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The potential of a European CCS market viewed from a Danish perspective

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1. Summary

CCS is necessary to achieve climate goals

CCS – the capture, transport and storage of CO_2 in underground reservoirs – is one of the technologies which will be vital in ensuring that international climate goals are met. Many emission sources are unable to achieve a sufficient reduction in emissions, which is why it is necessary to capture CO_2. In the long term, global net emissions must be negative, which requires the removal of CO_2 from the atmosphere. Therefore, CCS must play a key role, in conjunction with a number of other important initiatives, in fulfilling global climate ambitions.

Major differences in European countries' own CO_2 storage facilities

There are major differences in the facilities that European countries have available for storing CO_2. Countries with abundant access to underground reservoirs in the North Sea, for instance, such as Denmark, Norway and the UK, can store their own CO_2 emissions for many years. Other countries, such as Germany and Poland, have considerable storage requirements, but have fewer facilities for storing CO_2, while some countries have no capacity at all. This therefore creates a need to establish an international market for trading and transporting CO_2.

CCS costs less as the market matures

International cooperation can also help significantly reduce the cost of CCS. This is down to costs being high when storing small amounts of CO_2, with the potential of costs being halved in the case of larger volumes. In the short term, Denmark and other countries with good storage facilities are unable to capture sufficient CO_2 to achieve the beneficial economy of scale effects. They will only be achieved if the market's size increases, thereby giving rise to a need to establish a common European infrastructure for transporting and trading in CO_2 from several other countries.

Major market potential for CCS in Europe

The total amount of CO_2 which potentially may be stored across EU countries by 2030 is calculated at between approx. 360 and 790 million tonnes of CO_2. An annual market potential of this magnitude requires a well-established, reliable transport network and continuous monitoring of storage facilities. Such a system requires international coordination and standardisation, which can obviously be carried out under the auspices of the EU.

CCS can make a contribution to the Danish economy and employment

According to our estimates, a European market should be able to attain a total economic value of between DKK 450 and 1,000 billion. The countries participating in a future CCS market can look forward to sharing in the market, but there is uncertainty about the amount which will be assigned to each country. For example, if Denmark's share of the market amounts to 5-10 per cent, this will achieve an economic value estimated at between DKK 23 and 100 billion. If the CCS sector grows to such a size, it is also estimated that the number of jobs which can be created directly and indirectly in the CCS industry will range between 4,000 and 17,000.

Denmark as a potential trailblazer in the CCS sector

As things stand, Denmark's facilities in terms of operating as a recipient country for CO_2 storage are already good. However, this position will only be consolidated in the future as CO_2 emissions decrease and more suitable storage capacity facilities are being continuously mapped. The political goodwill for CO_2 storage already exists in Denmark, which is why Denmark is at the forefront of the effort to create a European market for capturing, transporting and storing CO_2. Large-scale CO_2 storage in Denmark may, at the same time, pave the way for investments in the development and application of capture technologies, which many companies would otherwise be reluctant to get involved in if there were no possibilities to store CO_2.

2. What is CCS?

CO_2 is captured and stored safely

CCS (Carbon Capture and Storage) is the term used to describe technologies and processes which first capture CO_2 and subsequently transport and store it.

Carbon capture plants isolate CO_2

CO_2 may be captured in several ways. The method usually used is based on a chemical process which involves, in simple terms, isolating CO_2 from the gases which are released by burning fossil fuels and as part of industrial processes. This can be done by installing carbon capture plants at sources producing large emissions of CO_2.

CO_2 is captured at "point sources"

The greatest potential for capturing CO_2 is offered by emissions from "CO_2 point sources". Examples of point sources include energy production based on coal or biogas, cogeneration power plants, waste incineration plants and CO_2-intensive industrial installations, involving, for instance, the production of cement and chemicals. Emissions from point sources can be broken down into biogenic and fossil emissions. Furthermore, CO_2 can also be captured directly from the air.

CO_2 is transported in a liquid state

CO_2 can then be transported to the locations where it is intended to be stored via pipelines or in tanks loaded on lorries or in purpose-built tankers. The captured CO_2 can be transported by applying pressure, which turns it into a liquid state.

The reservoirs used for storage include depleted oil fields, which are monitored for spills

CO_2 is stored by being injected into geological rock formations or depleted oil or natural gas fields, which are located deep in the subsoil. Suitable reservoirs for CO_2 storage are seldom available as they have to meet a number of important requirements, ensuring that CO_2 does not escape and seep back to the surface. Therefore, there is a constant search for suitable reservoirs which are subject to thorough assessments in terms of human and environmental safety, while any reservoirs used need to be continuously monitored along with the rest of the infrastructure.

3. CCS is necessary to achieve climate goals

CCS is necessary to achieve climate goals, but cannot be the only means

In order to achieve global climate goals, new technologies and techniques need to be applied, which help cut greenhouse gas emissions. CCS is one of the technologies that will have a crucial role to play. This is the consensus among a wide range of scientists and international organisations. This is stated, for instance, by the United Nations Intergovernmental Panel on Climate Change (IPCC) in its latest climate report. The Danish Council on Climate Change also assesses that for Denmark to achieve its 70% target, it will need to capture substantial volumes of CO_2.[1]

The contribution of new technologies to achieving climate goals is assessed in projections

At a global level, it is the 2015 Paris Agreement, in particular, which charts the direction for global climate ambitions. Under the agreement, UN countries are committed to endeavour to restrict the rise in the planet's temperature to less than two degrees above pre-industrial levels, while striving to limit the temperature rise to 1.5 degrees. This objective is typically referred to as the "1.5-degree target". The IPCC provides ongoing projections for global greenhouse gas emissions, which are monitored to ensure compliance with the objective. The projections illustrate a number of scenarios which reflect potential policy measures and technology implementations that have an impact on overall greenhouse gas emissions and, therefore, also on the planet's temperature. This means that projections can be used to keep an eye on whether the countries of the world are reducing their greenhouse gas emissions in line with the 1.5-degree target. For example, the significance is assessed of the fact that the world's economies are gradually phasing out the use of fossil fuels, while wind

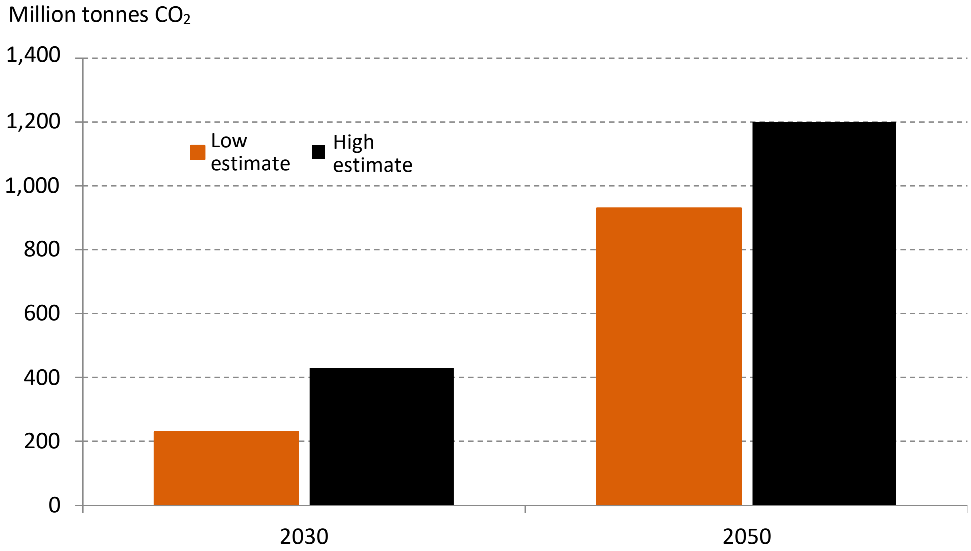
[1] IPCC (2022) and Danish Council on Climate Change (2020).

and solar energy are among the sources taking over. This also includes the significance of new technologies which are expected to reduce greenhouse gas emissions, such as CCS. This also applies to new climate-friendly building materials, such as new variants of concrete and steel, as well as to techniques deployed to reduce emissions from agriculture. Therefore, the projections give an estimate of how much each single technology, including CCS, is expected to contribute to the overall reduction in greenhouse gas emissions.

Huge CCS contribution required for EU to achieve Paris Agreement targets

The projections for greenhouse gas emissions show that CCS's contribution is vital to achieving the objectives of the Paris Agreement. This applies to both EU countries and the rest of the world. figure 1 presents the volume of CO_2 that needs to be captured in the various EU countries to put them on track towards the Paris Agreement targets by 2100. The figures are based on a number of projections, where CCS makes a contribution to varying degrees, but which all achieve the objectives of the Paris Agreement.[2] The annual volume of the CO_2 captured in these projections will amount to between 230 and 430 million tonnes of CO_2 in 2030. In 2050 it will increase to between 930 and 1,200 million tonnes of CO_2, see figure 1.

