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Carbon Capture and Storage in the European Union:

The role for combating climate change

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Abstract

The urgency of climate change is pressing on the development of different technologies to reduce greenhouse gas emissions among which carbon dioxide (CO_2) is the most abundant. A great source of CO_2 is the burning of fossil fuels. The installation of carbon capture and storage (CCS) technology could reduce the amount of CO_2 released from larger combustion processes by up to 90%. Fossil fuels stand for a great part of the total consumption of energy in the society today. To replace it so rapidly that strict climate change objectives will be reached with only increased energy efficiency and renewable energy would be difficult and would not be the most cost-efficient strategy. To be able to stabilize the atmospheric CO_2 level within this decade and in a cost-efficient manner, the development of CCS technologies is clearly needed as a complementary strategy.

Contents

1. Introduction

1.1 Background

The environmental debate today is very much concentrated on global warming and the causes behind it. Scientists all over the world have agreed upon that it is the rising level of carbon dioxide (CO_2) that is the main cause to the rising global temperature. In the Fourth Assessment Report from the Intergovernmental Panel on Climate Change, (IPCC, 2007a) it was stated that it is "with very high confidence" the humans who are causing the level of CO_2 in the atmosphere to rise by the burning of fossil fuels. There is also a rapid increase of CO_2 emissions in the world today. The industrialised countries count for the vast majority of emitted greenhouse gases, and the emissions continue to increase in several rich countries. Many developing countries have also increased their use of fossil fuels, especially the burning of coal to produce electricity. China is a good example of a country with a fast expanding industry and a rapid increase in electricity demand. China is also a country with great coal reserves and that is one reason to why they are building coal fired power plants. Consequently, the CO_2 emissions in China are rising fast but, on an individual level, the emissions per capita is still much lower than within e.g. the OECD, in particular compared to those in the USA.

There are many effects of a global climate change (IPCC, 2007b). A rising temperature will cause changes in the precipitation patterns. Regions with much precipitation today are likely to get wetter and dry regions may be even drier. A higher temperature in the atmosphere also affects the oceans. Water expands and glaciers are melting faster when the temperature is rising and this will lead to a rise in sea level. This will affect many regions all around the world and many people will be affected since coastal areas often are densely populated. All these changes will have effects on the economy. The Stern review (2006) estimated that a business as usual scenario may lead to loss of 5-20% of global GDP each year. The cost for action to prevent the worst impacts of climate change could be limited to around 1% of global GDP each year (Stern, 2006). This review shows on the importance of action to mitigate climate change.

There are several ways to reduce the CO_2 emissions. Substitution from fossil fuels to renewable energy resources and increased energy efficiencies are two ways of combating the

emissions. A third option is a technology called carbon capture and storage (CCS). Among those advocating CCS, e.g. the European Commission (European Commission, 2007a) these strategies are supposed to be used together to reach the emission targets. The distribution between the three strategies in the mitigation process is supposed to be individual for different countries or regions and depends very much on which kind of energy that is being used and what kind of demands the countries or regions have for their future use of energy. In the following, I will look closer at CCS in the European Union (EU).

Global climate change will have great impacts on our lives. Some people may benefit from it but for the majority it will mean a change for the worse. We humans need to take actions right away but we should not rush forward with solutions without a good understanding of the long-term effects. A solution that looks good today may be bad tomorrow. Concerning CCS, it is interesting to study the situation in the European Union in more detail, since the EU is an influential player in the global debate on climate change.

1.2 Aim and research questions

This essay has the aim to explore CCS as a climate change mitigation strategy for the European Union and to investigate what view key EU stakeholders take on CCS. I will investigate if CCS is a sustainable way to combat climate change from the perspectives of cost efficiency (i.e. to reach a specific objective in the cheapest way possible) and level of environmental safety. With "strategy", I mean the technical solutions for mitigating climate change and I will not look upon the different steering tools for climate change, nor for CCS as such.

The following more precise questions will be answered:

- What is CCS and what merits and shortcomings does it have?
- What are the attitudes towards CCS among key EU stakeholders and how could that influence the decision-making?
- Is it defendable from the mentioned perspectives, to use a technology that is based on the use of fossil fuels or can the emission targets be reached without it?

The essay will focus on carbon capture from industrial process streams and post-combustion capture, and the mitigation strategies and actors in the European Union, where both the EU Commission, companies and others recently have been advocated a fast development of CCS. The industry and environmental NGO's are considered to be the main stakeholders in this essay.

