Evaluation of direct air capture technologies for climate change mitigation based on a multi-criteria decision-making approach and life cycle assessment

(5) Decarbonization: industrial sector

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Motivation and central research questions

The unabated release of greenhouse gases, especially carbon dioxide, due to anthropogenic interferences poses an impending challenge to drastic climate change. Carbon dioxide removal could play a pivotal role in achieving the Net-Zero target by 2050 and restricting the average global temperature rise beyond 1.5°C. Direct air capture (DAC)[1] is gaining recognition as an effective strategy to decarbonize otherwise difficult industries by removing CO_2 from the air and storing the captured CO_2. Another benefit is to utilize the CO_2 present in the ambient atmosphere or industrial exhausts to produce carbon-neutral synthetic fuels. In order to assess the potential of this technology, some fundamental questions about the practical applicability of DAC need to be addressed.

- What are the factors that contribute to the total cost of CO_2 removal?
- What improvements in DAC technologies could reduce these costs further?
- How can current efficiencies of operating DAC technologies be increased without compromising the environment?
- How can CO_2 capture be increased without dramatically increasing energy costs?
- How can DAC technologies be identified that are less carbon intensive?
- What is the long-term cost, energy, environmental and social projection for the lifetime of a DAC technology?

Methodology

Research in the domain of DAC is gaining momentum with an emphasis on cutting down CO_2 emissions and removing the already existing CO_2. DAC is still in a very nascent stage of technology readiness (TRL 4 - 6) and only a few industries are operating at a significant scale[2]. Of the several different technologies available, the most common are sorption-based technologies[3] already operating at pilot scale. Furthermore, newer approaches such as DAC with membrane separation are a subject of research. Given the significance of DAC technologies in achieving a carbon-neutral society, a carbon-intensive holistic evaluation of the above questions is essential.

A thorough literature review of the present types of DAC technologies focusing on the operating principle is crucial to understanding the scope of this process. Also, it is important to identify the limitations associated with each of the DAC technologies to have an idea about the overall status. Based on the careful evaluation of the input resources like energy, water, land, chemical sorbents, and mechanical operating systems the estimated cost projections of CO_2 removal by different DAC technologies could be predicted.

Mathematical tools such as Multi-criteria decision-making (MCDM)[4] based on Operations Research could effectively resolve the conflicting parameters like the cost of capturing CO_2/ cost of input energy and resources, sustainable performance, etc. Life cycle assessment (LCA)[5] of the most relevant DAC technologies would also be an important tool as it provides valuable insight not only to determine net CO_2 removal of a DAC approach, but it can also help with the assessment of potential trade-offs with other environmental impacts. The LCA, performed by a cradle-to-grave analysis, considers the extraction of raw materials through the end-of-life. The analysis translates the emissions to the environment to their different impacts.

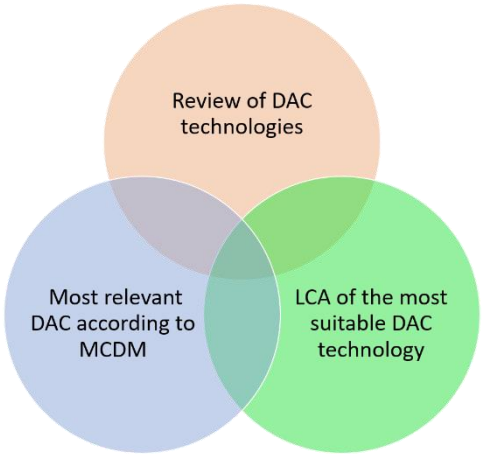

Figure: Overview of the different aspects of this study.

Results and conclusions

- This study includes a qualitative review and evaluation of different direct air capture technologies based on their readiness, resources used, output efficiency, and operational costs.
- The evaluation of the DAC technologies is performed using multi-criteria decision-making (MCDM) analysis and life cycle assessment (LCA) to conclude their potential for future operating systems.
- The results of this study will guide key decision makers in potential industries to adopt the best technology as per their preferred parameters, as the MCDA modeling and LCA will aid them to make the best decisions for adoption.

Literature

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