Figure 1 CO_2 capture required for EU to meet Paris Agreement targets (million tonnes CO_2)



Note: The low estimate is based on projections that include factors such as consumption behaviour among EU citizens becoming more climate-friendly and the use of fossil fuels in industry being restricted. The high estimate is based on a scenario where fossil fuels continue to be used to a significant extent.
Source: Butnar et al. (2020).

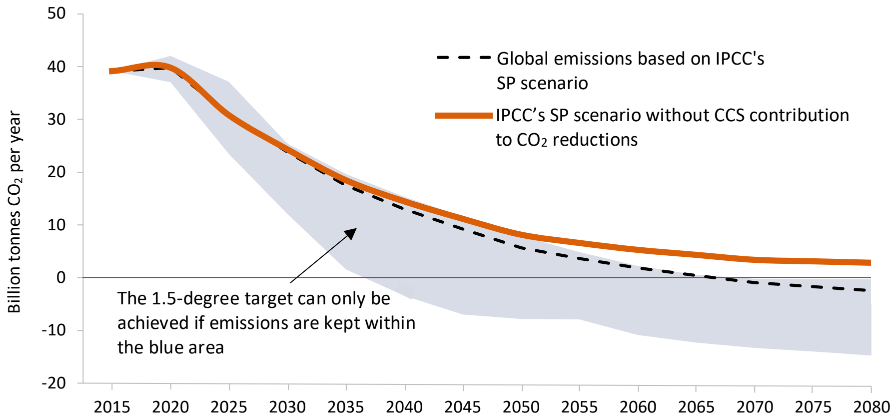
CO_2 will have to be removed from the atmosphere

Consequently, CO_2 capture is considered to play a key role in Europe. CCS is also regarded at a global level as an important part of the solution to the climate challenges. This is shown in figure 2, which reviews the IPCC's scenarios for the evolution in global emissions which is required to ensure compliance with global climate ambitions. The light blue area in figure 2 illustrates the IPCC's assessment of the range for future global CO_2 emissions compatible with the 1.5 degrees target. As long as all the countries in the world achieve emissions within this range, the IPCC estimates that the 1.5-degree target will be met with at least a 50% probability. The width of the range shows that global emissions from 2065 onwards must be no more than zero, but negative emissions of around 12.5 billion tonnes of CO_2

[2] (Butnar et al., 2020).

may also need to be achieved. What this means is that CO_2 will most likely have to be removed from the atmosphere.

Figure 2 Projection for global CO_2 emissions to ensure 1.5-degree target is achieved (billion tonnes CO_2 per year)



Note: The shaded area in the figure shows the range within which emissions can move to enable the UN's Intergovernmental Panel on Climate Change to assess in their climate change scenarios that the 1.5-degree target can be met. The figure's curves show the evolution of the IPCC's SP (shifting pathway) scenario, which, among other things, gives strong consideration to socio-economic growth. The dotted curve indicates the expected evolution with contributions from CCS, while the orange curve shows the same evolution, but with the contribution from CCS technologies discounted.

Source: IPCC, IEA and own calculations.

If socio-economic conditions are taken into account at a global level, CCS is required to achieve climate objectives

The dotted black curve in figure 2 illustrates the IPCC's stipulated emission levels in a highlighted scenario, which both are compatible with the 1.5-degree target and take into account the development in socio-economic relationships.[3] This ensures that the climate target is achieved while, at the same time, the global standard of living and inequality are subject to as little a negative impact as possible, which is why we consider this as one of the most relevant scenarios, as there is likely to be more support for the necessary actions required to achieve it. If all contributions originating from CCS are factored in, based on this scenario, the evolution will follow the orange curve. The orange curve appears outside the shaded area after 2050, and the climate target is likely by more than 50% not to be achieved.[4] In light of this, we need CCS if we are to avoid risking serious consequences arising from global warming and a deterioration in economic and social conditions.

[3] The "SP (Shifting Pathway) scenario".
[4] See Appendix 1 for more information.

Box 1: Need for CCS

i. **The climate transition is too slow**

In many sectors of the economy, it can be difficult to make a sufficiently rapid transition to climate neutrality. For example, if a well-functioning power plant is to be demolished simply because its CO_2 emissions are too high, this is an extremely costly action. This is where it can be beneficial to install a CO_2 capture system. Therefore, CCS can be a transition technology ensuring that global climate goals are met.

ii. **Not all emission sources can become CO_2 neutral**

This applies, for example, in agriculture and the cement industry. In the case of the majority of agricultural activities, it can be difficult or downright impossible to use CO_2 capture. The cement industry cannot become completely CO_2 neutral either, as during the production of cement a large amount of CO_2 is released directly from the materials involved. CCS can guarantee negative emissions in other sectors, thereby offsetting emissions from, for example, agriculture or industry.

iii. **In the long term, CO_2 will have to be captured from the air**

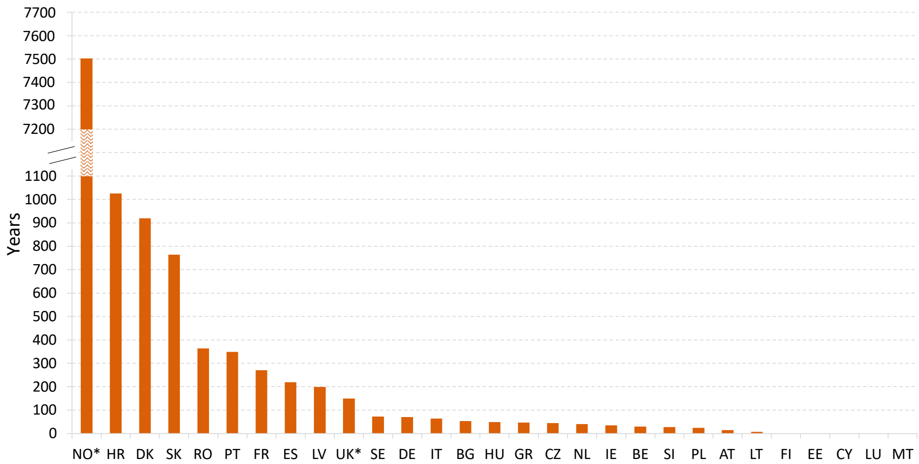
Finally, it is crucial that the world's net CO_2 emissions become negative in the long term. Otherwise, the Paris Agreement's 1.5-degree target cannot be achieved, which we describe in detail above and illustrate in figure 2. Negative emissions can basically be achieved by CO_2 capture from the air (Direct Air Capture, DAC) or from capture facilities at biomass power plants (using the BECCS technique). Alternatively, natural carbon sequestration can be achieved via vegetation and forests.

4. Major differences in European countries' own CO_2 storage facilities

Significant differences in storage capacity among EU countries

There are significant differences across European countries in terms of being able to store CO_2 underground. Some countries, including Denmark and Norway, have a lot of space, while other countries like Germany, Poland and Finland have less space or none at all. This is represented by the pattern in figure 3, which shows how many years a country can store its CO_2 emissions for (at current levels) in their own underground reservoirs.

Figure 3 Number of years of CO_2 emissions from point sources, which a country can store underground in its own reservoirs (years)



Note: The bars in the graph show the ratio of a country's total CO_2 emissions from point sources to its own storage capacity. Emissions are estimated for 2019, while storage capacity is based on the latest total inventory from 2005. In the case of Austria, Cyprus, Finland, Ireland, Malta, Portugal and Sweden, the data has not come from GEUS, but was collected from other third parties (see note to Table B.1).
* indicates a non-EU member state

Source: GEUS and own calculations.

Some countries have a lot of space, others none at all

As can be seen from figure 3, Norway has the largest storage capacity, with enough space to store its own point emissions for almost 7,500 years. Denmark also has surplus capacity and can, according to the calculation, store its own point emissions for more than 900 years. The figure is calculated as the number of times, the 19 million tonnes of CO_2, which was discharged from Danish point sources in 2019, can be stored in Danish soil, where in 2005 there was space for almost 17,500 million tonnes of CO_2. Most countries have far less storage space than, for example, Denmark, and many have almost no space. Countries like Finland and Estonia come right at the bottom, where the soil is assessed as not being suitable at all for storing CO_2.[5] In the countries with little or no space, they therefore have to find options for storing emissions in other countries.

