Comparison of carbon capture and storage with renewable energy technologies regarding structural, economical, and ecological aspects

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Abstract

To use coal in the future in a more environmentally-friendly way, the option of "carbon capture and storage" (CCS) is discussed. A first system-analytic view in the form of a life cycle analysis and a cost assessment combined with a systematic comparison with renewable energies regarding future conditions in the power plant market (2020) was done. The results show that assuming a realistic CO_2 emissions' separation rate of 88% at the power plant results in a greenhouse gas reduction by only 65% to 79%. Therefore it does not seem justified to talk about "CO_2-free" fossil power plants as proposed by industry and policy. Furthermore, renewables will be competitive with electricity from CCS power plants from the beginning of CCS technology in 2020 (wind power) or from 2030 - 2040 (mix of all renewables), depending on the price increase of the fossil fuels.

Keywords: carbon capture, LCA, renewables, cost, electricity

Introduction

Long-term energy system scenarios usually show a trend towards reducing coal as a source of energy for climate protection reasons. However, coal is the most abundant fossil fuel and many countries have considerable amounts within their borders. The question therefore arises how coal can be used in the future in a more environmentally-friendly way. In this regard the option of "carbon capture and storage" (CCS) is discussed. At present there are still many unanswered questions regarding safe, socially compatible as well as ecologically and economically sound applications of CCS. A system-analytic view in the form of a life cycle analysis (ecological balance) and a cost assessment combined with a systematic comparison with other measures of CO_2 reduction options (renewable energies, energy efficiency measures) are missing. These questions are examined in an interdisciplinary project conducted by four research institutes in Germany, financed by the German Federal Ministry for the Environment [1].

Methodology

The study is undertaken in three steps.

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(1) Review of the state-of-the-art: First the state of research activities of capture, transport, and storage of CO_2 are represented, regarding costs, energy balance as well as temporal and spatial availability. Thereafter the positions of relevant players from economics, science, politics, and society in Germany are queried and discussed.

(2) Ecological-economic systems analysis: The possible potentials of CCS in Germany are examined in different scenarios, starting from the present energy system and regarding the comprehensive power station renewal in the coming years as well as the availability from CCS over time. Afterwards, these scenarios are assessed for their ecological impacts and economic aspects.

The ecological assessment of technologies and scenarios is done via a life cycle analysis (LCA) according to ISO 14.040ff [2]. The energy and materials used for production, operation, and dismantling of the considered technologies are modelled in a material flow network. As time frame the year 2020 was chosen when the first commercially operated power plant including CCS is expected to start operation. The cost development is based on experience curves and corresponding learning rates, determined for different technologies in the literature ([3], [4]).

(3) Comparison with other CO_2 reduction options: The primary question is, to what extent CCS can become a bridge or a barrier for the transition into a future renewable energy system. A secondary question is how the energy economic potential of CCS can be assessed over time.

Fossil fired power plants including CCS

The fossil fired power plants (each of 700 MW_{el} and 7,000 h/a in operation) are modelled to be located in the Ruhrgebiet (western part of Germany), one of the biggest industrial areas in Germany with a long tradition of coal based electricity production. The CO_2 captured at the power plants is compressed and assumed to be transported via a 300 km pipeline to North Germany where a lot of empty natural gas fields exist. In view of failing data the sequestration step could not be modelled so far and had to be estimated. No leakage rate of the storage is assumed. A future situation (2020) is regarded by using higher efficiencies than in today's power plants. Table 1 shows the power plants modelled in the LCA, considering the three capturing methods usually discussed (pre-combustion, post-combustion, and combustion with oxygen).