1.3 Method

This essay is a qualitative study based on literature research. I have chosen to investigate the subject by taking part of scientific studies on CCS, as well as views held by key actors in the field. The information I have analysed was found by literature searching in scientific databases and on the internet in general. This search had the aim to find out how CCS works, in a wide sense, and how different stakeholders look upon this technology as mitigation for climate change. The different stakeholders were chosen to get a broad variety of opinions among influential actors regarding CCS.

In the literature search, I tried to find information from reliable, independent and common accepted sources, like the Intergovernmental Panel on Climate Change (IPCC). The IPCC is a co-operation between the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) and is open for all of their members. The role of IPCC is to review the scientific work on human-induced climate change and to give a comprehensive, objective and open view for policy makers and the public (IPCC, 2007c). IPCC could be considered as objective as possible, and is working to reach scientific consensus.

When it comes to the different stakeholders' views, it is necessary to read them with a more critical attitude. I have studied views held by the largest among companies and environmental organisations. In their policies the actors often argue from their specific point of view and want – of course- the reader to believe that their views are the best way to act accordingly. But my intention is not actually to judge in detail whether or not the stakeholders' views are more or less correct; I want to investigate them in order to understand what they might mean for the development, or not, of CCS in the EU

The choice of the three different environmental NGO's was made to get different views on CCS. They should also be working in many different countries so their views would not be influenced by a specific country.

The focus in this study was laid on the situation in the EU because the union plays an important role in the international work on climate change. The starting point is that the EU Commission recently came up with a series of proposals on new targets and policies for climate change. The timeframe for the essay also made it relevant to limit the work to the policies and stakeholders in the EU.

2. Theoretical background: Carbon capture and storage

2.1 What is carbon capture and storage?

Carbon capture and storage (CCS) consists of three stages: capture, transportation and storage. The capture of carbon dioxide (CO_2) can be done at power stations that use fossil fuels. The CO_2 is compressed to liquid form and can then be transported via pipelines to the storage site. It is possible to store the CO_2 in geological formations or depleted oil or gas fields. (IPCC, 2005)

The storage of CO_2 can be combined with oil and gas production to make it possible to extract more oil and gas. These techniques are called enhanced oil recovery (EOR) and enhanced gas recovery (EGR). By combining the storage with EOR or EGR, at least a part of the cost for CCS can be paid with the income from the oil or gas production. (IPCC, 2005)

2.2 Capture alternatives

There are several sources of CO_2 emissions, both natural and human made. From many of these sources it is possible to capture the CO_2 and remove it from the carbon cycle. If the CO_2 comes from burning of fossil fuels, the removal of the gas means that there is no addition to the atmospheric CO_2 level. It is also possible to capture CO_2 from the flue gases of biomass energy power plants. This is said to be the only way to reduce the atmospheric level of CO_2 (Read & Lermit, 2005).

Natural gas also contains some CO_2 and it is necessary to remove it before the transport to the customers because of the corrosion risk in the pipelines. The CO_2 that has been removed is released into the atmosphere where it contributes to the rising level of CO_2. Instead of releasing it, it is possible to capture and store it underground. This is already in progress at two natural gas plants in the world today, BP's In Salah plant in Algeria and a Statoil plant at Sleipner in the North Sea (IPCC, 2005).

To capture the CO_2 is not a problem today (IPCC, 2005). The big issue is the cost which varies a lot depending on many factors, e.g. the type of power plant, the amount of fuel that is

being used and what kind of capture method that is installed. A fair comparison for the cost of different capture alternatives is therefore not possible.

The most common way of post-combustion capture, is to let the flue gas come in close contact with a chemical solvent that is capable to capture the CO_2. The solvent is then transferred to an isolated chamber where it is being heated up to release the CO_2. The solvent is then sent back to the flue gas chamber to capture more CO_2. (IPCC, 2005)

A new method is under development which will be able to separate the CO_2 to a lower cost than normal post-combustion separation. The technology is called chemical looping combustion (CLC). A metal is used to fix the oxygen from the air as a metal oxide. The metal oxide is then transferred to the combustion chamber where the fossil fuel is injected. The atmosphere that is created by the carbonaceous fuel is reducing and the oxygen will be released from the metal and can react with the fuel. The flue gas from this combustion will consist of water and CO_2. The water is condensed and removed from the process. The CO_2 can then easily be compressed and transported to a storage site. (IPCC, 2005)

2.3 Storage sites

If the capture of CO_2 shall have any effect at all, safe storage sites are required. In this case, safe means non-leaking storage sites. The CO_2 can be stored in many different ways. Depleted oil and gas fields are often very suitable for CO_2 storage. The fact that they have kept the oil or gas safely underground without any leaking proves their appropriateness as storage sites. They are also very well examined by the companies who were running the oil or gas fields. Other kinds of geological formations that are capable of holding the CO_2 underground are saline formations. That is deep sedimentary rocks saturated with formation waters with a high concentration of salt (IPCC 2005). “Sleipner” is an example of a saline formation. The storage capacity of these formations is often very large.