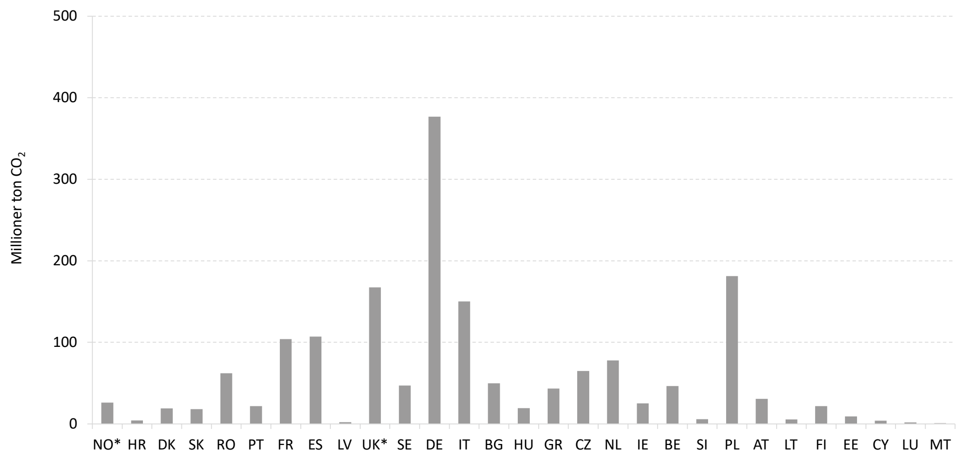
Countries with large storage needs often have little or no space

Germany is, at the same time, the country in Europe with the largest CO_2 storage requirement. This is illustrated in figure 4, which presents the European countries' total point source emissions. Germany emitted in 2019 almost 400 million tonnes of CO_2, while Poland emitted barely half that amount. If the figures presented in figure 4 are compared with the inventory of storage capacity in figure 3, it is evident that many countries which have little or no storage capacity often have a considerable potential storage requirement. Poland in particular is a salient example of this. Many countries discharge less CO_2 but will still have a significant storage requirement which they cannot fulfil themselves.[6]

[5] Shogenova et al. (2011).

[6] Note that not all point source emissions can be captured and stored underground; more details are provided on this point later in this document.

Figure 4 Point source emissions in European countries (million tonnes of CO_2)



Note: Emissions from point sources are calculated for 2019. For details, see Appendix Table b.1.
* indicates a non-EU member state

Source: GEUS.

Countries also differ in terms of legislation and policy framework

There are big differences between countries, but many countries have nevertheless a certain amount of storage capacity, as can be seen from figure 3. In this regard, however, it should be borne in mind that, in addition to the geological framework, political conditions play perhaps an even more important role in each country's ability and willingness to store CO_2. One example is Germany, where the current legislation severely limits the total amount of CO_2 which can be stored, while not allowing storage in the onshore reservoirs, which make up the majority of German storage facilities.

Broad support for CO_2 storage in Denmark

Unlike in Germany, there is broad political support in Denmark for developing the CCS value chain. Just recently a set of framework conditions for CO_2 storage in Denmark have been drawn up, which will allow underground storage in Denmark from 2025 (KEFM, 2022). This also includes discussions concerning options for support funds for CO_2 capture and storage or use (the “CCUS fund”), about Denmark operating as a recipient country for other countries' stocks of CO_2, as well as about the option of state co-ownership of licences for CO_2 storage, which may help spread the risk of large investments, while ensuring that a share of the profits goes to the Danish State.

Germany and other large emitters can store CO_2 in Denmark and other countries

If a country like Germany needs to find space for its sizeable emissions, while still adhering to its desire to avoid storage underground in Germany, it will very probably be necessary for them to be able to transport CO_2 to another country for storage. One obvious solution to this is to utilise the underground capacity available in the North Sea, since the distance is short and there is sufficient space available to store all German point source emissions for the many years to come. If the storage capacity available in Denmark is compared with the total volume of Germany's point emissions measured at current levels, all Germany's point emissions can be stored for almost 50 years. In actual fact, German storage requirements could be met for many more years, as the annual emissions, in the wake of the green transition, will continuously decrease over time, while not all point emissions will eventually be able to be captured and used for storage purposes.

Need for an international CO_2 storage market

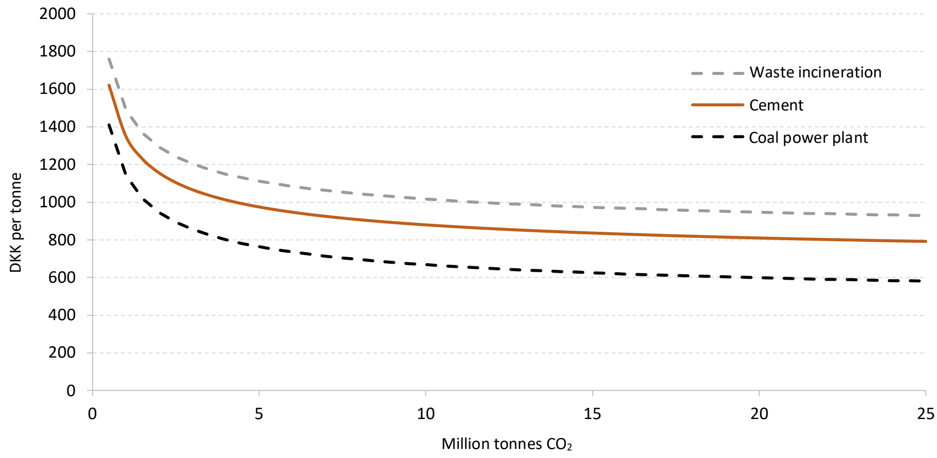
This is going on against the background of major international differences in the facilities available for storing CO_2. If we want to fulfil the requirement for CO_2 storage, countries cannot therefore stand on their own. Some countries will want to send CO_2 for storage, while other countries will prefer to act as recipient countries and sell their capacity. This requires international coordination in the form of a trading network, joint monitoring and establishing a common infrastructure for transporting CO_2. If a suitable level of international cooperation is achieved in this area so that the amount of CO_2 traded becomes sufficiently large, this will, at the same time, have a significant positive impact on the economic conditions underlying CCS, which we will go into in more detail in the next section.

5. CCS costs less as the market matures

CCS is expensive but becomes cheaper over time

CCS requires a large infrastructure. Capture plants at point sources must be assembled, a transportation infrastructure in the form of pipelines needs to be built, and storage facilities must be installed. This involves major investment, which must be arranged at the start of CCS implementation. This means that the tonnes of CO_2 initially stored are relatively expensive, but as the storage market grows, the average cost will gradually decrease. This pattern is illustrated in figure 5, which shows the trend in the average cost per tonne of CO_2 stored.

Figure 5 Costs of capture, transport and storage of CO_2 (DKK per tonne)



Note: The figure presents three different costs, which are dependent on where the CO_2 is captured. Only the capture cost varies between the curves, while transport via pipeline and offshore storage apply to all three calculations.
Source: Danish Energy Authority (2021c), Rubin et. al. (2015), Coulthurst (2021) and own calculations.

From the cement plant's chimney to storage under the North Sea

The calculations used in figure 5 are based on a number of assumptions about point sources, transport methods and storage locations, which have an impact on calculating the cost. To illustrate the costs involved with CCS, a scenario has been assumed where CO_2 is captured in a cement factory, after which the CO_2 is transported via pipeline to the North Sea, where it is stored in depleted oil deposits. Therefore, storage is assumed to take place in offshore reservoirs. In order to illustrate the sensitivity of the calculation in relation to other assumptions, the figure also shows cost curves where capture takes place either at coal-fired power stations or waste incineration plants.

Costs can be halved

The cost calculation in shows that CO_2 captured in a cement factory costs almost DKK 1,600 per tonne to capture, transport and store, if only 1 million tonnes are stored annually. If the annual volume is increased to, for example, 25 million tonnes, the cost will be just over DKK 800 per tonne of CO_2. The cost of storing one tonne of CO_2 can then be nearly halved, if the market expands sufficiently. Costs are most often reduced at the start as better use is gradually made of the pipelines, for instance. As the volume increases, the infrastructure will be used in the way it was intended, which is why cost reductions gradually decrease.

Denmark's emissions are not sufficient for CCS to be cheap enough

Our calculations show that a significant amount of CO_2 is required before the overall costs make CO_2 capture and storage worthwhile for individual emitters. Emitters can either choose to capture and store CO_2 or pay for CO_2 quotas. If CO_2 quotas are cheaper than capture and storage, emitters will choose to buy the quotas and continue with their emissions. Only when capture, transport and storage are cheaper than the quotas will it make sense for emitters to opt for this solution instead. Given that the quota rate in 2030 is expected to be between DKK 800 and 1,300, a significant volume of CO_2 will be required, amounting to the size of Denmark's annual capture volume of CO_2, which as expected will be roughly 5 million tonnes of CO_2 in 2030.[7] If this entire quantity is stored, the cost can be expected to be around DKK 1,000 per tonne.

