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Appendix 2: Emission avoidance analysis of reference projects

1. Introduction

With the agreement on “a strengthened framework for CCS in Denmark”[1] of 20 September 2023, a majority of the Danish Parliament decided to establish the “CCS Fund”. The total budget of the CCS Fund is approximately 28.3 billion DKK (2024-prices) and is scheduled for deployment from 2029 to 2044.

The purpose of the CCS Fund is to achieve CO_2 emission reductions and/or negative emissions by permanently and geologically storing fossil and/or biogenic or atmospheric CO_2.

The CCS Fund constitutes State aid for climate and environmental protection and is prepared following the Guidelines on State aid for climate, environmental protection and energy 2022 (“CEEAG”). This appendix accounts for the aid scheme’s compatibility with provision 115 in the CEEAG section 4.1.4 *Avoidance of undue negative effects on competition and trade and balancing* by estimating the subsidy per ton of CO_2 emissions avoided for each reference project.

The structure of the appendix is as follows: Section 2 outlines the applied methodology, and in section 3, the main assumptions for the avoided emissions analysis are accounted for alongside the assumed standard technologies and modalities used in the reference projects’ CCS activities.

In section 4, the total greenhouse gas (“GHG”) emissions avoided for each reference project are calculated and presented.

Section 5 summarizes and sets the net emission in relation to the subsidy level, i.e. the levelized cost of capture (LCoC), for the different technologies

The LCoC, which constitutes the subsidy required for each reference project, is estimated in Appendix 1 *Techno-economic assessment of CCS technologies.*

The calculations in this appendix are based on the offshore based CO_2 storage scenario described in Appendix 1 as this is the CCS value chain configuration with the highest project activity emissions.

2. Methodology

Based on the reference made in provision 115 in the CEEAG, the Innovation Fund’s methodological principles for the net calculation of GHG emission

[1] In Danish: “Aftale om styrkede rammevilkår for CCS i Danmark”. The agreement can be accessed here (in Danish)

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avoidance will constitute the basis for the method and general assumptions used in this appendix.[2]

In accordance with the EU Innovation Fund's methodology, the absolute GHG emission avoidance represents the difference, over a defined period, between all the emissions that would occur in a baseline scenario[3] in the absence of the reference projects and all the emissions from the project activity included in the system boundary delineation. Based on the Innovation Fund's methodology, emission sources included in the baseline scenario and reference project boundaries are:

Emission sources		**Value to be applied**	**Data unit**
Baseline scenario for: • CO_2 capture at waste incineration plants (Bas_{wip}) • CO_2 capture from biomass-fired CHP plants (BAS_{bchp}) • CO_2 capture at biogas upgrading plants (Bas_{bup}) • Direct Air Capture (Bas_{dac})	CO_2 that would be released or available in the atmosphere in the absence of the project activity.	Dependent on reference project	
Project: capture activities ($Proj_{capture}$)	CO_2 capture activities. Includes emissions from fuel and input material use for compression and liquefaction of the CO_2, as well as fugitive and venting pre-injection.	Dependent on reference project	
Project: transport, road ($Proj_{transport,road}$)	Transport of CO_2 by road. Includes emissions from combustion at tank trucks.	0.108	$kgCO_2e$ / tonne.km
Project: transport, maritime ($Proj_{transport,maritime}$)	Transport of CO_2 by maritime modal. Includes emissions from combustion at sea tanker.	0.030	$kgCO_2e$ / tonne.km
Project: injection ($Proj_{injection}$)	Injection at the geological storage site. Includes	0.005	$kgCO_2e$/tonne CO_2 stored

[2] Innovation Fund Annex C: Methodology for GHG Emission Avoidance Calculation. Published on 7 February 2022.

[3] The Innovation Fund methodology document uses the term "reference scenario". However, in order to avoid conflation with the term "reference project", the DEA has chosen to use the term "baseline scenario" instead.

	pipeline transportation from the intermediate CO_2 storage hub to the storage injection site. In addition to activities related to storage operation, the value to be applied also includes emissions related to construction and decommissioning of the storage facilities.		

Sources: The DEA's adaptation of table 3.1 & table 3.2 found in Innovation Fund Appendix C: Methodology for GHG Emission Avoidance Calculation, including standard emission factors for maritime and road transport modalities. Data pertaining to injection are based on information obtained from Northern Lights.