Table 1 Fossil fired power plants modelled in the LCA

Power Plant	**Fuel**	**Capturing method**	**Decrease of Efficiency**	**Capture rate**	**CO_2 to be stored**
			%	**%**	**Mt / a**
Pulverized Coal	Hard coal	Chemical (MEA) [a)]	49 > 40	88	3,57
Pulverized Coal	Lignite	Chemical (MEA) [a)]	46 > 34	88	5,11
Natural Gas Combined Cycle (NGCC)	Natural Gas	Chemical (MEA) [a)]	60 > 51	88	1,7
Integrated Gasification Combined Cycle (IGCC)	Hard coal	Physical (Rectisol)	50 > 42	88	3,4
Pulverized Coal (PC)	Hard coal	Oxyfuel	49 > 38	99.5	4,25
[a)] MEA = monoethanolamine					

Renewable power plants

Wind offshore power plants in the North Sea and solar thermal power plants in North Africa were chosen to generate renewable electricity. They are expected to run economically in the year 2020 and to provide Europe with electricity and firm power capacity [5]. The electricity is assumed to be transported via high voltage direct current (HVDC) lines to the Ruhrgebiet to consider the same location as chosen for the fossil fired power plants.

Results

From the view of a systems-analysis some first results can be shown.

(A) In a first approach the common fossil power plants described in table 1 were compared with each other (each of it without and with CCS) and with electricity from wind and solar thermal power plants. From the LCA results calculated regarding a situation in 2020 the greenhouse gases (weighted in CO_2-equivalents) are shown in figure 1. A separation rate of 88% of CO_2 (Oxyfuel: 99.5%) and a leakage rate of 0% are used.