International cooperation is needed

However, it is unlikely that the entire quantity of CO_2 captured will go into storage. CO_2 can also be used for ”Power-to-X”. The Danish government's Power-to-X strategy is devised so that a significant proportion of the CO_2 in Denmark will be used for this purpose (KEFM, 2021). If considerable quantities of CO_2 are reserved for use in Power-to-X, the volume of Danish CO_2 to be stored will decrease, which means that the cost per tonne of stored CO_2 may be fairly high. To guarantee potential storage capacity, which is large enough to be able to benefit from the economies of scale presented in figure 5, it is therefore absolutely crucial that international cooperation is established where the infrastructure and storage capacity are shared through a CO_2 market.

Startup costs are low for Denmark because oil infrastructure can be used

It should be noted that the above calculation is based on figures which take into account the use of already existing platforms, which have been currently used for oil recovery, but can now be used for storage. If storage facilities are going to be built from scratch, the costs will therefore be higher where small quantities are involved.

At small quantities costs will be lower using ships

In the example, we calculate transportation costs for pipelines, where the costs with small quantities is assumed to be higher than in the case of transport by ship. This is due to large initial costs for pipelines. In the case of small volumes, ships offer a flexible solution where the storage volume can be adjusted more quickly, but it would be difficult to achieve reductions in average costs for larger volumes on the scale recorded for the use of pipelines in .

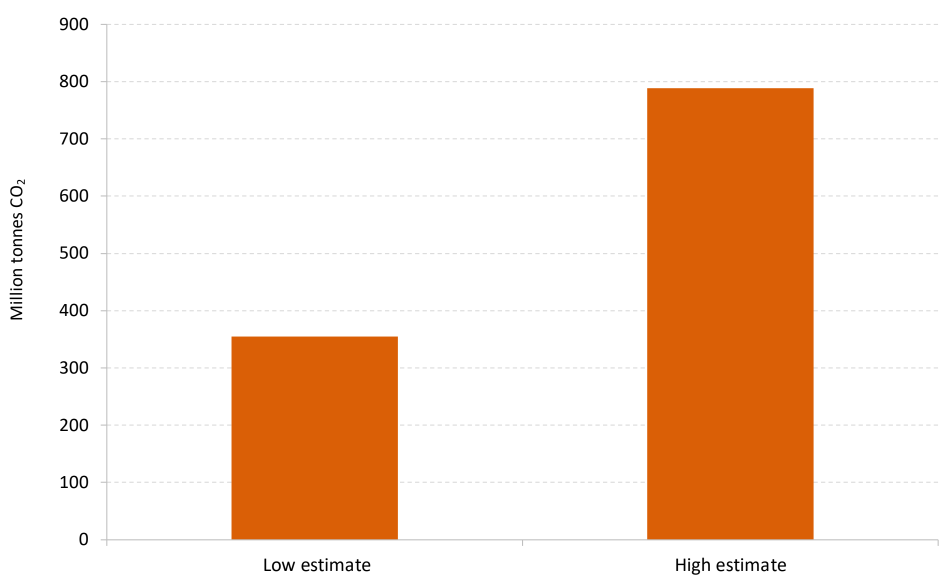
[7] Expected quota prices are calculated based on assumptions in Beck and Kruse-Andersen, 2020; Quemin and Trotignon, 2019; Perino and Willner, 2017 and on the current CO2 quota price of EUR 90 as at 31 January 2023, *see Appendix 5*.

6. The market potential for CCS in Europe

Between 360 and 790 million tonnes of CO_2 can be captured among EU Member States

The potential for trading CO_2 is considerable if Europe focuses on CCS. figure 6 shows an estimate for the total market potential in 2030 for the European countries which can be reasonably expected to trade with CO_2. The market potential is calculated here starting with a low and a high estimate of the quantity of CO_2 which can be expected to be captured for storage in each country. Based on the low estimate, approx. 360 million tonnes of CO_2 are expected to be stored in 2030, while the high estimate for the market potential gives a figure of roughly 790 million tonnes of CO_2.

Figure 6 The market potential for CCS in Europe in 2030 (million tonnes CO_2)



Note: The market potential is calculated as the sum of the capture potential for all countries in the EU. Norway and the UK are assumed to store their own emissions. We use the Danish Energy Agency's estimates for reductions in emissions from all point sources and the capture potential (they provide both a high and low estimate, based on technological assessments) from these point sources in Denmark for 2030. We assume that other countries have the same capture potential.

Source: OECD, Danish Energy Agency and own calculations.

Capture potential includes only those point sources where capture is possible

Unlike the total emissions referred to in previous sections of this document, we are looking in this case at the actual capture potential. Capture potential is less than the total emissions because it is not technically feasible or does not make economic sense to capture all point source emissions. In Denmark, the Danish Energy Agency has calculated a capture potential equivalent to between 26 and 57% of all point source emissions being captured for storage or use.[8] These figures may be lower if you wind down point sources more quickly than expected. It is important to mention on this point that we do not make any distinction between storage and use when calculating market potential.[9] If part of the capture potential is reserved for use, this reduces the need for storage. The future evolution in terms of

[8] Danish Energy Agency (2021a). Appendix 1 describes the details underlying the calculation.

[9] CO_2 capture and use (CCU) includes parts of the Power-to-X (PtX) technologies, enabling fuels to be produced using electrolysis and further processing.

requirements and willingness to pay for each part will determine how the volume for storage and use is distributed.

Tapping the great potential requires international cooperation

It should also be noted that CO_2 can be captured mainly from either biogenic or fossil fuel sources. Biogenic emissions come from burning biomass and biogas, while fossil emissions come from burning coal, gas and oil. In this document, we do not separate the two types, but acknowledge that CCS potential may depend on whether CCS is widely applied across fuel types in each country.

We do not differentiate between biogenic and fossil fuels

A market potential of the magnitude that we find in this case requires a comprehensive system for transporting and storing CO_2 to be established. Numerous storage facilities will need to be established in several countries to enable storage on this scale. At the same time, major investments and international cooperation are required to establish the infrastructure in the form of pipelines, collection points, ship connections and much more which is needed to transport CO_2.

7. The economic potential of CO_2 trading in Europe

New jobs to create the value chain for CCS

If a CO_2 market is created in Europe, it will have a significant economic impact on the countries involved. Primarily, a new CCS sector will emerge, which will require jobs involving the capture, transport and storage of CO_2. It will generate employment in sectors involving the assembly and maintenance of capture plants and laying pipelines, or create jobs for dockers and crew members on ships transporting CO_2. Lastly, storage will involve many of the same workplaces on platforms, as seen in the oil industry. Other sectors will also be affected, such as those supplying materials for the CCS industry and helping assemble the relevant installations. For example, the construction of pipelines will require building materials, which means that building material suppliers will also take on more staff. These jobs are included below when the volume of jobs created is assessed.

Major economic potential for Denmark

The economic potential has been calculated in figure 7 using different market shares – the greater the market share a country achieves, the greater the economic potential for each country. figure 7.a shows that if Denmark, for instance, achieves a share of 5% of the total European market, this will generate an economic value of between DKK 23 and 50 billion. It may also convert into between 4,000 and 9,000 jobs, which can be seen from figure 7.b. This is equivalent to Denmark receiving between 18 and 39 million tonnes of CO_2. Based on the CCS projects already announced in Denmark, where offshore projects alone in the North Sea will store 13 million tonnes of CO_2 from 2030, we consider that a market share of this size can be realistically achieved. If Denmark were to attain an even larger market share, the economic potential would increase accordingly. If a 10% market share is achieved, the economic value produced by the CCS sector will amount to between DKK 45 and 100 billion, which will in turn generate employment for between 8,000 and 17,000 people. This is equivalent to a volume of between 35 and 80 million tonnes of CO_2 being stored. It should be emphasised that no view has been taken in this case with regard to which market share is considered to be the most realistic for Denmark. Similarly, it is important to note that the figures only show how large the CCS sector can become and not the impact on the overall level of employment in Denmark.

