate them and be able to use the CO_2 on-site themselves. In 2025, the new capture unit will have a capture capability of 62.5 tons of CO_2 per year. Taking into account the current acquisition price of CO_2 at 1000€ per ton, the customer would start seeing profitability after the initial 3 to 8 years of the unit's 20-year lifespan, depending on the type of industry.

For utilization companies, in most of those cases company X does not offer carbon removal credits in parallel to the captured CO_2 that will be used as a feedstock. The strongest interest today derives from vertical farms, with partnerships already being formally formed. With com company in particular, situated in Switzerland, there is a plan to co-develop a pilot at their facility to provide the CO2 they utilize on-site. There are other partnerships being formed, to mention a few, another vertical farm company in Berlin, and a chemical company also in Berlin.

The second phase, Licensing (2027+), consists of licensing the use of the technology to scaling partners, especially cooling towers manufacturers and other industrial players. This means that the capturing unit can be embedded in the manufacturer's product, allowing the company to scale very quickly without the need to setup their own international production capabilities or maintenance fleets. They will be overseeing the deployment of carbon capture units using the company's technology themselves, and paying a licensing fee to do so.

For the licensing path, company X will take a 25% commission on the carbon removal credits from all installations leveraging their technology. To quantify this stage, by the year 2030, the company anticipates that an average installation on an industrial cooling tower will have the capacity to capture approximately 8,000 tons of CO_2 annually. This will be achieved at a cost range of 106-161€ per ton, encompassing both operational and capital expenses over the anticipated 20-year lifespan.

Although the average price of a carbon removal credit was 1113€ per ton in

2022, it is expected to decline in the future. This decrease is attributed to the limited number of buyers who can afford such prices at the required scales, as well as the maturation of the Carbon Dioxide Removal industry, which will result in increased supply. Nonetheless, there is an anticipated increase in demand for removal credits that is expected to outpace supply. This surge in demand is driven by net-zero targets and the growing number of commitments with deadlines set for 2030, 2035, or 2040. As a result, prices are likely to remain above several hundred euros per ton beyond 2030.

To finalize this topic, it also important to address financing, as the company currently does have profit from the technology. During the initial go-to-market, the pilot plants will be financed via public grants, loans, and pre-selling carbon credits. At full-scale, a licensing model will be implemented to scale with large industrial players. A licensing model is the most suitable path for a high-growth start-up with defensible intellectual property (IP) that wishes to have a meaningful impact on the climate crisis.

4.3.3 Customer segments

There will be three types of customer segments to be considered, one for each of the presented paths for revenue, those being utilization, carbon credits, and licensing.

In an internal market analysis conducted by company X, several groups of companies were identified as potential customers in terms of utilization. The industries that were identified are illustrated in Figure 22.

Figure 22 – List of possible utilization companies.

Carbonated drinks	Dry ice production	Lab-grown diamonds	Pulp paper and packaging
Carbonated snow	E-Fuels	Manufacturing - Automobiles	Steel hardening
Cement/concrete production	Fertilizer	Manufacturing - Aviation	Steel production
CO2 hubs-connected companies	Food	Manufacturing - Shipping	Water treatment
CO2-cooling	Glass	Oil drill sites	Welding
Composites (carbon fiber & graphite)	Greenhouse/Vertical farm	Petrochemical companies & textile fiber	

Source: Company X internal analysis.

As part of the analysis, a total of 305 companies were contacted to determine the most significant industries for the go-to-market strategy. The findings showed that carbonated beverage manufacturers and greenhouse, especially vertical farms, exhibited the highest interest in adopting the company's technology. Another sector that also appeared promising was Lab-grown diamonds, even tho behind the previous two.

Greenhouses require a CO_2 purity level of 0.12% as it is the optimal value for plant growth. Additionally, the greenhouse industry currently pays elevated prices for purchasing CO_2 due to the high transportation costs associated with low volumes. In contrast, company X offers the possibility of operating a capture unit on-site, eliminating the need for additional transportation expenses. Therefore, these greenhouse companies are excellent candidates as go-to-market customers. Moreover, aside from offering reduced prices, owning its own capture unit ensures supply chain stability by enabling customers to become self-sufficient in meeting their CO_2 requirements.

The carbonated drinks industry on the other hand, typically utilizes 6g of C_2 per Liter of drink. For their production, a level of 99.9% purity is required, and food-grade certified CO_2. Achieving a 99.9% purity level and obtaining the required food-grade certification pose challenges when it comes to company X's modules that initially captures CO_2 at approximately 90% CO_2, especially when in comparison to the low purity level required by the vertical farming industry. However, through a slight increase in energy usage, the desired 99.9% purity level can be achieved. Despite the challenges, targeting the vertical farming market presents immense opportunities due to its larger scale. Again, being able to become self-sufficient in providing CO_2 to their processes is a big advantage.

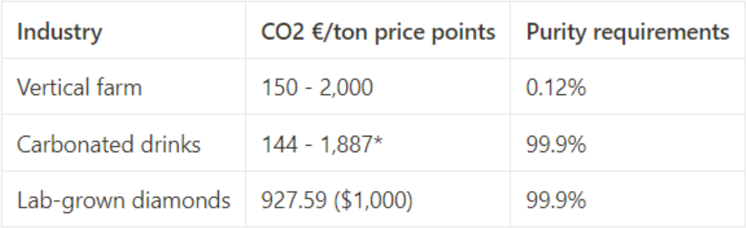
Furthermore, CO_2 is also used as a feedstock in the production of lab-grown diamonds. In this process, companies initially use CO_2 to produce methane, which is then transformed into lab-grown diamonds. Since these companies operate at very high temperatures, there is also the opportunity or leveraging their waste heat to reduce the energy consumption of the capturing unit. During company X's market analysis, it was revealed that the lab-grown diamond industry utilized 140 million tons of CO_2 in 2021. Moreover, it is projected that the market for lab-grown diamonds in 2027 will be 2.5 times larger than the industry size in 2020, showing the potential of this segment to become a relevant customer.

When it comes to the price paid per ton of CO_2, vertical farms and carbonated drinks producers pay the highest price for their CO_2, as can be seen in Figure 23.