The equations to be applied[4] for the calculation of absolute GHG emission avoidance for each reference projects will be:

CO_2 capture at waste incineration plants

$$\Delta GHG_{abs,ccs,y} = Bas_{wwwwp,y} - (Proj_{capture,y} + Proj_{transport,road,y} + Proj_{transport,maritime,y} + Proj_{injection})$$

CO_2 capture from biomass-fired CHP plants

$$\Delta GHG_{abs,ccs,y} = Bas_{bchp,y} - (Proj_{capture,y} + Proj_{transport,road,y} + Proj_{transport,maritime,y} + Proj_{injection})$$

CO_2 capture at biogas upgrading plants

$$\Delta GHG_{abs,ccs,y} = Bas_{bup,y} - (Proj_{capture,y} + Proj_{transport,road,y} + Proj_{transport,maritime,y} + Proj_{injection})$$

CO_2 capture at cement plants

$$\Delta GHG_{abs,ccs,y} = Bas_{cement,y} - (Proj_{capture,y} + Proj_{transport,road,y} + Proj_{transport,maritime,y} + Proj_{injection})$$

CO_2 capture at refinery

[4] This equation is the DEA's adaption of the equation found in section 3.3 in Innovation Fund Annex C: *Methodology for GHG Emission Avoidance Calculation.*

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$$\Delta GHG_{abs,ccs,y} = Bas_{refinery,y} - (Proj_{capture,y} + Proj_{transport,road,y} + Proj_{transport,maritime,y} + Proj_{injection})$$

Where:

$\Delta GHG_{abs,CCS,y}$ = Absolute GHG emissions avoided by the CCS project in tonnes CO_2e in a given year.

The values to be applied, including for the baseline scenario, are deemed constant throughout the fifteen years duration of the reference projects[5]. Therefore, the absolute GHG emissions avoided by the reference projects will be calculated for a given year only.

3. Assumptions

The estimation of the absolute GHG emission avoidance is based on a range of assumptions presented in the following.

According to the Innovation Fund's methodology, the emissions attributed to electricity consumed for injection and/or capture shall be zero.

The GHG emissions resulting from the storage activities are based on data obtained from the Northern Lights project. The GHG emissions from the use of electricity are based on an analysis[6] for the two power pricing zones in Denmark, DK1 and DK2. The expectation is that the average emission intensity of the two electricity zones in Denmark will be around or below 20 grams of CO_2 per kWh from 2029 and forwards. For the reference plants, an average value of 20 grams/kWh will be used for the entirety of the period. The electricity consumption included in the analysis is in the transport step. The electricity is used to liquefy the CO_2 to make it ready for transport and offshore injection.

In line with the assumptions made in appendix 3 *Techno-economic assessment of CCS technologies,* it is assumed that the capture amount of the reference project is sector dependent. The captured CO_2 will be transported from the reference projects' point sources to an intermediate storage/harbor terminal via truck or pipeline. From the intermediate storage, the CO_2 will be shipped via tankers to the offshore Danish storage site, where the CO_2 is injected for permanent storage.

Project emissions due to CO_2 capture will be based on CO_2 capture plants utilizing amine scrubbing technology. For power producing sectors, waste incineration and biomass fired power plants, no additional emissions from the capture is expected.

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[5] This is in accordance with the Innovation Funds methodology. See e.g. section 3.5 in Innovation Fund Annex C*: Methodology for GHG Emission Avoidance Calculation.*

[6] https://ens.dk/sites/ens.dk/files/Analyser/el-emissionsfaktorer_ens.pdf

Instead the energy use for capture reduces the power production, without affecting the emissions compared to the baseline scenario.

For biogas plants no emissions from the capture process is assumed. This is because the capture plant is running anyway to upgrade the raw biogas.

For the cement plant the energy needed for the amine based capture plant is assumed to come from a natural gas boiler. This energy use therefore has significant emissions.

Project emissions due to transportation will be quantified based on distance travelled. This methodology assumes the transportation of the CO_2 will be done through heavy goods vehicles via road or pipelines. The assumed standard technologies and modalities used in the reference projects' CCS activities are elaborated in section 3.

In total, the CO_2 carbon capture chain of the reference projects consists of several processes:

- Capture
- Transport to harbor terminal
- Transport from harbor terminal to offshore permanent storage
- Geological storage

These processes constitute the system boundary for the calculation of greenhouse gas emissions reductions, i.e. the set of processes to be assessed.[7]

The estimations are based on standard assumptions for each technology for carbon capture, transport and storage, in line with the assumptions made in appendix *3 Techno-economic assessment of CCS technologies*.

CO_2 transport

The estimations of the avoided emissions are based on the assumption that CO_2 is transported onshore by road or pipeline depending on sector and size of the emissions source. An average distance of 100 kilometers is assumed in the emission avoidance calculation for CO_2 transport by road (including round trip). CO_2 transport by pipeline is assumed to be 50 kilometers. It is assumed that no emissions come from the transport of CO_2 in pipelines.

Offshore CO2 storage

It is assumed that the CO_2 will be transported to an offshore storage. Here the CO_2 is injected into a reservoir for permanent storage. The CO_2 is transported offshore in a ship, and the round trip distance is assumed to be 500 km.

[7] See point 2.2.3 in Innovation Fund Annex C: Methodology for GHG Emission Avoidance Calculation.

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4. Estimation of reference projects' net emissions

CO_2 capture at waste incineration plants

For waste incineration, the baseline scenario for the reference project is calculated by dividing the captured amount of CO_2 (i.e. 500,000 tonnes) with the assumed capture rate of 90%. This yields a baseline scenario with yearly emissions of 555,555.6 tonnes of CO_2.