A third option for storage is in coal seams. Between the coal layers there are many micropores where gas molecules can be absorbed. Sometimes these pores contain methane and when CO_2 is injected, the methane will be replaced by the CO_2 molecules. It is possible to extract the methane and use it in other processes. This has been practised in the Allison Project, in the

San Juan Basin in the northern New Mexico, USA (IPCC, 2005). The goal of this projected was only to recover more methane. The effect that the CO_2 had on the coal seam was therefore not investigated. More research is needed to get a full understanding of how well the coal seams can hold the CO_2 safely stored underground.

The deep ocean is also an option for storing of CO_2 because of the high pressure that keeps the CO_2 in liquid form. This kind of storage has not yet been tested in big scale and the environmental effects of the method are not known. Research is needed in the field to examine the biological effects of the released CO_2, before this storage option can be used.

2.4 Uncertainties

Since CCS is a relatively new technology, it is associated with many uncertainties. Research is needed for a better understanding of how the CO_2 affect its surroundings when it is stored in very high concentration. That concerns both underground and ocean storage. The possibility of leakage from the storage sites and its consequences also needs more research. A high concentration of CO_2 is lethal to animals and humans which mean that a leakage could have very serious effects for the local surrounding. Any larger leakages would of course mean that the very idea with CCS (to store CO_2) is counteracted

Because CCS is a new technology there are no regulations in the EU yet about how to use it. Politic agreements are needed before full scale projects are being stage.

The public opinion and acceptance for CCS must also be investigated. Since climate change is something that affects all people on this planet, a common acceptance on how to slow it down is required.

The storage capacity in the world is very big and at the same time very uncertain. It is at least possible to store all CO_2 released in the world today and for several hundred years onwards, with the same emission rate as today. (IPCC, 2005)

To predict the cost for CCS is also very difficult. It depends on many factors, e.g. which kind of capture technology that is being used, how long distance there is between the capture and

the storage site and if it is combined with EOR or EGR. However, there are studies showing that costs for reaching specific targets for CO_2 levels could be lowered by using CCS (Azar et al., 2006). As shown in figure 1, the cost for reaching the 350 ppm stabilization target is considerably lower with CCS than in the scenario where increased energy efficiency and renewable energy sources are being used, the "no capture" alternative.

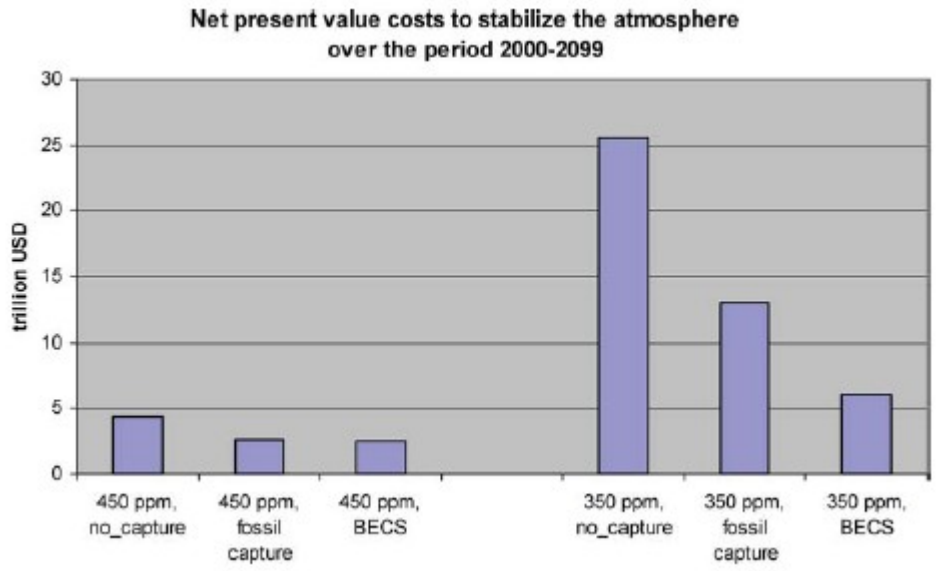

*Figure 1.*Net present value of extra energy systems cost to meet a 350 and 450 ppm stabilization target by the year 2100 compared to a baseline scenario with no CO_2 constraints. The discount rate is 5%/year. (Azar et al. 2006)