Big suppliers of commercial CO_2 today are Linde, AirLiquid and Messer. The price of CO_2 can be very volatile because it is directly influenced by the energy and gas price. Company X's product offers a solution where a reliable on-site source of CO_2 is provided. Additionally, companies that utilize the greenest available CO_2 can distinguish themselves from their competitors by showing the green stamp, enhancing their marketing and sustainability claims.

In terms of carbon credits, finding the right customers involves both companies themselves and marketplaces. Currently there are only voluntary buyers, like Airbus,

Figure 23 – Price paid for CO2.



Industry	CO2 €/ton price points	Purity requirements
Vertical farm	150 - 2,000	0.12%
Carbonated drinks	144 - 1,887*	99.9%
Lab-grown diamonds	927.59 ($1,000)	99.9%

Source: Company X internal analysis.

Stripe, Shopify and Microsoft. An overview of the major buyers of carbon removal credits can be seen in Figure 1, which includes not only credits from DAC but from other CDR technologies, such as biochar, enhanced weathering, BECCS, among others.

Table 1 – Top carbon credits purchasers according to cdr.fyi.

Name	Tons purchased
Microsoft	2,819,637
Airbus	400,000
NextGen	193,125
Frontier	121,409
JPMorgan Chase	63,752
Shopify	46,785
Swiss Re	44,035
UBS Financial	39,500
Stripe	14,184
Klarna	13,570

Source: (CDR, 2023).

The website of cdr.fyi provides a full list of carbon credits buyers, going up to 133 companies. The website brings data from 91 carbon credits suppliers, and 45 marketplaces. Companies like Airbus are buying those credits, because it's very hard for them to avoid emissions, so it is critical for the future viability of their business to invest heavily and early in carbon removal.

In the case of major software players such as Microsoft, Stripe, and Shopify, the dynamics is different. They engage in carbon removal efforts on a voluntary basis, as they have the financial capacity to do so, given that their revenue is less tightly linked to CO_2 emissions. Being pioneers in carbon removal gives them the opportunity to stand out in the competition for talent and also appeals to an increasingly climate-conscious consumer base that is continuously expanding.

All players have in common that they want to engage early with Direct Air Capture companies, so when a certain regulation will force carbon removal, they have already secured their supply, while prices might hit new highs.

On the carbon credits track, in the past months there has been strong interest from carbon credit marketplaces on company X's technology. These marketplaces are offering carbon removal credits alongside avoidance credits, thus enabling company X's early installations to command higher price points. Company X already has strong partnerships in this realm, in particular with one marketplace where the first credits are being offered to a potential buyer at a price of €1100 per ton of CO_2. This offering encompasses the delivery of 50 tons of CO_2 scheduled for 2025.

The last track, licensing, involves scaling partners, which are companies that are licensing the company's technology during the scaling phase from 2027. The company already has a strong partnership with a big energy company, that has been contributing significantly with the research side of company X, and are interested in becoming investors in the future. Besides the energy company mentioned, there is also a strong partnership with a German chemical distribution company, that has access to a large amount of industrial players who could potentially run the units at their industrial customers facilities. Company X will soon be incorporated in their sales brochure, facilitating the contact with their clients.

Although the licensing track is not as advanced as the preceding two tracks, with its deployment slated for 2027, the team at company X is already proactively engaging with potential customers and building relationships. Moving forward, company X intends to expand its outreach to additional companies, recognizing that licensing will play a pivotal role in its future business model.

4.3.4 Cost Structure

In Company X, the costs are currently classified into three primary categories: product development, product research, operational costs, and operational costs. These categories represent the key areas where the allocated funds from the initial fundraising round were distributed. The following paragraphs will provide a detailed breakdown of how the financial resources were allocated within each of these areas.

For the product development category, these costs encompass different stages of the carbon capture product's evolution. Initially, resources were allocated to set up the research setup for the first minimum viable product (MVP) of direct air capture. This setup enabled the capture of small amounts of CO_2 at a laboratory scale. Subsequently, significant investments were made to develop the first autonomous engineered prototype, which allowed for the capture of CO_2 at a kilogram-scale. Moving forward, Company X aims to transition to on-site research projects, which involve installing the prototype at industrial sites for validation purposes with utilization customers and scaling partners. These projects require substantial resources and involve negotiations with relevant stakeholders.

It is important to note that the costs associated with these activities are significant, but the exact value cannot be disclosed due to confidentiality reasons. The expenses can be attributed to the acquisition of a wide range of components, including software subscriptions for computer-aided design (CAD), pumps, tanks, heat exchangers, fasteners (screws, nuts, washers), tubes, hoses, connectors, tools, machines, and services such as welding and external manufacturing. Moreover, high-quality materials, such as stainless steel, are utilized, further contributing to the overall cost. Additionally, the sorbent, the chemical responsible for capturing CO_2, also represents an expensive yet fundamental resource.

For the product research realm, the costs so far are related to the development of an In-depth Techno-Economic Analysis (TEA), assembling a characterization setup, and developing a novel reactor. For the Techno-Economic Analysis, the analysis was optimized based on data and learnings from the real-life tests performed in the MVP. The study was conducted using the simulation software Aspen, and allowed for a better understanding of the costs associated with the carbon capture device itself. The analysis showed that biggest cost drivers of the product today are electricity and heat requirements, as usual for DAC technologies, and the sorbent and reactor design, as shown in Table 2. The actual values of cost and energy requirement cannot be disclosed for confidentiality reasons, however, to provide the reader with an overview on how the costs are distributed, including OPEX and CAPEX costs, in Table 2 the costs are given in terms of percentiles.

The price for purchasing the CO_2 is expected to reduce to a total of 532 €/t by 2025, considering OPEX, CAPEX and transportation. The reason for the current high energy requirement is that the process is not efficient, the first iteration was focusing only on having a operational device, with optimizations being implemented in the next versions.

Table 2 – Cost calculations for the first carbon capture prototype.

Cost	%
Net OPEX + CAPEX + transportation	100,0
Sorbent material and reactor design	51,4
Heat/Chilling	40,4
Fans	3,0
Transportation	0,8
Others	4,4

Source: Company X internal analysis.

The electricity price considered was 90,3 €/MWh. The cost of transportation can also be minimized if the infrastructure is built in an industry that consumes CO_2 as an input for internal processes or as a part of the product, as it happens for carbonated drinks, fire extinguishers, desalinization companies, among others.