Figure 7 Financial and employment potential of the CCS sector

Figure 7.a Economic value of the CCS sector (DKK billion)

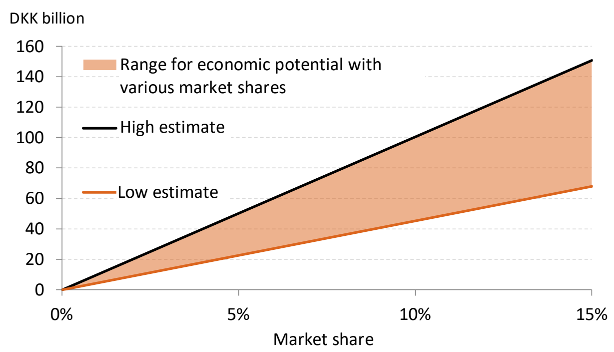
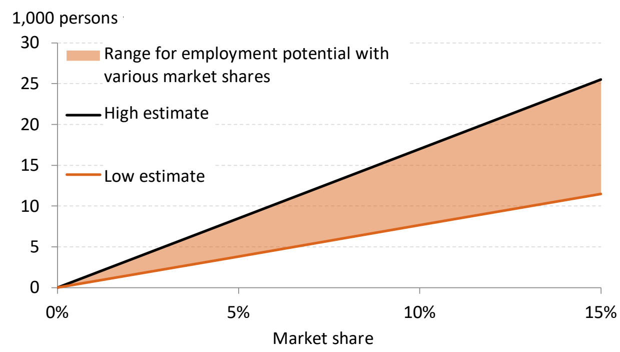


Figure 7.b Employment in the CCS sector (thousands of persons)



Note: The two curves in the figures illustrate the low and high market potential from Section 6, respectively, converted into economic value and employment. The shaded area illustrates therefore the possible potentials between the high and low range, which can be achieved for different market shares.
Source: DST and own calculations.

Denmark's overall employment is not expected to be affected

It is important to clarify that this does *not* mean an increase in employment for society as a whole. The jobs required by the sector are likely to be filled by people who come from other industries. The CO_2 market only creates an industry displacement. Therefore, there is unlikely to be a long-term rise in employment on the back of creating the CCS sector, since long-term employment is determined by the labour supply. However, it may boost prosperity if the CCS sector is more productive than the sectors where the labour originally came from. It is not possible to assess beforehand whether this will be the case. The economic value of the CCS sector will also not necessarily contribute to an increase in the total output of society. Whether this has an impact on the overall output depends on whether the CCS sector utilises the labour force and investments more efficiently than other sectors from which CCS must take them.

Calculations are based on conditions in the oil and gas industry

Moreover, the figures are fraught with considerable uncertainty. The calculations have been carried out based on the conditions in the oil and gas extraction industry as it is today. It is basically the most realistic industry to use, but it also typically has few jobs and a large infrastructure. Whether the same conditions will apply in the CCS sector is not a foregone conclusion. For example, in the short term, numerous jobs will be created in the CCS sector while it is being set up. But, in the longer term, there will be fewer jobs when the primary tasks involve maintenance and administration. It will be when the CCS sector's infrastructure has been set up that it will most resemble the oil and gas industry. Therefore, the calculations provided above for the number of jobs and economic value can be seen as a longer-term level.

The CCS sector can contribute up to 170,000 European jobs

The estimates in figure 7 are dependent on a calculation of the total CCS market potential, which is performed for the scenario where the relevant countries rely more or less completely on CCS. The potential can be converted into the total economic value and employment for the CCS sector. This can be done using the turnover, i.e. the quantity of CO_2 traded and the expected price. The total market potential is calculated for all EU countries, which will all share in the economic potential by either building capture plants and pipelines or providing storage facilities. Therefore, the total economic potential will be spread across all the countries involved. According to assessments, the CCS sector should be capable of achieving an economic value amounting to between DKK 450 and 1,000 billion. At the same time, the sector will have at European level the potential to create a total of between 75,000 and 170,000 jobs, distributed across sectors directly involved with CCS and in other sectors that are affected by the presence of the CCS sector.[10] The employment effect can vary over time, as the process of setting up the infrastructure etc. will require more jobs than when the infrastructure just needs to be maintained and managed.

The potential also depends on the price in the market

The expected turnover provides the basis for the calculations and depends on two factors, specifically the volume produced and the expected price that will apply on the market. The volume traded is determined by the market potential, which was reviewed in Section 6. With regard to the price, the calculations are based on an expected CO_2 quota price in 2030 of DKK 1,000. The CO_2 quota price is assessed as a relevant market price because a higher price will make CO_2 emitters buy CO_2 quotas rather than using the CCS market. At the same time, the provider of CO_2 storage will not go much below the quota price because they know that CO_2 emitters only have one alternative, i.e. quotas. This is, of course, fraught with uncertainty, as it will depend on the competitive conditions in the CO_2 market.

Denmark is competing with countries like Norway and UK for market share

The economic potential of CCS linked to, for example, Denmark depends on the market share that Denmark can achieve. The market share reflects partly how much CO_2 is sent to Denmark rather than to Norway and the UK, for instance, and partly how much of the process underpinning CCS that Denmark is responsible for. For example, Denmark will probably be mainly involved in storing CO_2, while capture and transport will account for a smaller part of the activity. Transport may also become a significant part of Denmark's contribution to CCS; however, this depends on the specific transport model chosen for the North Sea or onshore storage.

Early involvement may be beneficial

An important element for new technologies like CCS is that market benefits can be achieved by being among the first to store CO_2. The benefits can take the form of early development of expertise, attracting certain types of sought-after labour or early establishment of an expensive infrastructure. If this allows certain competitive advantages to be obtained, this may have a positive impact on market share.

8. Denmark's opportunities to be a major player are expected to increase

Denmark will have an ever-decreasing need for its storage capacity

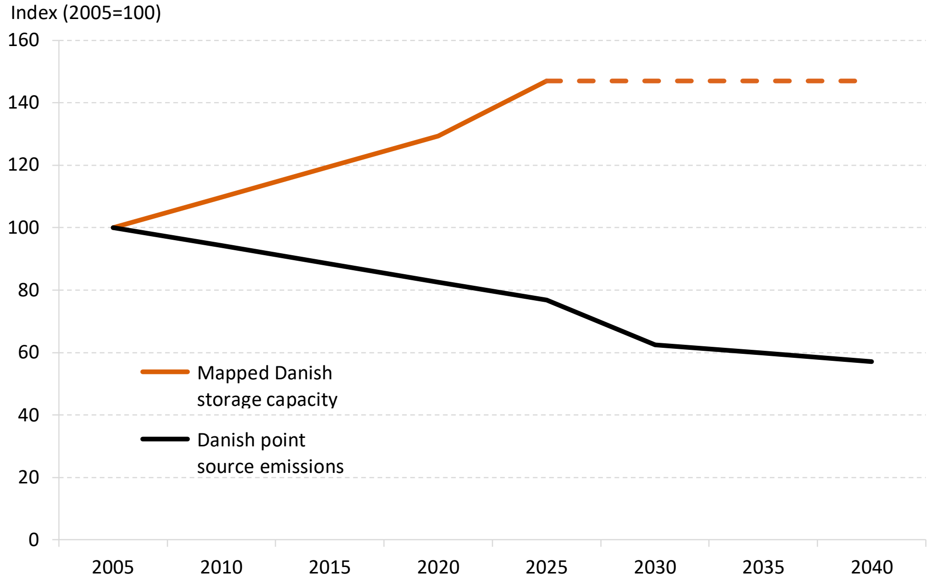
As described in the previous sections, Denmark already has good opportunities to become a key player in the international CO_2 market. These opportunities are expected to increase only as Danish emissions decrease as a result of the green transition. This means that Denmark will need storage capacity increasingly less, allowing it to be offered to other countries. This relationship is illustrated by the black curve in figure 8, which shows that the point source emissions in Denmark are expected to decrease by 43% between 2005 and 2040.

Storage capacity can only be expected to increase in the future

The orange curve in figure 8 shows that an ever-growing number of reservoirs have gradually been found under Danish soil in the last 15-20 years, which are ideal for storing CO2. From 2005 to 2022, the calculated storage capacity has increased from 17.5 billion to 24.6 billion tonnes of CO_2 – an increase of 47%. It is expected that more suitable reservoirs are found in the future, but the current level is retained in the figure (the dotted part of the curve) as there is uncertainty about the volume of any new findings.

[10] Note that the overall effects, including multipliers, are calculated based on conditions in Denmark. See Appendix 4.

Figure 8 Trend in Denmark's storage capacity and point source emissions, 2005-2040 (index, 2005=100)



Note: The dotted parts of the curve indicate an estimate of the future trend in terms of storage capacity in Danish CO_2 reservoirs, see

Source: GEUS and Danish Energy Agency.