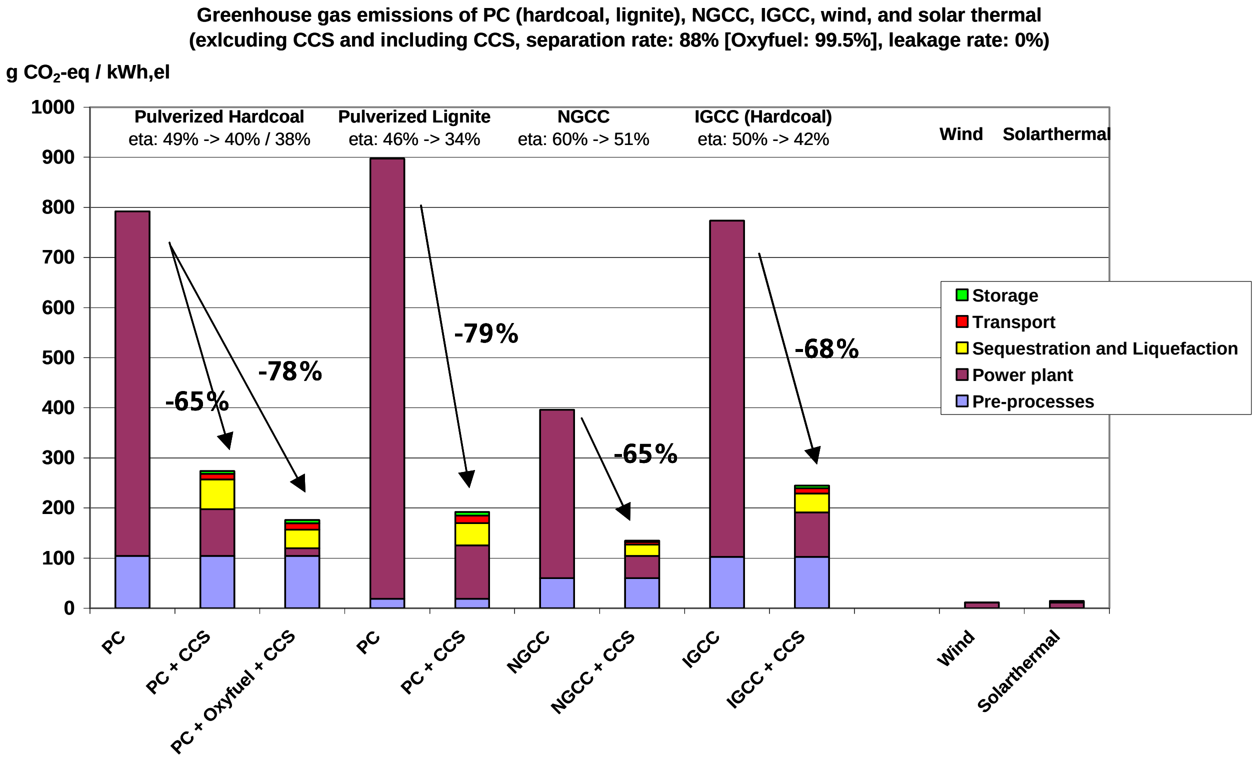

Figure 1 Comparison of greenhouse gas emissions for pulverized coal power plants (PC), an NGCC, an IGCC (each of them excluding CCS and including CCS with a separation rate of 88%), and renewables (wind offshore, solar thermal electricity).

The carbon dioxides emitted directly at the power stations are reduced by 88%. In contrast, the life cycle assessment shows substantially lower reductions of greenhouse gases in total (minus 65% to 79%). This is due to the fact that capture, transport, and storage require a lot of energy and that CO_2 and methane are emitted also in the pre-processes (mining industry, transport). Renewable electricity from wind power plants and solar thermal power plants causes only 2% of the fossil fired power plant's greenhouse gas emissions.

It is notable that the cleanest power plant *without* CCS (natural gas combined cycle) causes only 45% more emissions (400 g CO_2-equ./kWh) than the worst power plant *with* CCS (pulverized hard coal with 274 g CO_2-equ./kWh).

(B) Figure 2 shows a first comparison of the cost development of three fossil fuel based power stations (NGCC, PC until 2020, and IGCC from 2020) with plants based on renewable energies for a time period until 2050. For the price increase of the fossil fuels a lower and an upper variant were selected. For the price decrease of the renewable energies different learning rates were applied [3].

According to the upper variant of medium prices of fossil fuels a mix of renewable energies can become more economical than “CO_2-free” gas-fired power stations starting from 2025. “CO_2-free” coal-fired power stations moves later to 2030. With smaller price increases the intersection moves later to 2035-2040. Electricity from wind power alone will become cost competitive around 2020, which is regarded as a possible kick-off for industrial scale renewable power stations.