Still on the product research track, the characterization setup was a sorbent testing setup designed to enable the company to analyze and compare various sorbents under different conditions, and then optimize the DAC process and sorbent. For the characterizations setup, a lot of resources such as tubes, leak-tight connections, chemicals, and general laboratory supplies were necessary, which again are not cheap, but considerably less expensive than the prototype expenses.

For the novel reactor, the company worked in collaboration with established industry players and research institutes to bring fundamentally novel technologies to the world of DAC, leading to a potential capture cost of 532€/t in late 2025 and 161€/t by 2030. A in-dept analysis on the price progression can be seen in Table 3, along with capture capacity and energy requirement. One of these collaborations resulted in the design and simulation of a novel reactor using additive manufacturing technologies, and the latest version was translated into reality through a first small-scale prototype print. This will enable first physical validation of the reactor design, and inform the next design iterations. The research and development efforts surrounding the new reactor involved a considerable financial investment. Further funding is expected to be allocated for the validation phase following the upcoming fundraising activities. The allocated costs primarily encompass hiring specialized experts, equipping the laboratory for DAC-related purposes, and accelerating the development of this capture unit. The aim is to elevate the reactor to a full-scale product status within the next two years.

Table 3 – Predicted capture cost of CO_2, capture capacity, and energy requirement for the current and next versions of Company X's product.

Product version	Capture capacity (t/year)	Cost (€/t)
First prototype	5	1,715
Second prototype	62.5	798
First plant	500	532
At-scale plants	3,000	256
Megaton Scale	8,000	161

Source: Company X internal analysis.

From the first to the second prototype, the optimizations can be attributed to the development of a novel reactor, structural redesign, higher efficiency, and novel manufacturing, it also where the patents come into place. From the second prototype to the first plant, the previous prototype is up scaled, with one industrial installation including eight modules combined, and at this step the waste heat is integrated in the process. Moving from the first plant to at-scale plants involves having multiple operating plants, the integration a new sorbent, and the airflow retrofitting. Finally, the megaton scale is achieved by economies of scale.

Operational costs are related to general expenses like administrative and overhead costs, software subscriptions and licenses, travel and transportation, maintenance and repairs, insurance, office supplies, etc. Also included in the operational costs are the infrastructure and team expenses. In terms of infrastructure, the company is currently renting a temporary laboratory, where most of the characterization experiments are conducted, and also has a permanent location where the office, workshop, and future laboratory are situated. Located nearby a data center, the current location has plenty of waste heat available. Another advantage of the office position is the closeness with a brewery, a large CO_2 consumer and a potential utilization pilot partner. Additionally, located in an old gas plant campus, enormous gas tanks are still present on site, unused, and could possibly be filled with captured CO_2 down the line. In terms of the team expenses, the company already has the core team hired, including 7 permanent employees and 4 interns. The fields covered by these experts are: Molecular Chemist, Chemical Engineer, Process Engineer, and Mechanical Engineer, completed by the two founders and their innovative company building experience, along with a Business Developer to build partnerships and ensure commercial traction.

To summarize, the cost structure for Company X can be divided in three main categories, product development, product research, and infrastructure and team expenses. The biggest cost drivers are the ones associated with acquiring resources for the development of the prototype, and paying the highly specialized team of employees.

4.3.5 Key Partnerships

As shown in previous topics, company X's success relies heavily on having the right partners. Here a distinction between partners and customers is required. To simplify, customers would be the ones purchasing a company's products or services. On the other hand, partners are entities that collaborate with the company in strategic alliances to achieve shared goals or objectives. In the previous section, it was shown how many of the customers are in some way also partners with company X, especially on the licensing track. But besides the relationships mentioned related to costumers, there a few relationships being build that should be explored outside of the costumer sphere.

The first one worth mentioning are pilot companies, which are companies responsible for running a paid pilot, meaning to cover the company's costs within 2023 to validate the proposed approach outside of the workshop. Company X is in the final negotiations to co-develop pilots with ate least two German companies, with a few others on their corner. In this agreements, the company will run a module similar to the prototype developed in 2023 on their site, while covering CAPEX plus additional expenses. These companies might become costumers in the future, but for now are exclusively partners.

Another significant partnership to be considered is with sequestration companies. These companies specialize in storing CO_2 deep underground in decommissioned gas fields located between 2 and 3 kilometers below the Earth's surface. Alternatively, some sequestration companies convert CO_2 into mineralized concrete. Company X already has a strong partnership with a company that is developing new carbon-negative concrete. This type of concrete enables the creation of carbon-negative buildings, which implies that the more these buildings are constructed, the greater the positive impact on the climate.

Scaling partners or multipliers are industrial players such as cooling tower operators, where the approach developed by company X can be validated faster. These partners play a vital role in the scaling process by providing real-world testing opportunities and leveraging their existing infrastructure and expertise. By partnering with established industry players, Company X can gain valuable insights, validate their technology more rapidly, and establish trust with potential customers in the market.

For conducting research and development, advisors, niche experts, and academic institutions have become important partners. These partnerships enabled the company to accelerate their development, by sharing learnings and contacts from partners own industries and expertise. One of these partnerships is currently providing assistance with the new reactor design and simulation, and manufacturing.

Moreover, a partnership with several regulatory bodies ensures that company has a comprehensive view of the regulatory landscape regarding direct air capture. This includes already solid partnerships with German and Global entities.

4.3.6 Customer Relationships and Channels

In Company X, the two founders actively engage in various activities to build and cultivate customer relationships. They participate in industry events to connect with potential partners and customers, proactively schedule introduction calls to establish initial connections, and bring along an excellent storytelling and a compelling pitch deck to effectively communicate their value proposition. Moreover, they are constantly investing in developing a global network, actively looking for opportunities to expand their connections and establish impactful relationships. These efforts help build strong relationships with customers and boost the company's growth opportunities.

The main channel through which the company connects with partners and customers for the first time is by sending emails or calling to set up an introductory meeting and present their product, spreading the company's name. Once a relationship is formalized, they keep in touch via email, where updates are sent monthly and a direct line of communication is open. Additionally, the company maintains an active presence on LinkedIn, recognizing its significance as a leading social media platform for professional networking.

