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Comparative Assessment of Levelized Costs in Carbon Abatement Strategies

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Abstract

In response to growing pressure for a low-carbon economy, it is vital to assess the financial and practical impacts of carbon abatement strategies. Industry studies highlight the need for accurate cost evaluations, innovative funding models, and technological advancements to achieve cost-effective emission reduction.

This study compares the levelized costs of carbon abatement methods to identify the most viable approaches for significant Scope 1 and Scope 2 reductions, including Carbon Reduction (fuel replacement, electrification, process efficiency, brownfield modifications, waste heat utilization), Utilization (CCU for e-Methanol, e-SAF) and Sequestration (CCS), offering insights to policymakers and industry stakeholders into the most efficient technological and financial pathways for achieving Scope 1 and 2 emission reductions, which can lead to more efficient allocation of resources and better implementation of carbon reduction initiatives.

Introduction

The urgent global imperative to transition toward a low-carbon economy has intensified the need for robust evaluation that balances the financial, technological, and operational challenges of carbon abatement strategies. As industries face mounting regulatory and societal pressures to mitigate greenhouse gas emissions, a systematic approach to assessing the cost-effectiveness of various emission reduction methods becomes essential.

Carbon Capture, Utilization, and Storage (CCUS) technologies have emerged as pivotal components in achieving significant reductions in Scope 1 and 2 emissions. These emissions, stemming directly from industrial activities and energy consumption, represent critical targets in the broader effort to decarbonize industrial sectors. Among CCUS strategies, carbon reduction (via fuel replacement, electrification, process efficiency improvements, and waste heat utilization), utilization (conversion of CO_2 into e-products such as e-Methanol and e-SAF), and sequestration (long-term geological storage of captured carbon) offer diverse pathways to reduce emissions. However, these approaches entail varying levels of capital and operational investments, technological readiness, and practical constraints, necessitating a comparative analysis to identify the most viable solutions for industries.

The analysis offers valuable insights into the thresholds at which each strategy becomes economically viable and technically competitive. This paper aims to set the stage for an in-depth discussion of methodologies, results, and the broader implications of CCUS technologies in enabling sustainable carbon management and achieving global climate objectives. By bridging the gap between technological innovation and financial practicality, the study offers actionable insights for policymakers, industry leaders, and stakeholders driving the transition to a sustainable future.

Methods

Based on data from case studies developed within the last 5 years, the technical and economic impact of the different CO_2 abatement strategies (Reduction, Utilization and Sequestration) has been assessed comparing the projected reduction of scope 1 and 2 emissions (vs the baseline), Levelized Cost of Carbon Abatement (LCOC), technical feasibility, and qualitative risks.

This study focuses on evaluating the Levelized Cost of Carbon Abatement (LCOC) for key abatement strategies, offering a nuanced understanding of their economic and technological feasibility. LCOC serves as a critical metric, summarizing the trade-offs between the financial burden and the environmental benefits of implementing specific carbon reduction measures. By analyzing data from recent industrial projects, including capital expenditure (CAPEX), operational expenditure (OPEX), and CO_2 savings, this work provides a holistic assessment of the performance of these strategies under different scenarios of emission reduction targets.

The baseline emissions were defined as the initial emissions recorded at the outset of each project, providing a standardized reference for evaluating the effectiveness of various carbon reduction, sequestration, and utilization strategies. The applicable emissions accounted towards the baseline and subsequent reduction calculation were defined considering the following: Scope 1 emissions correspond to the direct emissions from the facilities; Scope 2 emissions correspond to emissions from purchased or acquired electricity, steam, heating, and cooling.

Comprehensive data was collected, encompassing key parameters such as utilities consumption, capital expenditures (CAPEX), operational expenditures (OPEX), and CO_2 savings. Data processing involved estimating the percentage reduction in carbon emissions by comparing post-implementation emissions to the defined baseline. Additionally, the levelized cost of carbon (LCOC) was calculated for each strategy, integrating both CAPEX and OPEX to assess the financial feasibility of emissions reduction efforts. The final analysis involved a comparative assessment of the percentage reduction in carbon emissions against the LCOC for each of the three strategies. This approach allowed for a robust evaluation of both the technical effectiveness and cost-efficiency of each method, offering insights into the trade-offs between emissions reduction potential and economic performance.