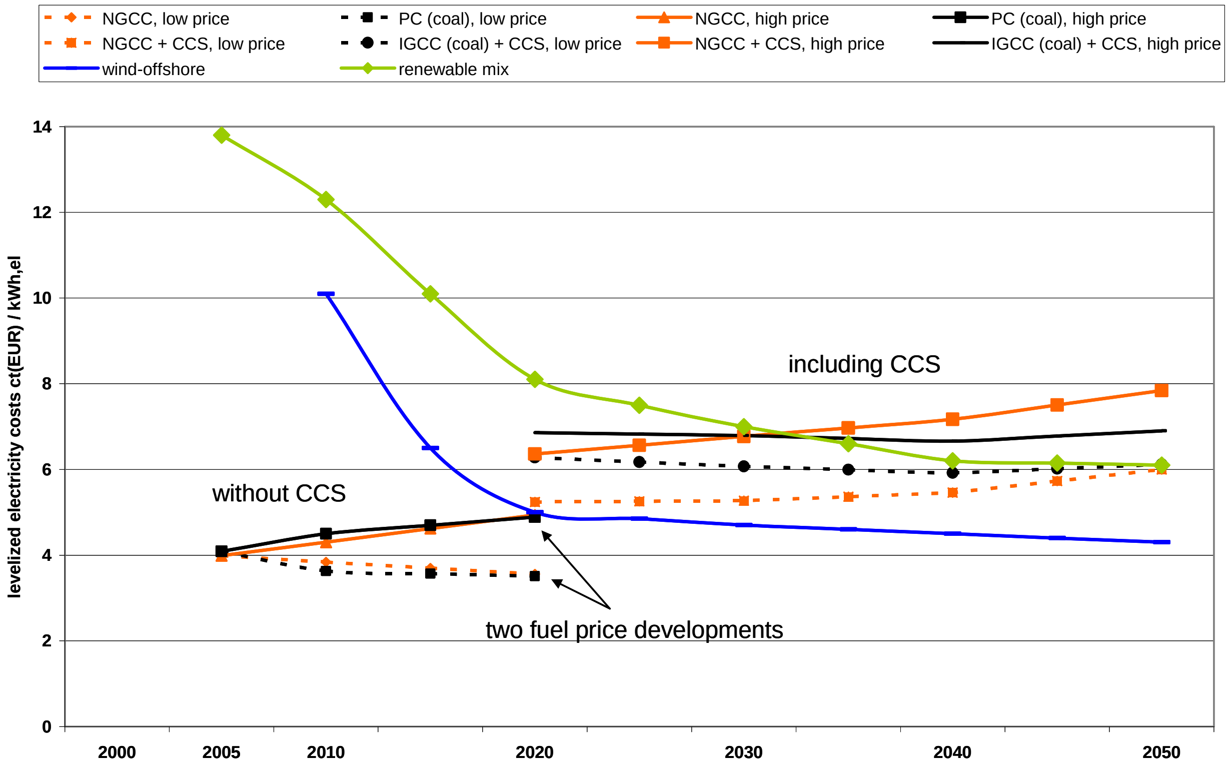

Figure 2. Electricity production costs - comparison between “CO_2-free” power plants and renewable power plants between 2020 and 2050 (each with low and high development of fossil fuel prices)

(C) The time when CCS technology is introduced into the market will have an impact on climate policy and energy economics. Substantial factors are the average running time of power stations as well as the availability of CCS technologies and the development of energy demand over time. Figure 3 shows that there is a substantial need to replace power stations in Germany in the coming two decades during which time CCS technologies will not be available on an industrial scale.

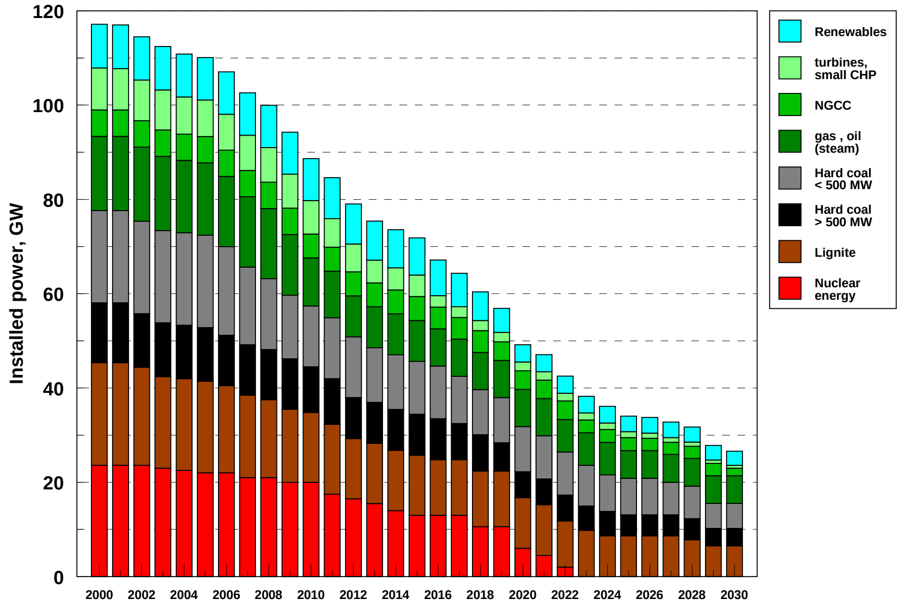

Figure 3. Development of presently installed power plant capacity in Germany (regarding a running time for fossil power plants of 40 years, for small CHP of 30 years, and for renewables of 20 to 50 years)

In March 2006 the German power utilities announced a first power plant renewal program. 32 big power plants (most of them fired by coal, some few fired by natural gas) with an installed power of 18 GW will be modernized in the next decade. This leads to a substantial structural determination of Germany's future electricity system. On the one hand the CO_2 emissions are reduced definitely by replacing old power plants with an efficiency of 36% to 38% by new plants with an efficiency of 46%. On the other hand these power plants cause CO_2 emissions of about 68 Mt/a which are determined over the next 40 years and prevent the government from establishing an effective climate protection regime. At time the share of these emissions in the electricity production sector is only 22%. In contrast, in a climate protection scenario as developed in [3] for the German government with the aim of reducing the CO_2 emissions by 80% in 2050, no more than these 68 Mt/a CO_2 emissions are allowed for the electricity sector in total (see figure 4)!