4.3.7 Key Activities and Resources

The key activities that must be performed by Company X to ensure that the value proposition will be delivered to customers can be divided in two realms, the business and the product side. On the product side, these activities are research and development, manufacturing and testing, installation and maintenance, delivery and transportation of modules. On the business side, these activities include marketing, market analysis, establishing partnerships, customer acquisition, regulatory compliance, financial management, and ongoing support. A summary of what these activities imply can be seen in Table 4.

The Key Resources on the other hand, are related to the fundamental assets, capabilities, and elements that are necessary for its operation and value creation. Key Resources and key activities are often analyzed together as they are interdependent and mutually reinforcing. In case of Company X, the main resources were mapped and shown in Table 5.

It is important to give an extra attention to the first resource mentioned in Table 5, regarding human resources. People are the most important resource in pretty much every company, and that is not different for Company X. Being a small company, every member is extremely important, and hiring the right people to compose the team is a key element to ensure Company X's success.

Table 4 – Main activities of Company X.

Activity	Description
Research and Development	Continuous research and development of the direct air capture modules
Manufacturing and testing	Manufacturing the product and testing to evaluate their performance
Installation and maintenance	Installing the modules at customers sites and perform regular maintenance
Delivery and transportation of modules	Transport the capture modules from the company to the customers' site
Marketing	Promoting Company X, raising awareness about direct air capture, communicating with potential customers, policymakers, partners, and the public
Market analysis	Analyzing the multiple markets affecting the business, such as carbon capture, carbon offsets and carbon credits, cooling towers, waste heat, and direct air capture
Establishing partnerships	Identifying and establishing partnerships with suppliers, investors, customers, and other stakeholders to facilitate funding, market access, and collaborative opportunities
Customers acquisition	Identifying, contacting, and engaging with possible customers, considering the targeted customer segments
Regulatory compliance	Keeping track of environmental regulations, permits, and compliance requirements related to carbon capture, DAC, storage, and emission reduction
Financial management	Administrating financial resources, securing funding for the company's activities, creating and maintaining connections with investors and possible investors
Ongoing support	Providing continuous support to customers

Source: Author assessment.

Table 5 – Main resources of Company X.

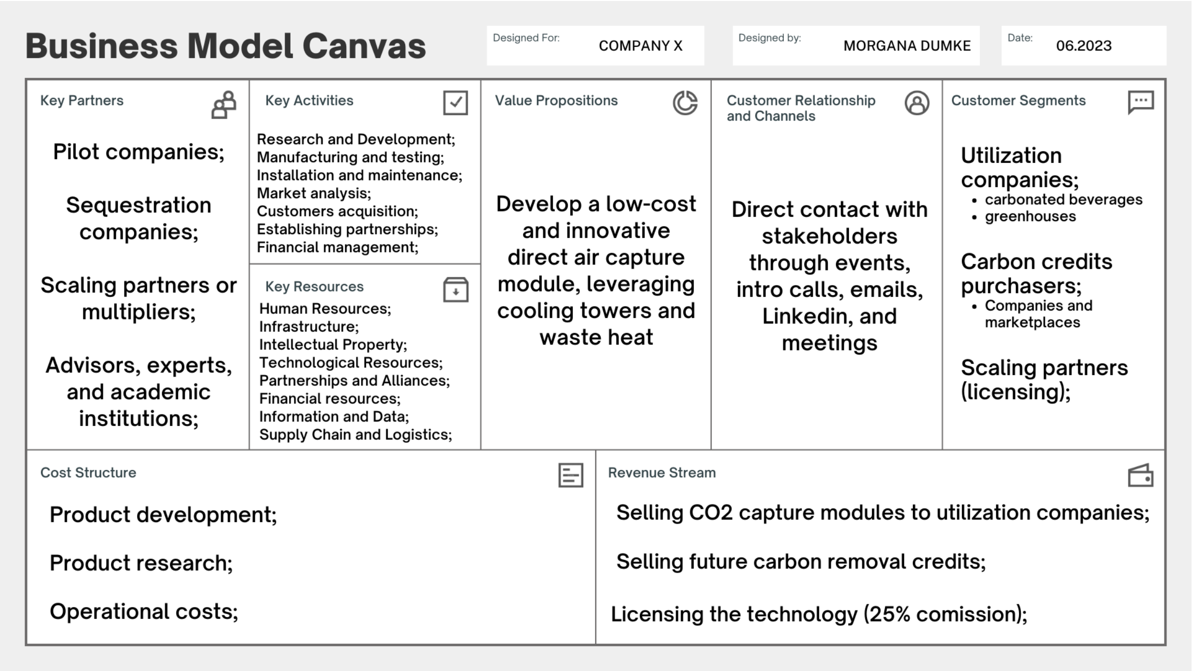
Activity	Description
Human Resources	Skilled and qualified personnel, including employees, consultants, executives, and specialized professionals
Infrastructure	Physical location where the team can perform its activities on product and business sides, including main office, workshop, and chemical laboratory
Intellectual Property	Patents, trademarks, copyrights, trade secrets, research findings, knowledge, expertise, and know-how
Technological Resources	Hardware, software, networks, databases, websites, and other IT systems
Intangible Assets	Brand reputation, customer loyalty, relationships with suppliers and partners, organizational culture, and knowledge management systems
Partnerships and Alliances	Collaborations, joint ventures, and partnerships with other organizations, companies, carbon marketplaces, utilization companies, and licensing companies
Financial resources	Capital, funding, and financial reserves
Information and Data	Information regarding the product's performance, customer satisfaction, market data, and general analytics
Supply Chain and Logistics	Materials, chemicals, and components required for the products and operations

Source: Author assessment.

4.4 PROPOSED BUSINESS MODEL FOR COMPANY X

After individually analyzing every component of the business model for Company X, the findings can be summarized using a visual tool. In this particular instance, the proposed model draws inspiration from (AG, 2019) and has been tailored to suit the specific context of Company X. The result can be seen in Figure 24.

Figure 24 – Canva business model for Company X.