2.5 Advantages and disadvantages

The advantage with coal as a source for electricity production is its reliability. It isn't affected by weather or season like wind power and hydropower. It is possible to produce electricity at any time of the year and deliver it to the customers. There are also a lot of coal supplies in the world and with the current rate of production it will last for approximately two hundred years (World Energy Council, 2004). The process from mining to combustion and delivery of electricity is well known and functioning. One negative effect with coal combustion is the large amount of CO_2 that is being produced, but coal also emits sulphur dioxide and particles. By combining CCS with fossil fuel combustion the CO_2 emissions can be reduced by 80-90% compared to the same plant without CCS installed (DTI, 2006).

The capture of CO_2 requires energy and this means that the amount of coal and natural gas that is used will rise to cover the higher energy demand. As long as the best available technologies for flue gas cleaning are being used, the amount of sulphur dioxide, particles and other pollutants that are being released will be very low and the environmental effects of the increased use of fossil fuels will be moderate.

A disadvantage with CCS is that it requires energy to extract and transport the CO_2 to the storage sites. This means that more fossil fuels are needed to produce the same amount of electricity for the customers, which means that environmental problems associated with fossil fuels will increase. This also leads to a higher price for electricity, because the companies need to cover the cost for CCS.

The coal subventions are also a problem. Without them it would often be unprofitably to use coal as an energy resource. The installation of CCS will give the coal industry one more argument for continuous coal subventions, which could lead to a prolonged use of coal.

3. CCS in EU

3.1 Proposals from the European Commission

An energy policy for Europe, called "Energy for a changing world", has been accepted and proposed by the European Commission. Targets for this policy are:

- reduce greenhouse gas emissions by 20% by 2020, 30% if an international agreement is being accepted
- improve energy efficiency by 20% by 2020
- raising the share of renewable energy to 20% by 2020
- increasing the level of bio fuels in transport fuel to 10% by 2020 (European Commission, 2007b).

The EU Commission is working to keep the global temperature rise below 2°C above pre-industrial levels and the proposals is the first steps to reach that target. The Commission is developing an enabling legal framework for CCS which will be presented by the end of 2007 (European Commission, 2007a).

Fossil fuels stand for over 50% of EU's electricity production and are today very important for a safe and secure delivery of electricity to the community. The European Commission has made a proposal on how fossil fuels can still be in the energy mix without counteracting the climate change emission targets. It says that fossil fuel combustion has to be combined with CCS for a continuing use of fossil fuels. (European Commission, 2007c)

The cost for CCS is very uncertain because of the heavy development that is going on. The EU Commission is predicting the cost for CCS to be in the range if €20-70 per tonne of CO_2. Major technological improvements are anticipated and in a medium- to long-term perspective the costs of CCS by 2020 is estimated at about €20-30/tCO_2 (European Commission, 2007c). This will make the costs for coal fired power generation with CCS by 2020 to be 10% above or even on the par with current levels. As a comparison, the Swedish tax on CO_2 is €98/t CO_2 (Prop. 2006/07:1), which means that it would most likely be cheaper to install CCS than to pay the tax for emitting CO_2.

3.2 Actors

3.2.1 Industry

In order to reach the emission targets that EU has proposed, the industries need to cut their CO_2 emissions. Companies that use a lot of fossil fuels in their processes are in general very optimistic about CCS. By installing the new technology they will reduce their CO_2 emissions greatly without changing the energy resource. The Carbon Capture and Storage Association (CCSA) is bringing the companies together to promote the positive benefits of CCS for the policy makers and the public (CCSA, 2006).

The International Chamber of Commerce (ICC) stated in 2003 that "development, commercialization and widespread dissemination of technologies to help reduce greenhouse gas emissions is the most economically feasible way to meet the long-term challenge of climate change" (ICC, 2003). CCS is one of the different technologies they promote. ICC also believes that this can best be achieved within a free-market setting for business and industry.