Results

The following figure was developed including data-points from 15 carbon reduction strategies, 5 carbon capture and sequestration and 3 carbon capture and utilization studies and technologies developed within the last 5 years, as well as including the potential benefits from 45Q Tax Credit for Carbon Sequestration and Utilization from industry and power projects.

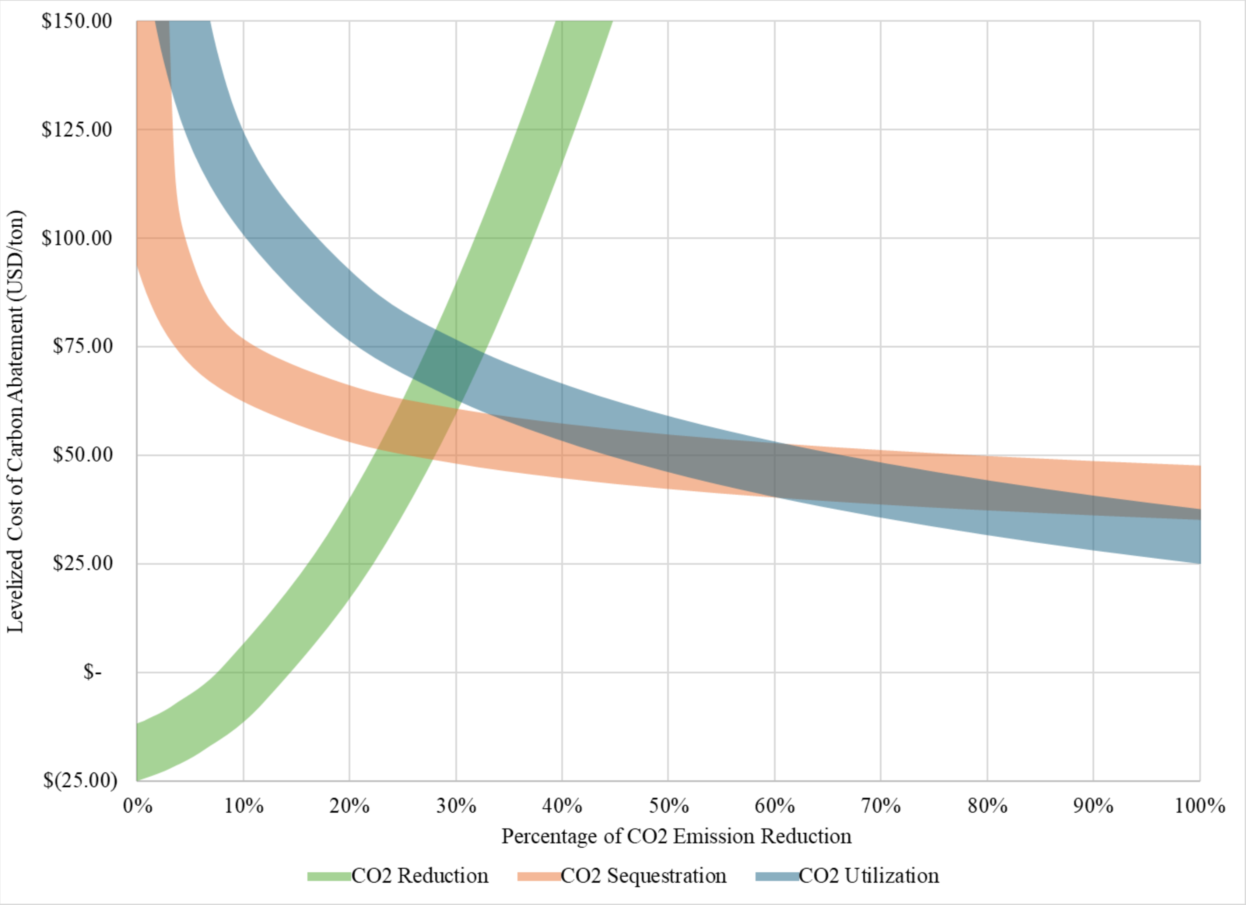

Figure 1. Comparison of Levelized Cost of Carbon Abatement Strategies

For targeted emissions reduction below 25-30%, CO_2 reduction is the most cost-effective approach with Levelized Cost of Carbon Abatement values below 50 USD/ton and achieving negative LCOC of around -25 USD/ton under 10% emissions reduction.