Business Model Canvas

Designed For: COMPANY X

Designed by: MORGANA DUMKE

Date: 06.2023

Key Partners

Pilot companies;

Sequestration companies;

Scaling partners or multipliers;

Advisors, experts, and academic institutions;

Key Activities

Research and Development;
Manufacturing and testing;
Installation and maintenance;
Market analysis;
Customers acquisition;
Establishing partnerships;
Financial management;

Key Resources

Human Resources;
Infrastructure;
Intellectual Property;
Technological Resources;
Partnerships and Alliances;
Financial resources;
Information and Data;
Supply Chain and Logistics;

Value Propositions

Develop a low-cost and innovative direct air capture module, leveraging cooling towers and waste heat

Customer Relationship and Channels

Direct contact with stakeholders through events, intro calls, emails, Linkedin, and meetings

Customer Segments

Utilization companies;
- carbonated beverages
- greenhouses

Carbon credits purchasers;
- Companies and marketplaces

Scaling partners (licensing);

Cost Structure

Product development;

Product research;

Operational costs;

Revenue Stream

Selling CO2 capture modules to utilization companies;

Selling future carbon removal credits;

Licensing the technology (25% comission);

Source: Author.

To summarize, the company's value proposition is to develop a low-cost and innovative direct air capture module, through the use of cooling towers and leveraging waste heat. To achieve that, the company maintains close contact with stakeholders, including clients, investors, multipliers, and advisors, among other relevant partners. The strategic combination of key activities and resources ensures the company's progress toward its envisioned value proposition. The company generates revenue through three primary channels, each catering to specific customer segments. Utilization companies buy the captured CO_2 to use as feedstock in their products or services, carbon credits purchasers pay for carbon removal credits delivered by the company, and scaling partners pay 25% commission for licensing the technology.

While the business model proposed may not have been specifically designed around a sustainable framework, it does incorporate sustainable elements. One notable aspect is the inclusion of leveraging waste heat within the value proposition. By repurposing heat that would otherwise be wasted, the process becomes more energy efficient. This integration of waste heat contributes to reducing energy consumption and demonstrates a commitment to resource conservation.

Moreover, the social and environmental considerations are evident in the product itself. The product's ability to mitigate carbon emissions brings benefits not only to the environment but also to society as a whole. By addressing carbon emissions, the business actively contributes to the collective effort of combating climate change and promoting a cleaner, healthier planet.

Although the business model may not have been purposely built using a sustainable framework, the integration of sustainable elements, such as waste heat utilization and carbon emissions mitigation, signifies a conscious effort to minimize environmental impact and enhance societal well-being.

When examining the revenue streams, certain concerns emerge that must be addressed. Firstly, selling future carbon removal offsets entails companies paying for offsets that will only be implemented at a later date, potentially years after the purchase. This raises questions regarding the repercussions if a company closes down before the offsets are fulfilled or fails to deliver the promised offsets. Considering the newness of the technology and the need for further optimization to attain the desired level of maturity, the risks of potential failure and falling short of the desired performance levels remain significant.

It is important to address these concerns surrounding the revenue streams and develop strategies to mitigate the associated risks. Clarifying contractual obligations, ensuring financial safeguards, and establishing contingency plans can help safeguard against possible adverse outcomes. Additionally, actively pursuing technology improvements and performance optimization can help minimize the likelihood of failure and enhance the reliability and effectiveness of the carbon removal process. By addressing these concerns proactively, the company can guarantee the profitability of its revenue streams and mitigate the risks associated with the technology's current developmental stage.

The sale of carbon capture modules appears to be the most secure revenue track as it involves immediate purchases, granting clients instant access to the technology upon acquisition. However, it remains crucial for the company to ensure adherence to appropriate procedures, encompassing maintenance and the delivery of promised results.

To establish a strong foundation for customer satisfaction and trust, it is imperative for the company to prioritize the implementation of robust protocols. This includes regular maintenance to ensure the modules function optimally and deliver the expected outcomes. By providing reliable after-sales support and promptly addressing any concerns or issues that may arise, the company can foster long-term customer relationships and uphold its commitment to delivering promised results.

Furthermore, clear communication of the company's obligations, as outlined in contractual agreements, can help set proper expectations with clients. By being transparent about the maintenance requirements and the anticipated results, the company can proactively manage customer satisfaction and avoid any potential misunderstandings. By prioritizing adherence to procedures, providing comprehensive maintenance support, and consistently delivering the promised results, the company can uphold its commitment to customer satisfaction and bolster the reliability of its revenue stream derived from module sales.

The third revenue track, licensing, presents numerous uncertainties and is not intended for implementation prior to 2027. Consequently, it is crucial for the company to develop a well-defined plan to navigate this avenue successfully.

A crucial starting point is ensuring that the necessary patents are in place. This step is essential to protect the company's intellectual property and establish a solid foundation for licensing agreements. Additionally, drafting comprehensive and robust contracts with clients is paramount. These contracts should clearly outline the terms, rights, and obligations associated with the licensing arrangement. By addressing these foundational elements, the company can position itself for success in the licensing track. Once all the bases are covered, licensing has the potential to become a significant and reliable source of income for the company.

Overall, with the implementation of the proposed business model, Company X is well-positioned to successfully deploy its products and gain a substantial market share in the direct air capture industry. Other companies were analyzed, and considering the similarities and differences outlined during the competitor's analysis, Company X seems to be in a position where is not the most mature company in terms of technology readiness but has differentiators that place the in a good spot. The commitment to developing a strong network has been bringing multiple benefits to the company, paving the way to receiving investments and building strong relationships with possible consumers and partners. Additionally, Company X integrated two technological aspects that set them apart, those being waste heat integration and repurposing existing infrastructure (cooling towers).

4.5 RISK ASSESSMENT AND MITIGATION

Performing a risk assessment and mitigation analysis is a crucial step in the development and implementation of a business model. By conducting a thorough risk assessment, businesses can identify and evaluate potential risks that may stand in the way of the successful attainment of their objectives, enabling them to anticipate and prepare for challenges, uncertainties, and negative events that may compromise their success. Ultimately, by recognizing and addressing risks, businesses can improve their ability to navigate uncertainties, protect against potential threats, and increase the likelihood of achieving desired outcomes.

In the context of Company X, a risk mitigation analysis was conducted internally, and it is summarized in Table 6.

Table 6 – Risk assessment and mitigation for Company X.