The Swedish energy company Vattenfall is working very hard with CCS technologies. On May 29, 2006, they started to build their pilot plant for so-called clean coal. It is a 30 MW oxyfuel plant and it should be in operation in 2008. With this power plant Vattenfall will be able to monitor the process in bigger scale and if everything turns out right they will build a 300MW demonstration plant which will be ready in 2015. They believe that CCS will be commercially available in 2015-2020. (Vattenfall, 2007)

The Norwegian oil and gas company Statoil has several CCS-projects running. The Sleipner gas plant is the only one running with the CCS technology today but several different projects are in the making. Some of the projects are co-operations with Shell or BP. (Statoil, 2007)

3.2.2 Environmental NGO's

There are several environmental NGO's in Europe and here follows an account for the view on CCS from three of them.

Bellona

The Bellona Foundation is an international environmental NGO based in Oslo, Norway. The organisation is financed by industry, business, individuals, project oriented grants from philanthropic organisations and the Norwegian government. It's recognised as a technology and solution oriented environmental movement with offices in Europe and the USA. The organisation has the ambition to be a watchdog for industry in the 21st century to make sure that the technological advances are accompanied by sound ecology. (Bellona, 2007a)

Bellona has not stated any own emission or temperature targets. Instead it is working with the Kyoto Protocol (Bellona, 2007b) and with the industry to help them reduce their emissions.

The organisation states that CCS is needed in the work against climate change as a part solution to reach an acceptable level of CO_2 in the atmosphere. It also advocates solar and wind energy to replace old fossil fuel plants. It believe that nuclear energy will stay in the energy mix, but it press on the urgency for developing a safe way to store the nuclear waste. (Bellona, 2007c)

Greenpeace

The Greenpeace European Unit is part of the international Greenpeace network and is based in Brussels. It is independently funded and do not accept donations from governments, corporations or political parties. It monitors and analyses the work of the EU institutions, expose deficient EU policies and laws, and challenge EU decision-makers to implement progressive solutions. (Greenpeace, 2007a)

Greenpeace has the aim to stabilise greenhouse gas concentrations at a level below 400 parts per million (ppm) CO_2-equivalent in the atmosphere. When this level is reached, the concentration has to be reduced if the global temperature rise is to be kept below 2°C above pre-industrial levels. (Greenpeace, 2007b)

Greenpeace advocates renewable energy and improved energy efficiency to reduce the CO_2 emissions and phase out coal and nuclear power entirely. It believe that it is possible to reach the emission targets for EU without the use of CCS, by phasing out all of the coal fired power plants and instead use renewable energy.

Together with the European Renewable Energy Council (EREC), a report called "Energy Revolution – A sustainable world energy outlook" (EREC and Greenpeace, 2007) was published in January 2007. This report shows that increased efficiency and renewable energy sources is a possible way to lower CO_2 emissions and at the same time produce the amount of energy that is demanded. However, even in this report, coal remains an energy source for decades to come, although on substantially decreased levels.

WWF

World Wide Fund for Nature is an independent foundation with national organisations all over the world. It has the goal to halt and reverse the destruction of our natural environment. It is founded by donations from individuals, corporations, foundations, governments and aid agencies. The organisation has an office in Brussels who works to influence the policies and activities of the EU. (WWF, 2007a)

WWF has the target to keep the global temperature rise below a 2°C increase compared to pre-industrial levels. To reach this goal, it has several milestones that it believes are needed to implement. The targets for climate change will be reviewed in July 2007. (WWF, 2007b)

To combat climate change, WWF promotes renewable energy and energy efficiency. It also believe that CCS is necessary because fossil fuels are and will be in the energy mix for some time to come and the only way to still use fossil fuels and reach the emission targets, is to combine it with CCS. (WWF, 2007c)

4. Discussion and conclusion

To reduce the CO_2 emissions, a lot of changes are required. We humans have a very high reliance to technical solutions and their capability to solve the problems we create. For the most of the time it is working but to combat climate change we need to take on a complementary approach. That is because the situation is very urgent and we don't have the techniques to change the way we are going without doing any changes in our ways of living and thinking. The reliance on fossil fuels is the biggest problem when it comes to climate change mitigation. Fossil fuels have been used since the 18th century and the demand for it has been growing ever since. Today, many countries are in a period of rapid growth. Industry and the public in developing countries demand more and more energy to be able to reach the same standard as the developed countries in the west. Since fossil fuels technologies are well working and are available, these demands are often met by the construction of fossil fuelled power plants. The rapid increases of the living standards and independency for the people in the developing countries have also made it possible for more people to buy their own cars. Together with the large emissions of CO_2 from the rich countries and their increased use of energy, the CO_2 emissions are rising rapidly.