9. References

Anthonsen, K. L., Christensen N. P. (2021). *EU Geological CO_2 storage summary.* Danmarks og Grønlands Geologiske Undersøgelse, Rapport 2021/32

Beck, U., Kruse-Andersen, P.K. (2020). ”Endogenizing the Cap in a Cap-and-Trade System: Assessing the Agreement on EU ETS Phase 4”. *Environmental and Resource Economics*, 77, 781-811

Butnar, I., Cronin, J., Pye, S. (2020). “Review of Carbon Capture Utilisation and Carbon Capture and Storage in future EU decarbonisation scenarios”. *Final Rep 57*

Carneiro, J.F., Boavida, D., Silva, R. (2011). ”First assessment of sources and sinks for carbon capture and geological storage in Portugal”. *International Journal of Greenhouse Gas Control*, 5(3), 538-548.

Coulthurst, A., Lugal, L., Rowland, K. (2021). *CCUS Development Pathway for the EfW Sector*

EA Energianalyse (2020). *Notat om CCS-teknologier*

Energistyrelsen (2021a). *Punktkilder til CO2 – potentialer for CCS og CCU*

Energistyrelsen (2021b). *CCS – Internationale erfaringer – Sikkerhed, natur og miljø*

Energistyrelsen (2021c). *Technology Data – Carbon Capture, Transport and Storage*

Energistyrelsen (2022a). *Klimastatus og – fremskrivning, 2022*

Energistyrelsen (2022b). *Klimastatus og -fremskrivning 2022 (KF22): CO_2-kvotepris*

FCT (2015). *CO2 Capture and Storage in Portugal - A Bridge to a Low Carbon Economy*

Federal Ministry for Sustainability and Tourism (2020). *Long-Term Strategy 2050 - Austria*

Gerrard, A.M. (2000). “Guide to capital cost estimating” (Fourth edition). *Institution of Chemical Engineers*

GEUS (2021). *Fangst, lagring og anvendelse af CO_2 (CCUS) - Tekniske barrierer for CCUS I Danmark.*

Hänsel, M. C., Drupp, M.A., Johansson, D.J.A. m.fl. (2020). ”Climate economics support for the UN climate targets”. *Nature Climate Change*, 10, 781-789

Hansson, J., Hackl, R., Taljegard, M. Brynolf, S., Grahn, M. (2017). “The Potential for Electrofuels Production in Sweden Utilizing Fossil and Biogenic CO2 Point Sources”. *Frontiers in Energy Research*, 5.

IEA Greenhouse Gas R&D Programme (2002). *Pipeline transmission of CO2 and energy.* Report Number PH4/6

IPCC (2022). *Climate Change 2022 Mitigation of Climate Change*

IEA (2020). *Energy Technology Perspectives 2020. Special Report on Carbon Capture Utilisation and Storage CCUS in clean energy transitions. CCUS in Clean Energy Transitions.*

KEFM (2022). *Rammevilkår for CO2-lagring i Danmark – Opfølgning på Danmarks CCS-strategi.* Klima, Energi og Forsyningsministeriet

KEFM (2021). *Regeringens strategi for Power-to-X.* Klima, Energi og Forsyningsministeriet

Klimarådet (2020). *Kendte veje og nye spor til 70 procents reduktion*

NORDICCS (2016). *Building Nordic Excellence in CCS*

OECD (2023). Greenhouse gas emissions. https://stats.oecd.org/Index.aspx?DataSetCode=AIR_GHG (data hentet 30. januar 2023)

Perino, G., Willner, M. (2017). "EU-ETS Phase IV: allowance prices, design choices and the market stability reserve". *Climate Policy*, 17(7), 936-946

Poulsen, N., Holloway, S., Neele, F., Smith, N.A., Kirk, K. (2014). *CO2StoP Final Report - Assessment of CO2 storage potential in Europe.* Danmarks og Grønlands Geologiske Undersøgelse Rapport 2014/56

Quemin, S., Trotignon R. (2021). "Emissions trading with rolling horizons". *Journal of Economics Dynamics and Control*, Vol. 125, 104099

Reiter, G., Lindorfer, J. (2015). "Evaluating CO_2 sources for power-to-gas applications – A case study for Austria". *Journal of CO_2 Utilization*, 10, 40-49.

Rogelj, J., Popp, A., Calvin, K.V. m.fl. (2018). "Scenarios towards limiting global mean temperature increase below 1.5°C". *Nature Climate Change*, 8, 325-332
Ea Energianalyse (2020)

Rubin, E.S., Davidson, J.E., Herzog, H.J. (2015). "The cost of CO_2 capture and storage". *International Journal of Greenhouse Gas Control*, Vol. 40, 378-400

SEAI (2008). *Assessment of the Potential for Geological Storage of Carbon Dioxide for the Island of Ireland*

Shogenova A., Shogenov, K., Vaher, R. m.fl. (2011). "CO_2 Geological Storage Capacity Analysis in Estonia and Neighboring Regions". *Energy Procedia* (4), 2785-2792.

Tsilingiridis, G., Sidiropoulos, C., Pentaliotis, A. m.fl. (2010). "A Spatially Allocated Emissions Inventory for Cyprus". *Global NEST Journal*, 12(1), 99-107.

Van der Spek, M., Fernandez, E.S., Eldrup, N.H., Skagestad, R. (2017). "Unravelling uncertainty and variability in early stage techno-economic assessments of carbon capture technologies". *International Journal of Greenhouse Gas Control*, Vol. 56, 221-236

ZEP (2011). *The Costs of CO2 Storage – Post-demonstration CCS in the EU*

Appendix 1: the need for CCS - more detailed explanation of the figure and underlying calculation.

The UN Climate Panel (IPCC) carries out ongoing projections for global CO_2 emissions with the aim of showing possible paths towards achieving the Paris Agreement's objective that the planet's temperature must only rise by 1.5 degrees in relation to the pre-industrialisation level. They do this by creating scenarios for global CO_2 emissions which will achieve the 1.5-degree target with a probability of more than 50%. Therefore, there are scenarios that only just achieve the target set with a 50% probability, while some scenarios achieve it with a greater probability. This could, for example, be because some scenarios have several measures incorporated, such as faster phasing out of fossil fuels and a faster conversion rate in agriculture. The shaded area in figure 2 represents a range for all these possible combinations of measures which reduce CO_2 emissions to an extent that meets the 1.5 degree target with a probability of more than 50%.

There are many pathways towards achieving the 1.5-degree target, each of which has different features and considerations. For example, some pathways take into account the fact that fossil fuels must be completely phased out. This scenario fails to take into account that some countries may find it difficult to make the transition quickly enough, which is why a ban on fossil fuels would entail major economic consequences for those countries. In other words, those countries would hardly enter into agreements containing such bans, which means that such a pathway is unlikely to be realistic. Other pathways weigh up both climate considerations and socio-economic conditions. For example, according to the IPCC's "Shifting Pathway", it is increasingly the population's consumption habits that ensure a reduction in CO_2 emissions. As another example, lower energy demand for households can be achieved through better housing or changes in transport habits. At the same time, many of the CO_2 reductions result from improved energy consumption in industry. This is therefore a process which makes extensive use of new technologies. This offers the advantage of not affecting economic activity and social conditions. However, it is important to stress that this is still one of the most ambitious pathways to take, but the same is true for all the pathways that lead to the Paris Agreement's objectives being achieved. However, the "Shifting Pathway" is considered to be an option that more countries will be able to look into themselves, as it does not affect their industry and jobs to the same extent as some of the other paths. In light of this, this scenario is the basis for the dotted curve in figure 2.

The IPCC's "Shifting Pathway" includes a contribution to CO_2 reductions from CCS. The IPCC calculates contributions from CCS at 2.5 Gt CO_2 in 2050 (Figure 3.15 in IPCC (2022), IMP-SP scenario). However, the IPCC does not calculate contributions from CCS for other years, so the assessment of the trend in the years 2030-2080 is based on other sources.

To find a technical calculation level for the contribution of CCS to reducing global CO_2 emissions, the calculation is based on (IPCC, 2022) and (IEA, 2020). Both indicate that CCS will only really become relevant from 2030 (IPCC, 2022, Figure 3.7 and IEA, 2020, Figure 2.2). Therefore, we assume a linear phasing-in of the CCS figure from the IPCC (2022) from 2030 to 2050, so that the volume of 2.5 Gt CO_2 is achieved by 2050. For the continuing trend, we look at the IEA (2020), which has made a projection for the contribution made by CCS to CO_2 reductions in the energy sector up to 2070. The relative trend from 2050 to 2070 from the IEA projection is then applied at the IPCC level for 2050, giving a profile towards 2070. Thereafter, the IEA's trend from 2050 to 2070 will be maintained in the years 2070-2080.