Risk	Mitigation strategy
Upscaling not moving fast enough	Defining clear milestones and measurable progress;
Supply chain delaying R&D, impacting costs, and impacting the ability to convince future customers	Building relationships with multipliers (large industrial players) that will be able to open doors to large numbers of customers and bring credibility to Company X.
Uncertainties in the carbon removal market	Competition for carbon removal credits sells; Investing in the utilization market; Conducting continuous market analysis and monitoring; Building strong relationships with customers and partners; Diversifying the range of products to reach different market segments.
Technical and Engineering Challenges	Investing in research and development, collaboration with experts and industry partners to address technical limitations
Regulatory and Policy Uncertainty	Monitoring regulatory developments, engaging with policymakers, and keeping the business model flexible to adapt to changes in regulations.
Intellectual Property and Competition	Properly patenting the technology; Establishing strategic partnerships; Continuous monitoring the competitive landscape.

Source: Company X internal analysis and author assessment.

By properly assessing the mentioned risks, Company X should be in a good track to successfully deploy a direct air capture technology, which also includes retrofitting cooling towers and re-purposing industrial waste heat for optimization. The company has a diversified plan for revenue streams, and it is investing heavily on R&D, intending to improve its technology and reduce costs. The company has already built good connections, and is building a strong network that places them in a strategic position in the carbon capture market.

The company has a strong business model in motion, as showcased in this study, with a defined customer segment and strong revenue streams. The solutions being developed align with the customers financial interests in reducing emissions, vastly lowering their reticence to implement the emission-reducing policies and processes that are urgently needed. The current market for carbon capture technologies and initiatives is growing, and the cap for allowed emissions is becoming tighter every year, making this resource gradually more scarce, and this businesses that access this demand exponentially more interesting. With that, Company X should be able to achieve its goals, and not only reach profitability in the upcoming years, but also complying with fighting climate change and helping to put the world back on a sustainable, much needed path.

5 CONCLUSION

This thesis has provided a comprehensive analysis of how to build a business model for a Direct Air Capture (DAC) company, with a specific focus on Company X as a case study.

During this study, a thorough literature review on DAC, CDR, CCS, the voluntary carbon market, policies and market mechanisms, and business model definitions was conducted, providing a solid foundation for readers to understand DAC, its environment and the structure of a business model. During results and discussion, company X's current structure was explored, including an overview of its business and technology. Following the deep dive into the company, a market assessment was conducted, where the topics covered were competitor analysis, product analysis, customer analysis, and regulations. Finally, analyzing data gathered during the literature review, market assessment, and company X's internal analysis, a visual business model for Company X was defined, considering both the company's current strategies and suggestions for further improvement.

The findings of this research reveal that DAC shows a big potential in addressing the urgent need for carbon mitigation and achieving sustainability goals. DAC has some advantages when compared to other Carbon Dioxide Removal (CDR) technologies, like low land use and scalability, however, cost and energy requirements are still challenges. Company X's technology, characterized by a structured bed reactor of low complexity and high durability, demonstrates its commitment to innovation and efficiency. The analysis of competitors highlights the unique selling points and differentiation strategies that Company X can leverage to position itself favorably in the market, like the incorporation of cooling towers and waste heat into the product.

The examination of the voluntary carbon market highlights the increasing demand for carbon removal credits and the potential revenue streams available to DAC businesses. In the voluntary carbon market the competition with alternative - and cheaper - CDR technologies is intensive, and the elevated cost of DAC puts this industry in a tough spot. While DAC companies currently can only offer prices between 400\$/tCO_2 to over 1000\$/tCO_2, afforestation and other CDR projects can offer prices as low as 10\$/tCO_2. Company X, like other DAC companies, still has a long way to go to optimize the technology and make it cheaper. In order to achieve economies of scale, and reach the desired 100\$/tCO_2, there are four main steps, which are: successfully integrating waste heat into the process, optimizing the technology with a focus on reducing energy demand, researching new sorbents, and building an innovative more advanced contactor, leveraging additive manufacturing. All of these mentioned advances should be conducted over a period of approximately 12 years, with the fully optimized model being launched in 2035. Those advances will be gradually implemented along the way, with market-ready modules being launched progressively.

Considering the sustainable goals and climate change actions getting more attention every year, and countries trying to achieve the goals set to them in the Paris Agreement, the need for cutting emissions is increasing, and fewer carbon credits are emitted every year, the gap for carbon emissions is shrinking, forcing companies to look for solutions to decarbonize their industries, even if at higher prices.

The regulatory landscape surrounding carbon capture is an essential aspect to consider in developing a business model for DAC. Understanding the evolving policies and incentives will be instrumental in positioning company X strategically and capitalizing on emerging opportunities. Depending on the country or region where the company chooses to operate, the policies and regulations can have a deeper influence on the outcome, facilitating or limiting the company's success.

After analyzing every aspect of Company X's business in the context of a business model, a visual business model was proposed, including value proposition, revenue streams, cost structure, customer segments, key partners, key activities and resources, customer relationships and channels. The proposed business model considered the company's current structure and inputs from the literature review and author assessment, resulting in a holistic business model that can lead the company to achieve its goals and conquer a spot in the direct air capture market. While challenges persist, including cost implications, logistical complexities, and the need for supportive policy frameworks, the thesis concludes that building a sustainable business model for DAC is both viable and necessary. By addressing these challenges, harnessing technological advancements, fostering strategic partnerships, and capitalizing on the growing demand for carbon removal, company X can establish itself as a key player in the DAC industry.

There are several limitations to consider when it comes to DAC (Direct Air Capture). One major challenge is the dynamic and fast-paced nature of the environment, which necessitates frequent updates to the business model in order to adapt to new developments. Furthermore, we are eagerly awaiting the emergence of untapped markets that could make use of DAC technology. For instance, there is ongoing research into using new fuels for aviation that incorporate CO_2 as a feedstock, in addition to exploring its applications in fields such as agriculture and the chemical industry. Additionally, as DAC is in the early stages of development, the future of this technology is still unsure and comes with a lot of risks. Lastly, it is important to note that the business model presented was specifically tailored to suit the circumstances of Company X during the time of the study. This means that the effectiveness of the business model may vary if applied to different companies or at a different point in time. Companies operating in diverse countries and regions, employing distinct technologies and value propositions, will likely require adaptations to the business model in order to accommodate the unique differences that may arise.

In conclusion, this thesis emphasizes the growing potential of DAC as a solution for combating climate change and provides a roadmap for developing a successful business model in this thriving field. By exploiting Company X's unique strengths, market differentiators, and relevant regulatory frameworks, the company can pave the way for a more sustainable future while creating long-term value for stakeholders and contributing to global carbon reduction efforts.

