DOES CARBON CAPTURE AND STORAGE LOCK PEOPLE INTO FOSSIL FUEL USE? - A CRADLE TO GRAVE ANALYSIS

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Overview

Existing studies on Carbon Capture and Storage (CCS) only focus on costs and carbon dioxide (CO_2) reduction that arise at the power plant and geological storage. These studies do not consider additional expenses and emissions at the input and output pathways. Therefore, I use a simulation model containing input data from different studies to estimate the life-cycle CO_2 abatement costs. I show that the true costs vary between 60 and 90 US-Dollars per ton of CO_2. Since it is not evident whether CCS is an efficient mitigation option, it is compared to a variety of renewable energy sources. On average, it is cheaper to avoid one ton of CO_2 by means of wind energy, but costs arising from the use of solar energy are higher. Consequently, in the context of climate change the possibility of using CCS contributes to an extension of the fossil fuel use period.

Methods

An economic efficiency analysis of a new technology needs to be based on a cradle-to-grave perspective to capture most side and rebound effects, which directly emerge in case of adopting the technology. To estimate the entire CO_2 abatement costs, I built a System Dynamics model, which contains input data from different existing studies. This model aims to capture the most important cost and emission parameters along the full chain of electricity generation and allows for a comparison between usual and CCS power plants. In this study, my model focuses on retrofitting existing power plants with CCS technology, but it can easily be adjusted to calculate different settings. Because it is very hard to compare simple emission and cost data, a key figure that combines both crucial dimensions is needed. According to the often-used figure "abatement costs", I introduce the so-called "cumulative abatement costs" (CAC). It is defined as the ratio of total additional full-chain costs caused by a power plant's CCS retrofit or by the integration of another environmentally friendly technology and the net cradle-to-grave emission savings. Furthermore, I perform a comparison between the CACs for CCS systems and renewable energy sources. It allows for making a statement on the often quoted "renaissance of coal", because low emission reduction costs linked with high emission savings may cause an extension of the fossil fuel – especially coal – use period, even against the backdrop of strong climate policies. To capture the effect of variation in input parameters and to verify the results I use Monte Carlo simulations.

Results

The results for the reference plant models without CCS are the following: The specific total emissions of the coal-fired plant are almost double the gas-fired plant's emissions, with 0.92 tCO_{2eq}/MWh and 0.5 tCO_{2eq}/MWh. The levelised costs of electricity (LCOE) sum up to 39 \$/MWh for coal and 65 \$/MWh for gas plants. Considering the CCS retrofit, the total specific emissions decline significantly in both cases. They decrease by more than 70% in the case of coal and by more than 60% in the case of gas. Although the absolute increase in LCOE is lower for gas plants (increase by 45 \$/MWh vs. 23 \$/MWh), the CACs are considerably higher, because of lower absolute reduction in CO_2 emissions. They mount up to approximately 76 \$/tCO_{2eq} for electricity production by means of gas, and 69 \$/tCO_{2eq} by means of coal. Since these results are calculated on basis of representative but deterministic input data, I perform additional sensitivity analyses regarding univariate deterministic as well as multivariate probabilistic variation. The results of the Monte Carlo Simulation can be seen in Figure 1 and 2. The results are the following: In case of retrofitted coal-fired plants about 70% of all Monte Carlo outcomes show that CACs range between 60 and 90 \$/tCO_{2eq}. Despite the CCS retrofit, about 75% of all runs show that LCOE are still less than 100 \$/MWh. In 45% of all outcomes, LCOE of the retrofitted coal-fired plants are even lower than 65\$/MWh, which equal the base scenario LCOE of the non-retrofitted gas-fired plants. In case of gas-fired plants the Monte Carlo Simulation reveals that almost 75% of all configurations come with CACs of less than 90 \$/tCO_{2eq}. The median LCOE is at 98 \$/MWh, but the 75% quintile is already at very high 137 \$/MWh. However, it is not clear whether CCS technology is an efficient carbon dioxide mitigation technology that contributes to an extension of the fossil fuel use period. To answer this question, I compute the CO_2 abatement costs for some renewable energy sources taking average emission and cost figures from different studies into account.