$\Delta GHG_{abs,ccs}$	$Bas_{wip,y}$	$Proj_{capture,y}$	$Proj_{Liquefaction}$	$Proj_{transport,\text{-}road,y}$	$Proj_{transport,\text{-}maritime,y}$	$Proj_{injection}$
483000	555,556	55555,6	1600	5400	7500	2,500

The absolute emissions avoided by CO_2 capture at a waste incineration plant is 488400 tonnes of CO_2 per year. This equates to a relative net emission reduction effect of 96,6%.

CO_2 capture at biomass fired CHP

For biomass-fired CHP, the baseline scenario for the reference project is calculated by dividing the captured amount of CO_2 (i.e. 500,000 tonnes) with the assumed capture rate of 90%. This yields a baseline scenario with yearly emissions of 555,555.6 tonnes of CO_2.

$\Delta GHG_{abs,ccs}$	$Bas_{wip,y}$	$Proj_{capture,y}$	$Proj_{Liquefaction}$	$Proj_{transport,\text{-}road,y}$	$Proj_{transport,\text{-}maritime,y}$	$Proj_{injection}$
483000	555,556	55555,6	1600	5400	7500	2,500

The absolute emissions avoided by CO_2 capture at a biomass-fired CHP is 488400 tonnes of CO_2 per year. This equates to a relative net emission reduction effect of 96,6%. The relative net emission reduction is the same for the two scenarios involving biomass CHP, as the only change is the amount of full load hours.

CO_2 capture at biogas upgrading plant

It is assumed that the entire amount of CO_2 can be captured from the biogas upgrading facilities. Therefore, the emissions of the baseline scenario are 50000 tonnes of CO_2.

The majority of the required equipment for CO_2 capture is already installed at biogas upgrading plants, as it is necessary to separate CO_2 from biogas to achieve a gas quality that can be used in the gas system.

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$\Delta GHG_{abs,ccs}$	$Bas_{bup,y}$	$Proj_{capture,y}$	$Proj_{liquefaction,y}$	$Proj_{transport,-road,y}$	$Proj_{transport,-maritime,y}$	$Proj_{injection}$
47760	50000	0	160	1080	750	250

The absolute emissions avoided by CO_2 capture at a biogas upgrading plant is 47760 tonnes of CO_2 per year. This equates to a relative net emission reduction effect of 96,6%.

CO_2 capture at Cement plants

For cement plants, the baseline scenario for the reference project is calculated by dividing the captured amount of CO_2 (i.e. 900,000 tonnes) with the assumed capture rate of 90%. This yields a baseline scenario with yearly emissions of 1.000.000 tonnes of CO_2.

The energy need of the capture at a cement plant is assumed to be covered by a natural gas boiler. The energy use of the natural gas boiler has significant CO_2 emissions and therefore the capture part for a cement plant has high emissions.

$\Delta GHG_{abs,ccs}$	$Bas_{bup,y}$	$Proj_{capture,y}$	$Proj_{liquefaction,y}$	$Proj_{transport,-road,y}$	$Proj_{transport,-maritime,y}$	$Proj_{injection}$
729.950	1.000.000	249169,9	2880	0	13500	4500

The absolute emissions avoided by CO_2 capture at a cement plant is 729.950 tonnes of CO_2 per year. This equates to a relative net emission reduction effect of 81,1%.

CO_2 capture at Refinery

For a refinery, the baseline scenario for the reference project is calculated by dividing the captured amount of CO_2 (i.e. 250,000 tonnes) with the assumed capture rate of 90%. This yields a baseline scenario with yearly emissions of 277,778 tonnes of CO_2.

The energy need of the capture at a refinery is assumed to be covered by a natural gas boiler. The energy use of the natural gas boiler has significant CO_2 emissions and therefore the capture part for a cement plant has high emissions.

$\Delta GHG_{abs,ccs}$	$Bas_{bup,y}$	$Proj_{capture,y}$	$Proj_{liquefaction,y}$	$Proj_{transport,-road,y}$	$Proj_{transport,-maritime,y}$	$Proj_{injection}$
200.063	277.778	69214	800	2700	3750	1250

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The absolute emissions avoided by CO_2 capture at a refinery is 200.063 tonnes of CO_2 per year. This equates to a relative net emission reduction effect of 80,0%.

5. Summary and subsidy per tonnes of emissions avoided

The subsidy per tonnes of emissions avoided is calculated using the levelized cost of capture from Appendix *1 Techno-economic assessment of CCS technologies*:

Table 1. Estimated levelized cost of avoidance, DKK. pr. ton captured CO2

Sector/industry	Total costs	Total savings	Levelized cost of capture	Net emissions reduction	Levelized cost of avoidance
Waste to energy	1440	-300	1060	96,6%	1100
Biogas	920		920	96,6%	950
Biomass (Scenario 1)	1500		1520	96,6%	1570
Biomass (Scenario 2)	1780		1780	96,6%	1840
Cement	1040	-660	380	81,0%	470
Refinery	1600	-1220	400	80,0%	500