Emissions reduction above 25-30% require extensive modifications that increase the LCOC of the CO_2 reduction strategies above 50-60 USD/ton, making Carbon Capture and Sequestration feasible at this range.

At emissions reduction percentages above 60% Carbon Capture and Utilization yields the same LCOC as CCS both having a cost of abatement around 40-50 USD/ton.

Discussion

As observed in Figure 1, CO_2 reduction alternatives, such as fuel replacement, electrification, process efficiency improvements, and waste heat utilization can be considered as the "low-hanging fruit" of the Carbon Abatement strategies. It is possible for Owners and Developers to reduce the amount of Scope 1 and Scope 2 emissions up to a 10% of the baseline while maintaining or improving project and plant economic performance due to the easy implementation of the solutions and the immediate returns obtained after the CO_2 reduction alternatives are in place.

CO_2 reduction strategies that target Scope 1 and Scope 2 reduction above 10% require higher capital investment and operating costs, as well as higher intervention of existing operating systems. Therefore, the LCOC quickly escalates from a margin of profitability (negative LCOC) to more than 50 USD/ton for 25-30% reduction and more than 125 USD/ton for 35-40% reduction. At this point, the use of CCS alternatives becomes feasible, benefiting from the economy-of-scale and the 45Q Tax Credits that are applicable to these projects. However, the technical viability of building the infrastructure required for CCS (i.e. points of CO_2 capture, CO_2 processing and purification required, compression, transportation, availability of sequestration wells) and the permitting required should be carefully considered, as the Levelized Cost of Sequestered Carbon can be greatly impacted from changes in these variables.

Similarly, with emission reduction percentages above 60%, CCU becomes competitive with CCS due to the benefits from economy-of-scale and the additional revenue from the products obtained through the repurpose of the CO_2 captured (i.e. e-Methanol and e-SAF). Additionally, the implementation of circular economy strategies through CCU has demonstrated improvement of Owner's ESG metrics and good-will. However, stakeholders should consider the new infrastructure required, such as hydrogen generation facilities (for e-products), market engagement and new product logistics before moving on with these opportunities, since these are highly variable and could negatively impact the economic performance of the projects.

Finally, although relevant for improving the economic performance of the CCS and CCU projects evaluated, the 45Q Tax Credits alone are not sufficient to make these projects profitable (reaching negative LCOC) as evidenced by the 50 USD/ton gap presented in the Figure above. However, this gap could be closed by optimizing the economics of some of the multiple variables involved, such as CO_2 processing and purification, compression, transportation, sequestration wells, hydrogen generation (for e-products), logistics and market engagement. Therefore, it is recommended to concentrate the efforts and carry out further analysis to optimize these variables and close the feasibility gap of CCUS initiatives.

Conclusions

Through comparison of case studies covering different Scope 1 and Scope 2 Carbon Abatement methods, CO_2 reduction alternatives can be considered as the "low-hanging fruit" of the Carbon Abatement strategies, achieving reduction of Scope 1 and Scope 2 emissions and improving project economics at lower percentages of Carbon Abatement. However, scaling the CO_2 reduction alternatives to abate more than 30% of the baseline emissions significantly increases LCOC and negatively impacts project economics. At this point, CCS alternatives start to become competitive and are better suited to handle higher percentages of Carbon Abatement, followed closely by the CCU alternatives, which become more feasible above 60% CO_2 Emissions reduction.

On the other hand, 45Q Tax Credits alone are not sufficient to make Carbon Abatement projects feasible in the US, with an average gap of 50 USD/ton. However, multiple variables are contributing to increased costs of carbon abatement and therefore, industry-wide efforts should concentrate in optimizing these variables to close this gap and improve profitability of Carbon Abatement projects.

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