5.1 FUTURE RECOMMENDATIONS

For future developments and studies, in terms of the business model of Company X, a deep dive into cooling towers could provide a more accurate analysis, and a waste heat assessment could provide more detailed insight into the business. Furthermore, if the company plans to expand to other countries, it is essential to adapt the proposed business model to account for variations in regulations, laws, and available incentives.

From a broader perspective, there are several recommendations for the advancement of direct air capture (DAC) technologies. Technological advancements in DAC, such as improved reactor designs, innovative sorbents, and process optimizations, can enhance efficiency, reduce costs, and increase scalability.

In terms of policy and regulatory support, it is crucial to advocate for more supportive and enforceable policies and regulations that foster the growth of the DAC industry. This includes government incentives, funding programs, and carbon pricing mechanisms that encourage the deployment and commercialization of DAC technologies.

Furthermore, exploring new market opportunities for DAC and carbon capture, particularly in sectors such as aviation, transportation, and agriculture, where CO_2 can be used as feedstock, can drive further scalability and commercial viability of the technology.

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APPENDIX A – COMPETITORS ANALYSIS

Company	Description	Technology	CO2 Removal capacity (tCO2/y)	Cost / Price (EUR / tCO2)	Business model / profit	Location	Served market	Level of readiness (1- 10)
Climeworks	Capturing CO_2 directly from the air by only using renewable energy, energy-from-waste, or other waste heat as energy sources.	Air is drawn in through a fan located inside the collector. Once sucked in, it passes through a filter (with solid sorbent) located inside the collector which traps the carbon dioxide particles. When the filter is completely full of CO_2, the collector closes, and the temperature rises to about 100°C, which causes the filter to release the CO_2 so we can finally collect it. The CO_2 can then be safely and permanently stored underground;	6.900,00	1250	Subscriptions plans where people pay to remove CO2 monthly, but the CO2 will be removed only 6 years from now; Partnership with carbon storage companies (Carbfix);	Accross Europe, main operations Switzerland and Iceland	Renewable fuels, food, beverage, agriculture;	9
Carbon Engineering	Focused on the global deployment of megaton-scale Direct Air Capture technology. AIR TO FUELS™ plants combine CE's Direct Air Capture technology with hydrogen generation and fuel synthesis capabilities to deliver low carbon intensity synthetic fuel.	The process starts with an air contactor – a large structure modelled off industrial cooling towers. A giant fan pulls air into this structure, where it passes across thin plastic surfaces that have potassium hydroxide solution flowing over them (liquid sorbent). This non-toxic solution chemically binds with the CO2 molecules, removing them from the air and trapping them in the liquid solution as a carbonate salt.	1.850,00	Not specified	DAC + Storage plants or DAC + Fuells;	Canada and USA	Carbon neutral fuel; CO2 capture and storage for shopify and oil enhancement companies;	9
Global Thermostat	Global Thermostat powers global carbon removal and the circular carbon economy, using one of today's most advanced carbon removal technologies.	Solid adsorption process; Uses highly efficient fans to blow air through proprietary contactors that bind to CO2, which is then separated out with low-temperature heat.	14.000,00	Current: 600 Target: 300	Partner with organizations around the world who are developing and deploying projects to store or utilize carbon dioxide from the air; They develop the carbon capture device and sell it, not going all the way through to transporatation and storage.	USA	Carbon removal and sequestration for companies that want to reduce their carbon footprint;	8
Carbyon	Start-up founded in 2019 with the purpose of turning direct air capture of CO2 into an affordable and scalable technology.	Fast swing process by means of a rotating drum that contains a material, modified to efficiently capture CO2 out of air. This fast swing process is the key to lowering the energy consumption as well as the machine cost.	1.000,00	Current: ? Target: 50	Still very early stages; Business strategy not yet very well disclosed, but focus seem to be on selling the captured CO2 or storing it underground.	The Netherlands	Renewable fuels; Controlled Environment Agriculture (CEA); Underground storage; Companies that want to reduce carbon footprint;	7
Heirloom	Leveraging the natural power of limestone to remove 1 billion tons of C02 by 2035 using the world's most cost-effective Direct Air Capture technology.	Limestone is one of the most abundant rocks on the planet, capturing massive amounts of CO2 from the air over years. Heirloom's technology accelerates this natural process to just days. The CO2 captured is permanently embedded in concrete used in building projects by CarbonCure. We heat limestone mineral powder in a renewable-energy powered kiln to remove the CO2. Our partners then permanently and safely sequester this CO2 in deep geological reservoirs, or in long-lasting materials like concrete.	Not specified	Current: Not specified Target: < 100 by 2030	Sell carbon credits;	USA	CO2 is permanently stored underground, or in building materials like concrete; Companies that want to reduce carbon footprint;	Not specified
Mission Zero Technologies	Mission Zero is a DAC startup with a patent-pending breakthrough technology and is on a mission to close the carbon cycle. Since its incorporation in the summer of 2020, the company has won various accolades and been featured on multiple shortlists including the 2020 Diamond List. The company is currently developing its first pilot for launch in 2023 in Thetford, UK, in partnership with O.C.O Technology and is planning a first commercial project with 44.01.	Our DAC process produces high-grade CO2 supplied continuously, on-demand, on-site and is entirely electrically powered. We've shown that our electrochemical separation consumes 3-4x less energy than existing thermal regeneration approaches. The process leverages existing, scaled and mature technologies such as cooling towers and electrochemical water purification.	Current: 0 Target: 1000 (minimum)	Target: <100	Partnership with CO_2 users as well as sequestration partners with access to appropriate infrastructure; building materials;	England	Building materials; Companies that want to reduce their carbon footprint;	5
Hydrocell	CO2 capture & efficient heat recovery from exhaust air	The Direct Air Capture unit combines Hydrocell's high performance HCell brush-type heat exchanger and the regenerative CO2 scrubber.	Not relevant	Not relevant	Heat recovery products; regenerative and non–regenerative CO2 scrubbers for use in hypoxic rooms, laboratories, demineralized water tank breathers and other applications; Hydrogen storage units; Air cleaners; Brush-type heat exchangers; DAC appliances;	Finland	Customers who already buy the other products; DAC is not the only product and not the main source of income.	4