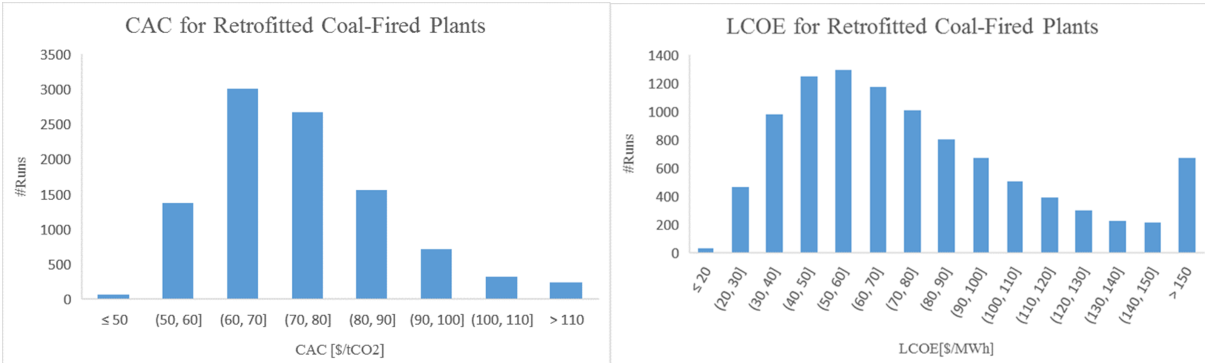

Figure 1: CAC and LCOE for retrofitted coal-fired plants

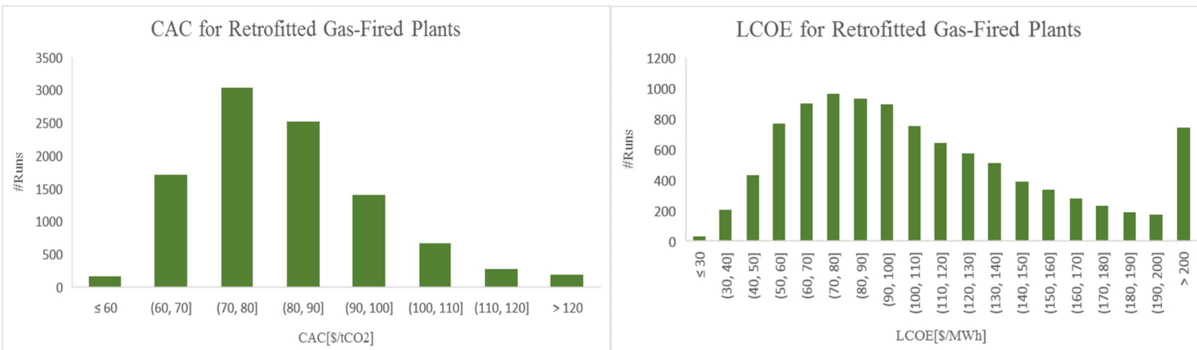

Figure 2: CAC and LCOE for retrofitted gas-fired plants

Photovoltaics come with average specific life cycle emissions of approximately 0.046 tCO_{2eq}/MWh and LCOE of 112 $/MWh. Thus, the costs of carbon dioxide avoided amount to more than 83 $/$tCO_{2eq}$ for a replacement of coal-fired plants and 103 $/$tCO_{2eq}$ for gas-fired plants. Assuming average emissions of 0.025 tCO_{2eq}/MWh and LCOE of 77 $/MWh in case of energy production by means of wind turbines, the abatement costs are lower than those of CCS technology (replacing coal: 42 $/$tCO_{2eq}$; replacing gas: 25 $/$tCO_{2eq}$). The electricity costs arising from the use of geothermal stations are similar to the energy production by means of the wind converter. Nevertheless, the abatement costs are higher in both cases (coal: approximately 50 $/$tCO_{2eq}$; gas: 36 $/$tCO_{2eq}$), because there are more greenhouse gas emissions during the plant´s life-cycle, that result in specific emissions of approximately 0.17 tCO_{2eq}/MWh. To estimate the avoidance costs of hydro power, I take average specific emissions and LCOE of 0.04 tCO_{2eq}/MWh and 55 $/MWh as reference value. Consequently, the CACs are low in the case of replacing coal-fired plants (less than 20 $/$tCO_{2eq}$) or even negative in case of replacing gas-fired plants, because hydropower stations are advantageous over gas-fired plants regarding as well the LCOE as the specific emissions.

Despite the comparatively low avoidance costs of wind and water energy stations, it has to be considered that the supply of renewable energy is extremely weather-dependent and, thus, inflexible and unreliable. Furthermore, if there are extreme weather conditions and a low electricity demand at the same time, there must be a possibility to store energy to use it at times of higher demand. Due to energy losses and rising costs for storage and energy-grid management, the true abatement costs may be higher, indeed.

Conclusions

Based on the results I draw the following two conclusions. First, it is cheaper to avoid one ton of greenhouse gas by retrofitting existing coal plants than by retrofitting exisiting gas plants. Second, adopting CCS is not per se more expensive than energy production by renewables, even if a gradle-to-grave perspective is considered. Thus, taking environmental and economical aspects, recent research progress in the field of capture technology and the necessity of grid stability into account, CCS technology has the potential to contribute substantially to the extension of the fossil fuel use period. In particular, the option of CCS may cause an ongoing "renaissance" of coal that establishes the importance of coal in the energy sector over the next decades, even against the backdrop of strong global warming policies, because the results suggest the following: It is most cost and carbon efficient to replace existing gas-fired plants by renewables, if possible, and to equip suitable existing coal-fired plants with CCS systems.