The methodology is clearly subject to considerable uncertainty, as is the case with all projections. In addition, the calculation is based on the fact that the energy sector's use of CCS can be extended to other sectors that have chosen to use CCS in their production by 2050.

Within the academic literature, the IPCC's main conclusions are corroborated by, among others, Hänsel et al. (2020) and Rogelj et al. (2018). In the former work, calculations are performed for the optimal pathway for CO_2 emissions aimed at achieving the 1.5-degree target. They find, across model assumptions, that negative emissions are key to achieving the target. In the second paper, the researchers have investigated, in line with the IPCC, different ways to keep the temperature rise to 1.5 degrees. They consider that CCS is not just a necessity, but that there is a need to upscale CCS technology in the coming years to a considerable degree. According to the authors, this technology will help remove from the atmosphere somewhere between 4 and 30 years of CO_2 emissions, equivalent to the level of emissions currently being discharged, in the years up to 2100. The wide range in the requirement for CO_2 reductions is due to the fact that there is uncertainty about which direction the energy sector is going in. For example, society can continue to use fossil fuels longer, but then use CCS to counter these. This will provide a higher CCS potential than if the energy sector and industry make the transition more quickly, but in all cases, CCS is needed to achieve the Paris Agreement targets.

Appendix 2: Technical calculation principles for costs with CCS

Our estimates for the overall cost of CCS are based on three subcomponents. The three subcomponents are capture, transport and storage. The following describes how each subcomponent is calculated and the methodological options used to calculate them.

The general method used to calculate costs is based on the calculation methods described in ZEP (2011). In this document, the costs are annualised and then discounted using an 8% discount rate. The service life of a project is assumed to be 30 years. Annualisation provides us with a number of uniform annual cash flows with the same current value as the initial cost in period 0.

Capture

The cost of capturing CO_2 varies considerably across different capture methods (IEA, 2020). For our calculations, we have selected three specific capture technologies: cement, power plants and waste incineration. In the calculation, the price per tonne of captured CO_2 is assumed not to depend on the volume of CO_2 captured. This is because carbon plants have to be installed across many point sources, assuming a constant level of technology (i.e. there are no learning effects in the short term).

Capturing accounts for the largest proportion of the overall costs. The capture cost from cement production amounts to DKK 606 per tonne (EA Energianalyse, 2020). However, there is considerable variation in the capture cost depending on where the capture takes place. This depends in particular on the amount of CO_2 emitted from the production concerned. For example, coal-fired power plants discharge considerable emissions, while waste incineration emits less. Therefore, the capture cost at coal power plants amounts to an average of DKK 400 per tonne (Rubin et al., 2015), while the cost is approx. DKK 750 per tonne for waste incineration (Energianalyse, 2020; Coulthurst et al., 2021).

When the different capture costs are illustrated in figure 5, the intention is to show the possible range of costs. For example, it is likely that coal-fired power plants will contribute significantly to CCS in the short term, while in the long term they will be phased out. In the long term, cement production and waste incineration will therefore be the primary sources of CO_2 capture compared to the current situation. The use of waste incineration is expected to increase at a European level in the future. In Eastern and Southern Europe, for example, waste is often landfilled, which is not sustainable over time. Therefore, there must be a transition towards incineration.

The actual capture costs depend not only on the point source but also on the capture plant itself. For example, capture installations can be retrofitted to old factories, which will be more expensive compared to capture installations at new factories, where they are installed from the outset. The plant's rate of utilisation will also be a key factor in the cost. For example, capture installations in factories with long burning times will be more efficient than if the factory only emits CO_2 for shorter periods. Consequently, cost estimates should be regarded as averages, which can vary significantly from one point source to another.

Transport

Transport costs are based on the Danish Energy Agency's cost catalogue for CO_2 capture, transport and storage (Danish Energy Agency, Energistyrelsen, 2021c). The main transport costs comprise costs for the construction of the pipeline and pumping stations, while costs for power and daily operation account for a small part of the overall costs. The pipelines involve a large initial investment, which entails high costs for small volumes of CO_2 transported. As the volume rises, the pipelines will be used to an increasing extent, thereby resulting in a reduction in costs.

The Danish Energy Agency has calculated the annual cost of transport for one, three and five million tonnes of CO_2. In order to estimate the costs in the case of very large volumes, this document has made a technical calculation assessment of the costs for 50 million tonnes. Overall, this gives four estimates for the cost of transport. A correlation is estimated between these points, which describes the trend in costs with varying volumes.

We calculate the transport cost using exponential estimation, as described in Gerrard (2000).

The main equation in the calculation method is:

$$C = C_{ref}\left(\frac{Q}{Q_{ref}}\right)^n$$

where C is the unknown cost of a capital good (e.g. the cost of pipelines) with the production capacity Q. The production capacity in the case of pipelines is how much CO_2 needs to be passed through them. C is not known beforehand for all levels of Q and must therefore be estimated. This is done on the basis of a known cost for pipelines C_{ref} for a certain production capacity Q_{ref}. It is a reference point which allows the cost to be identified in the case of other production capacities. n is a scaling exponent, which controls how the cost develops when scaling production capacity. In order to use this method, we need to know C_{ref} and Q_{ref} respectively and make an assumption about n..

C_{ref} can be found by first calculating the capital cost for constructing a pipeline with an annual CO_2 transport of 2.5 million tonnes. The calculation is based on a pipeline which is 500 km long and has a maximum capacity of 300 tonnes of CO_2 per hour. In addition, there is a pumping station that must be able to maintain the pressure inside the pipe. The overall cost is converted into an annual cost using the method described above. In addition to the capital cost, there are also annual operational costs as well as power costs.

The calculation is performed for different flow levels. This is where we use exponential estimation to calculate the cost of the pipeline at different levels of production.

The following is an example calculating the price of a pipeline with an annual flow of 10 Mtpa:

$$Cost\ (10\ Mtpa) = 300\ million\ \times \left(\frac{10}{2{,}5}\right)^{0{,}6} = DKK\ 689\ million$$

The calculation assumes that energy costs and operational costs depend linearly on the flow in the system.

The method of exponential estimation is well established in the literature and used in several places. Apart from in Gerrard (2000), the method is also used in Van der Spek et al. (2017) and IEA Greenhouse Gas R&D Programme (2002). In terms of which scaling exponent to choose, a value of between 0.4-0.8 is usually used and typically a value of 0.6 (DEA, 2021c).

Storage

Just like transport costs, storage costs are based on the Danish Energy Agency's technology catalogue. In this instance, the costs are assumed to be for offshore storage, as the first CO_2 storage projects involving Denmark will be in the North Sea. Offshore storage is more expensive than onshore, as there are costs for platforms and ships. In addition, the cost of pipelines is near enough twice as high if they are to be laid under the sea.

The Danish Energy Agency (Energistyrelsen, 2021c) has calculated itself the costs for one, three and five million tonnes of CO_2. A technical calculation assessment is again carried out of what the cost would be for 50 million tonnes, along with an evaluation of the link between quantity and cost. It is storage costs in particular that there are affected by large scale effects. Storage alone costs almost DKK 700 per tonne if the annual storage volume of CO_2 is 0.5 million tonnes. For example, at 50 million tonnes, the costs will fall to DKK 78 per tonne. It is therefore crucial that the amount of CO_2 captured will be large enough to achieve this cost reduction.

When calculating the storage costs, we use four points for expenditure at different volumes, based on which we estimate a trendline between the points where a trend is chosen to be a power function. We use this trendline to calculate the costs for different intermediate volumes.

The first three points are the cost of storage at a level of one, three and five million tonnes per year. These costs are generally taken directly from the Danish Energy Agency (Energistyrelsen, 2021c). However, we have had to make a number of adjustments for platforms and wells. This has been done to smooth out the large capital investments required by a volume of more than five Mt. Without this technical calculation adjustment, the cost function would have been erratic and difficult to interpret.