Noya	Noya is developing a world-leading Direct Air Capture technology that's scalable and cost effective, partnering up with clean energy and CO2 storage companies, and offering carbon removal credits, verified by third-party auditors.	Adding of a blend of CO2-absorbing chemicals to the water in the cooling towers. Then an attachment to the cooling tower is added to activate a regeneration process to convert the captured CO2 back into gas. Noya uses activated carbon to filter out carbon molecules from the air, the "Brita-filter" .	Current: 0 Target: 1000	Target: <100	Partnership with carbon storage and carbon utilization companies; Selling carbon credits; Selling the captured carbon to industry;	USA	Companies that want to reduce their carbon footprint; Industries that use CO2 as input (not specified yet);	4
Origen	Origen is a climate tech company with groundbreaking technology to enable lime-based carbon dioxide removal (CDR). Origen's zero-carbon process reimagines the production of lime, a mineral that naturally removes CO2 from the atmosphere.	Limestone (CaCO3) is heated in an oxi-combustion kiln, where a stream of pure oxigen (O2) is injected, resulting in two separate products: zero-carbon lime (CaO) and pure carbon dioxide (CO2). One tonne of Origen's zero-carbon lime can remove about 800kg of CO2.	Current: 0 Target: 1000	Target: <100	Selling the captured CO2 to utilization companies or storing it permanently underground.	England	Companies that want to reduce their carbon footprint; Industries that use CO2 as input (not specified yet);	6
8 Rivers	Calcite carbon removal project: Direct air capture through calcite's process, which captures CO2 directly from air and sequesters it underground, aiming to support the world's climate targets by removing over a billion of tons of CO2 for less than $100 per ton.	The Calcite process passes air with ≈415 PPM CO2 across calcium hydroxide in a large warehouse, absorbing CO2 from the air into calcium carbonate crystals. The calcium carbonate that's created is cycled into a kiln to regenerate calcium hydroxide and capture CO2. The Calcite process accelerates the carbonation of the calcium. Simplicity and speed are key for this technology.	Current: 0	Target: <100	They sell ZeroCal lime to industries;	USA	Lime purchasers: construction, cement and steel manufacturing, and water purification;	4
Skytree	Skytree harnesses carbon through the power of decentralized direct air capture technology (DDAC).	A fan draws in ambient air, that bypasses Skytree's patented filter that captures CO2 (adsorption) and then releases it when the sorbent is saturated (desorption) using a triggered release.	Not specified	Not specified	Skytree works with well-established industry partners in climate control, automotive and filtration to jointly develop products and integrated solutions that are of economical value to customers across the globe	The Netherlands	Vertical farming; Water treatment; Greenhouse; Fuels; Permanent storage;	7
Soletair Power	Soletair Power develops carbon capture systems for effective CO2 removal utilizing retrofittable direct air capture technology. Soletair Power's technology is the first in the world to integrate atmospheric carbon removal utilizing ventilation systems in buildings.	The building's HVAC system pulls in air, that is then pushed through the company's proprietary sorbent (amine based), where CO2 is selectively adsorbed. When the filter is saturated, the machine is closed and regenerated via vacuum & heating to collect the captured CO2. The captured CO2 is stored and transported for making concrete. The system itself is fully automated. It can be connected to several IoT sensors and also to the building's automation system.	20t per year for 1 module in a commercial building	Not specified	The company adapts the utilization od the CO2 depending on the customer needs and location; Partnership with storage companies; Multiple types of units offered, including buildings, indoor, and outdoor solutions.	Finland	Buildings; Concrete manufacturing; Synthetic fuels; permanent storage;	9
Sustaera	Sustaera technology is DAC 2.0, building off the learnings of previous technologies but focusing on scale and cost through modularity and an innovative chemical reaction pathway to allow for step change in cost reduction and rapid scalability.	Sustaera's technology uses naturally available abundant materials, which rapidly absorb atmospheric CO2, and can be efficiently regenerated by integrated electrical heating powered by renewable energy.	Current: 0 Target: 1000	Target: <100	Not specified	USA	Carbon utilization and storage.	7
Verdox	Verdox is using only electricity to remove carbon dioxide both directly from the air and from emission sources. The company is commercializing its electroswing adsorption (ESA) platform technology, originally developed at MIT, to remove carbon dioxide from industrial emissions and the air with 70% energy savings versus conventional approaches.	Gas mix containing CO_2 enters the system, and a specific voltage is applied, adding electrons and activating. The activated electrodes bind CO_2 to the electrodes. A different voltage is then used to remove the electrons and release pure concentrated CO_2. Instead of using heat for the desorption, Verdox uses specfic voltages to release the CO2, reling then only on elecricity.	Not specified	Not specified	Partnership with carbfix for carbon mineralization;	USA	Focuses on bothCCS and DAC;	6
Carbon collect	Carbon Collect's MechanicalTree™ captures carbon dioxide from passing wind, eliminating the need for forced convection using the fans and blowers employed by other DAC solutions. It is scalable (gigaton capable) and energy efficient. Installed onsite, the MechanicalTree™ can also provide a source of green CO2 for a range of uses in industry, construction and agriculture, replacing CO2 manufactured from fossil fuels, and eliminating transport and logistics.	The Mechanical tree, with tiles up to 10m long, becomes saturated with CO2 after 20 minutes n the wind. Once saturated, the tiles are pulled down and enclosed for the regeneration phase, where the CO2 is removed, which must happen under a vacuum. The tiles are then extended again for a new cycle to begin. The capturing part does not use electricty, as it is a passive process, no forced airflow, and energy is only required for the regenration part; Moisture driven CO2 sorbent;	Current: 10.000 (theoretical)	Not specified	Sellins the captured CO2 to utilization companies or permanent storage;	USA	Agriculture, food, beverages, CO2 based fuel, permanent sequestration, cement and concrete curing, steel manufacture, pharmaceuticals, fire suppression, carbon fibre, EOR, fertilizers.	5
CarbonCapture	We create high-quality carbon removal credits by combining atmospheric carbon removal with permanent geological storage.	Solid sorbents; Permanent CO2 storage; The exact amount of CO2 our DAC systems capture is precisely metered and measured; Deeply modular, open systems architecture.	10.000,00	Not specified	Selling carbon removal credits, with a third-party verification report for the credits; Focus on small modularized units;	USA	CO2 permanently stored underground; synthetic fuels, low-carbon concrete, carbon black, or other industrial products that require clean CO2.	7