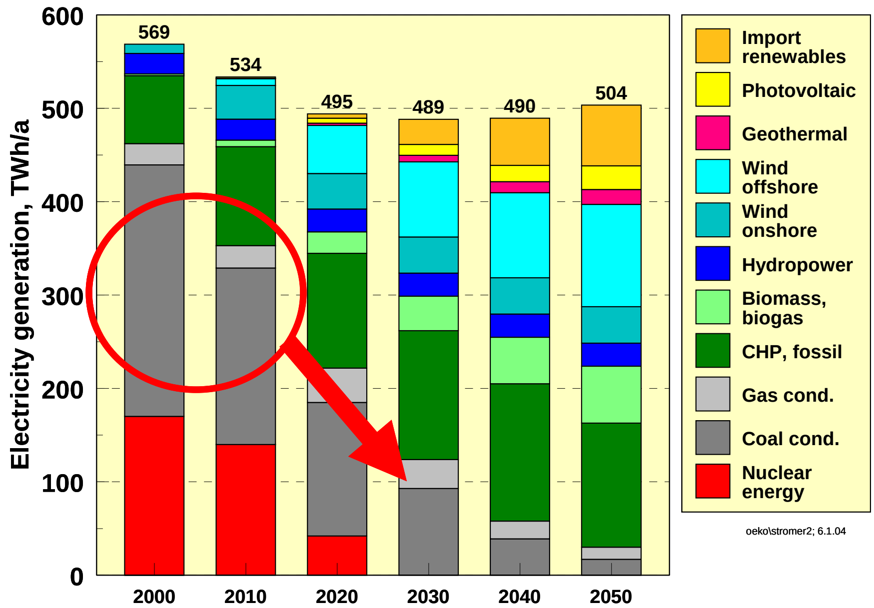

Figure 4. Necessary reduction of fossil fired power plants within the climate protection scenario for the German electricity production until 2050 (source: [3])

Against this background, the question of the retrofit possibility of CCS arises. To what extent can conditions be created, so that a later coupling of a CO_2 capture is technically possible and can be applied with the smallest auxiliary costs? To what extent these additional expenditures appears justified with today's incentives of climate protection, is to be examined in the next step of the project.

Conclusions

a) The current thinking only looks to the reduction of CO_2 from the operation of the power stations themselves. Additionally, we argue, the emissions of the pre-processes (e.g. coal production and transport to the power plant) as well as transport and storage of CO_2 have to be considered.

b) According to the Kyoto Protocol not only the CO_2 emissions, but also the greenhouse gases in total have to be reduced - in case of Germany by 21% until the year 2010. A CO_2 emissions' separation rate of 88% however only results in a reduction of greenhouse gases by around 65% - 78%. It is therefore not justified to talk about "CO_2-free" power plants.

c) From the calculations done so far, no direct cost advantage for technologies using fossil fuels is recognizable compared to advanced renewable energy technologies. Of course, future cost development following mass market effects and technology improvements (learning curves) is connected with uncertainties for both technologies.

d) From an energy economic perspective the development of the electricity generation and the resulting demand for new plants over time is the crucial factor determining the potential for CCS. Looking at Germany as a specific case study the main impact factors are the average operation time of the power plants, the availability of CCS technology for the power plant market, the nuclear energy policy, the resulting electricity demand, and the fossil fuel mix. Regarding an ambitious sustainable electricity scenario with an ecologically optimized extension of renewable energy utilization the option CCS comes too late for Germany.

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