Finally, we have performed a theoretical calculation for the cost of storing 50 million tonnes per year. This calculation has been performed using exponential estimation. The Danish Energy Agency has assumed that the storage infrastructure can be used for 30 years. Therefore, the amount captured is 1500 million tonnes over 30 years. The Danish Energy Agency performs a calculation for five million tonnes of CO_2 per year, i.e. 150 million tonnes of CO_2 captured over 30 years. Therefore, 150 million tonnes of CO_2 is the reference volume. This is linked to an overall reference cost of approx. DKK 12 billion. Since we want to find the cost for 50 million tonnes of CO_2 captured annually, this gives a total of 1500 tonnes of CO_2 over 30 years. Finally, a scaling factor of 0.6 is used, which is also assumed by the Energy Agency (2021c). As a result, the calculation gives a total cost over 30 years of DKK 47.5 billion:

$$\left(\frac{1500\ tonnes\ CO2}{1500\ tonnes\ CO2}\right)^{0{,}6} * DKK\ 12\ billion = DKK\ 47.5\ billion$$

Appendix 3: Calculating capture and market potential for CCS in Europe

The calculation of the market potential is described below based on the figures from table b.1. There are no aggregated, international figures available for the trend in emissions from point sources, or for the capture potential from these. We are therefore using figures available for Denmark (Danish Energy Agency, Energistyrelsen, 2021a), based on the assumption that the trend in the other countries in the analysis follows the expected trend in Denmark. The figures therefore represent an indicative estimate of the market potential, but are assessed representatively, as some countries can be expected to experience a higher or lower decrease in point sources or expected capture potential. But there is no hard knowledge indicating that it should differ significantly from the trend or expectation in Denmark.

To provide an up-to-date estimate, we will estimate the capture potential for 2030. This requires us to adjust existing inventories for actual and expected trends since the last comparable inventory, which dates from 2005. In order to find out the capture potential, we will use raw values for the annual emissions from point sources in 2005 from GEUS (Anthonsen et al., 2021) and project the value to 2019, assuming that each country's point source emissions over the period have been reduced by the same ratio as the country's overall CO_2 emissions (OECD, 2023). To find the expected emissions from point sources in 2030, we will use figures from the Danish Energy Agency (Energistyrelsen, 2021a), which estimates that, between 2019 and 2030, point source emissions in Denmark will have been reduced by 8%.

The capture potential is difficult to estimate, especially across countries, as it requires the capture potential to be mapped at each of the many thousands of point sources. In addition, different types of point sources are expected to be phased out, scaled down or exist to varying degrees across countries. For example, in industrial-intensive countries such as Germany, we can expect large reductions in emissions from point sources in industry over time, while on the other hand, we can expect an increase in other types of point sources that relate to, for example, waste incineration. Data is not available at this level, which is why we assume that the low and high estimates provided by the Danish Energy Agency for the capture potential from Danish point sources correspond to the capture potential in the other countries in the analysis (Danish Energy Agency, Energistyrelsen, 2021a). The high estimate of the capture potential as a share of emissions in 2030 is 57.1% while the low estimate is 25.7%.

Please note that according to GEUS, the figures for underground capacity may be subject to some uncertainty. The inventory is still considered as the best comparable basis for an overall inventory across countries.

Norway and the UK are not included in the calculation of the European market potential, as they are already far advanced with their own CCS projects, and are therefore not expected to export CO_2 to Denmark or other potential recipient countries.

Table b.1 Point source emissions, capture potential and overall CO_2 storage capacity in selected countries

	Annual CO_2 emissions from point sources in 2019	Expected annual CO_2 emissions from point sources in 2030	Capture potential, high estimate	Capture potential, low estimate	Calculated storage capacity
	Mt CO_2 per year				
Belgium	46	43	24	11	1.392
Bulgaria	50	46	26	12	2.665
Cyprus*	4	4	2	1	0
Denmark	19	18	10	5	17.482
Estonia	9	8	5	2	0
Finland*	22	20	11	5	0
France	104	96	55	25	28.144
Greece	43	40	23	10	2.006
Netherlands	78	72	41	18	3.130
Ireland*	25	23	13	6	872
Italy	150	138	79	36	9.604
Croatia	4	4	2	1	4.256
Latvia	2	2	1	0	404
Lithuania	5	5	3	1	37
Luxembourg	2	2	1	0	0
Malta*	1	1	0	0	0
Norway	26	24	14	6	194.845
Poland	181	167	95	43	4.286
Portugal*	22	20	11	5	7.560
Romania	62	57	33	15	22.600
Slovakia	18	17	10	4	13.842
Slovenia	6	5	3	1	159
Spain	107	99	56	25	23.439
Sweden*	47	43	25	11	3.400
Czech Republic	65	60	34	15	2.896
Germany	377	347	198	89	26.330
UK	167	154	88	40	24.922
Hungary	19	18	10	5	950
Austria*	31	28	16	7	455

Note: The annual CO_2 emissions from point sources in 2019 are calculated on the basis of the point source emissions in 2005, which are multiplied by the ratio of the total CO_2 emissions in 2005 and 2019 in each country. The expected CO_2 emissions in 2030 are calculated as the emissions from point sources in 2019 adjusted for an expected reduction by 2030 of 8% (the figure is based on the Danish Energy Agency's expectation for Denmark, which is used for all countries). The high and low estimates for capture potential are based on data from the Danish Energy Agency (Energistyrelsen, 2021a). Data for countries marked with (*) do not come from GEUS, but from the following sources: Hansson et al. (2017), NORDICCS (2016), Tsilingiridis et al. (2009), Shogenova et al. (2011), Reiter & Lindorfer (2015), Federal Ministry for Sustainability and Tourism (2020), SEAI (2008), Anthonsen & Christensen (2021), Carneiro et al. (2011) and FCT (2015).

Source: GEUS, OECD, Danish Energy Agency and own calculations.

Appendix 4: Calculation of the overall economic potential

The economic potential is calculated on the basis of input/output (IO) tables. IO tables are part of the national accounts and keep track of which inputs an industry uses, including labour, capital and services from other industries. At the same time, the tables also show how much of an industry's production, i.e. output, goes to other industries. Therefore, the tables present a picture of the economy's interaction across industries and of how much the industries depend on each other.

When an industry increases its production, it can be seen via the IO tables how many more inputs that industry needs to attain the new production level. For example, it needs to hire more employees and needs more services and capital from other industries. This has a direct impact on employment and production. There is also an additional impact from the fact that when the industry expands its production and increases demand in other industries, the other industries must also increase their production and hire more people, producing an additional impact on employment and production. This is known as the "multiplier effect".

A third effect can be identified in some cases, but is omitted here. The majority of employees were initially unemployed and have received a higher income being employed. This means that they increase their consumption and then production rises further. This effect has been removed in the calculations because constant structural employment is assumed in the case of demand-driven economic changes. The CCS market is demanding more employees, while supply is unchanged. Therefore, the calculations assume that those employed in the CCS market are already in work, which means that they potentially have a limited financial gain (if any at all) from being employed in the CCS sector.

Statistics Denmark calculates multipliers for production and employment respectively using the IO tables. The multipliers for the "oil and gas extraction" industry are used as the basis, and this is the "simple multiplier" used. This is precisely the multiplier that takes into account the additional demand for production from other sectors, which is generated by the additional turnover in the oil and gas industry, but omits the impact of increased employment on private consumption. The multiplier for production is calculated at 1.28, i.e. if production increases by DKK 1 million in the oil and gas extraction industry, it will increase production by DKK 1.28 million across industries. Similarly, the multiplier for employment is calculated at 0.216, i.e. when production increases by DKK 1 million, it will increase employment by 0.216 employees. Therefore, an extra DKK 5 million must be generated before employment in the sector increases by one. The multiplier is also available for full-time employment, where it is calculated at 0.18. However, it does not reflect the number of posts, which is why employment is calculated in terms of a headcount. The multipliers have been calculated for 2019.

Appendix 5: Calculation of the CO_2 quota price

Projections for the CO_2 quota price can be made on the basis of a conventional Hottelling approach. This kind of projection is based on the price of an asset evolving at the prevailing real interest rate. The perception is that an owner of a CO_2 quota has the option to sell now, or wait until next year. If the owner sells today, the money can be put into investments that give a return corresponding to the real interest rate. The owner retains the quota if the expected price increase is greater than the return on selling and investing on the current day. If the quota is retained, it is withdrawn from the market and the supply of quotas decreases. It increases the price today, which reduces the expected price increase (since the price has not changed next year). When the expected price increase matches exactly the return on selling the quota and investing today, the owner will be equally satisfied with either selling or keeping the quota. The market is therefore in equilibrium.

The articles by Beck and Kruse-Andersen (2020), Quemin and Trotignon (2019) and Perino and Willner (2017) assume different real interest rates of 5%, 3% and 10% respectively, which are assumed to be accurate for the projection for the quota price. Based on a quota price measured on 31 January 2023 at DKK 675, the price in 2030 according to the three real interest rates will amount to DKK 950, DKK 830 and DKK 1,315 respectively.[11] Since DKK 1,000 is a fairly average price in this range, this is the calculation assumption underlying the market potential.

[11] Source (consulted 31 January 2023): https://www.eex.com/en/market-data/environmentals/spot#%7B%22snippetpicker%22%3A%2252%22%7D