To stop this development, a shift from fossil fuels to renewable energy is needed. A more fundamental change for a sustainable use of energy is to use it in a more efficient way, i.e. to decrease the energy demand. To reach the targets for CO_2 emissions, set up by EU, these two strategies alone will probably not be enough because of the rapid growth in energy demands. A big issue here is that the energy is needed today and at the moment it is not possible to create all this energy with renewable sources. This is why there are so many coal fired power plants built today. It wouldn't have been such a big problem if they where all built with CCS (given that the technology holds what it promises), but since the technique isn't fully developed the power plants are built without it.

The development today, with all new fossil fuelled power plants, makes CCS to a needed mitigation strategy. As long as the development for CCS is financed separately from the research for more energy efficient solutions and renewable energy, it will be a good option to mitigate climate change. There is a very urgent need to speed up the work with climate change mitigation and all available techniques are necessary. In the long run, renewable energy and energy efficiency are the best solutions to reduce the human impact on the climate

system. IPCC has e.g. shown increased efficiency to be cost efficient, sometimes available at negative costs (IPCC, 2007d). But, according to the IPCC we need urgent measures, and therefore all doors should be kept open. The dependence on fossil fuels has to be reduced fast. CCS is a good technique to reduce the CO_2 emissions, but it doesn't reduce them to zero. This means that there will still be an addition to the CO_2 level in the atmosphere, as long as fossil fuels are being burnt. This is why a complete phase out of fossil fuels is needed in the long run to really get the atmospheric level of CO_2 under control.

To ensure that the development of the different technologies isn't counteracting each other, political guidelines are required. This is needed to make sure that the development of one technology isn't drawing financial resources from the others. For instance CCS could be paid for by industry in order not to draw money from research and development in e.g. renewables. All three of the technologies is needed in the short-term mitigation work and in the long-term perspective, renewable energy and a more efficient way of using energy are the best solutions for a sustainable energy production.

The different stakeholders' views are already today influencing the decision-making in EU and will continue to do so in the future. A great example of that is the proposal from the EU Commission about the targets for renewable energy and energy efficiency. I believe that this can be ascribed to the environmental NGO's and their promotion for renewable energies and energy efficiency.

The politicians need a broad spectre of views in order to make good and sustainable decisions for climate change mitigation. The views from all different stakeholders are important in the politic decision-making. The views from the environmental NGO's are important for the protection of nature, because the nature doesn't have a voice of its own. Business and industry are the ones to develop and implement the technologies and may also, depending on the regulatory frameworks that will be developed for CCS, stand for a big share of the cost for this. They also create a lot of job opportunities and are essential for the prosperity of a country or a region. This makes them to important actors in the work to mitigate climate change.

Comparing the various positions taken by the actors studied in this essay, it is clear that CCS has support from all different kinds of actors, with some opposition. Several actors are also working towards almost the same greenhouse gas concentration level in the atmosphere and

they are all predicting that coal will be in the energy mix for a long time to go. Given the information today, CCS seems to be a necessary technology to reach ambitious climate change objectives due to the large amount of coal fired power plants. According to the studies by Azar et al., CCS is also cost-efficient and can act as the first step to a less unsustainable power generation and a stabilized climate.

The aim of this essay was to explore CCS as a climate change mitigation strategy for the EU and to investigate what view key EU stakeholders take on CCS. The main research questions concerned the merits and shortcomings of CCS, the attitudes towards CCS among key EU stakeholders and how could that influence the decision-making, and whether or not it would be defendable from environmental and economic perspectives to use CCS when it fundamentally is based on continued use of fossil fuels.

My study shows that CCS is a good method to quickly reduce the CO_2 emissions. It can be cost efficient but it will be able to keep up the use of fossil fuels. The attitude to CCS is in general positive among the key EU stakeholders, with opposition from e.g. Greenpeace, which indicated that the decision-making on CCS will move on. With the urgent need for a rapid reduction of greenhouse gas emissions, it is necessary to use CCS and fossil fuels to be able to reach the emission targets and at the same time produce the amount of energy that is needed, given increased efficiency, in the society today and in the future.

Even though I conclude that CCS is needed, it is also important to not forget about the other two strategies; renewable energy and increased energy efficiency, which are even more promising than CCS, but unfortunately too limited in their impact, given the urgency of climate change. All three strategies are essential in the work with climate change mitigation.

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