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Carbon Dioxide Capture and Storage (CCS) in Germany

A technology assessment in consideration of environmental, economic and social aspects

Supervison

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Summary

Increasing population and increasing demand for goods and services have resulted in a steadily increasing energy demand in the past decades. The development is expected to continue and even intensify in the electricity sector by technologies such as heat pumps and cooling systems. For the mitigation of climate change by the reduction of greenhouse gas (GHG) emissions many technologies are available and also necessary. Carbon Dioxide Capture and Storage (CCS) is a technology mainly discussed in the context of coal power generation and therefore suitable for the application in Germany having a large share of fossil power generation and also potential carbon dioxide (CO_2) storage sites.

The aim of this study is the assessment of the potential implementation of CCS in Germany in the context of sustainable development. The analysis therefore encompasses an environmenatal assessment based on life cycle analysis (LCA) as well as an economic assessment based on the calculation of electricity generation costs, external costs and CO_2 capture and avoidance costs. The study is completed by the discussion of the legal and social aspects of the implementation of CCS in Germany.

The LCA was carried out based on three lignite-fueled power plants equipped with post-combustion CO_2 capture, oxyfuel combustion and pre-combustion CO_2 capture respectively and the subsequent pipeline transport to geological storage sites for an expected commissioning in 2025. An assessment of Germany's power generation sector and geological situation lead to the restriction on pipeline transport and onshore geological storage in saline aquifers and depleted gas fields. Lignite power plants were found to be suited for the implementation of CCS due to the high CO_2 intensity of lignite, the large share of lignite power production in Germany and the existence of specific CCS projects at such power plants.

The reduction of the life cycle GHG emissions due to CCS is large (81-91%) depending on the CO_2 capture technology, the transport distance and the storage depth and mainly arises from the reduction of CO_2 emissions from the operation of the power plant which is directly targeted by CCS. But these reductions are achieved at the expense of additional other environmental impacts on human health, ecosystems and natural resources e.g. due to the increased emission of air pollutants, the increased fossil fuel consumption and the increased land use due to the CCS infrastructure resulting in life cycle environmental impacts reductions due to CCS of only 14-50%. Lignite-fueled power plants based on oxyfuel combustion technology offer the largest reduction in life cycle GHG emissions (89-91%) and life cycle environmental impacts (43-50%) for the electricity production as well as for the CO_2 avoidance. Compared to the life cycle burdens of most renewable energies and nuclear power, lignite-fueled CCS power plants nevertheless cannot compete. The LCA results are very sensitive to the assumptions on power plant efficiencies, CO_2 capture rate, the emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM) and the solvents required for CO_2 capture. These parameters are very project-specific and have to be definded carefully in order to gain valuable information on the overall environmental impact of the project and CCS technology in general.

The cost assessment was carried out based on an average generation cost calculation which was supplemented by the calculation of CO_2 capture and avoidance costs as well as the estimation of external costs of electricity production. In contrast to the LCA, the cost analysis is not project-

specific but mainly based on literature. It not only includes lignite but also encompasses hard coal and natural gas as fuels.

The implementation of CCS leads to a significant increase in the electricity generation costs for all CO_2 capture technologies and for all fuels due to the additional investments in CO_2 capture units, pipelines and storage sites as well as due to the increased fuel use induced by the power plant's efficiency loss because of CCS implementation. The increase for the expected commissioning in 2025 is found to be from 4.4 to 7.0-7.6 €cts_{2005}/kWh_{el} for lignite, from 2.4-2.8 to 5.2-5.3 €cts_{2005}/kWh_{el} for hard coal and from 5.6 to 8.3 €cts_{2005}/kWh_{el} for natural gas, whereby the cost ranges arise from the different CO_2 capture technologies. The sensitivity of the average generation costs to the fossil fuel price development is high, especially for hard coal and natural gas. Lignite-fueled CCS power plants instead profit from a low and stable fuel price and are therefore expected to offer base load electricity in the cost range of run-of-river, geothermal and offshore wind power generation.

The CO_2 avoidance costs are lowest for lignite-fueled oxyfuel combustion power plants (41 €/t CO_2 in 2025) favored by the high CO_2 emission intensity of lignite, the relatively low efficiency of lignite power plants, the high CO_2 capture rate of the oxyfuel combustion technology and the expected low price of lignite. Besides the availability of the technology and the competitiveness with other mitigation technologies given by the CO_2 avoidance costs, the CO_2 emission price is crucial for the cost-effective implementation of CCS too. The CO_2 emission price has to increase significantly from today's roughly 15 €/t CO_2 to at least 40 and 47 €/t CO_2 for lignite and hard coal CCS power plants respectively for their economic competitiveness to the corresponding conventional power plants in 2025. Natural gas CCS power plants even require 109 €/t CO_2 for being competitive in 2025 what seems to be illusory from today's point of view.

The internalization of external costs from power generation due to GHG emissions, air pollution, radioactive emissions and land use changes is expected to increase the competitiveness of CCS power plants. The external costs are nevertheless largely dependent on the valuation of the potential damages from GHG emissions.

Besides the economic and environmental factors, societal factors contribute to any successful technology implementation too. Germany is obliged to implement the CCS directive of the European Union in German law this year, what is supposed to create the legal certainty for the investments in future CCS projects. The legislation must be complemented by congruent political decisions on GHG emission targets, subsidizations of renewable energies and further important issues such as the nuclear phase-out. The yet uninformed public must be involved via an open and honest discussion including goals, risks and burdens of the CCS implementation in Germany.

A thorough assessment of all aspects of the German energy system including environmental, economic and social aspects is required to lead the development into a more sustainable direction.