International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(REVIEW ARTICLE)

Enhancing life cycle assessment methodologies for carbon capture and utilization technologies: A comprehensive guideline for improved decision-making

Muhammad Ahsan *

Baker Hughes, Energy Transition and Decarbonization, Houston, United States of America.

International Journal of Science and Research Archive, 2024, 12(02), 2941–2944

Publication history: Received on 20 June 2024; revised on 28 June 2024; accepted on 10 July 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.12.2.1180

Abstract

Carbon Capture Utilization and Storage (CCUS) is an emerging technology that aims to reduce carbon dioxide (CO_2) emissions from industrial processes and power generation. This paper presents a comprehensive Life Cycle Analysis (LCA) of CCUS, evaluating its environmental impacts from cradle to grave. The LCA includes the stages of CO_2 capture, transportation, utilization, and storage. The goal is to provide a holistic understanding of the potential benefits and drawbacks of CCUS, guiding policymakers and industry stakeholders in decision-making processes. Although LCA is a standardized method, there is significant variability in current LCA practices due to differing methodological choices, which limits their effectiveness for decision support. Applying LCA to CCU technologies introduces additional challenges, particularly because CO_2 serves both as an emission and a feedstock. The guidelines aim to enhance the comparability of LCA studies by providing clear methodological directions and predefined assumptions regarding feedstock and utilities. Increased transparency is achieved through detailed interpretation and reporting guidance. By improving comparability, the guidelines support more informed decision-making, enabling more efficient allocation of research funds and time towards the development of technologies for climate change mitigation and negative emissions.

Keywords: Life Cycle Analysis; CCUS; CO_2; Emission; Sustainability

1. Introduction

The increasing concentration of CO_2 in the atmosphere is a significant driver of climate change. To mitigate this, various strategies have been developed, including CCUS. CCUS involves capturing CO_2 emissions from sources such as power plants and industrial facilities, transporting it to a storage site, utilizing it in various applications, or storing it underground.

Objective

This paper aims to conduct an LCA of CCUS to assess its overall environmental impact, including potential benefits and limitations. The analysis will cover the entire lifecycle, from CO_2 capture to its final storage or utilization, providing insights into the sustainability of CCUS as a climate mitigation technology.

2. Methodology

2.1. Life Cycle Analysis Framework

The LCA framework follows the ISO 14040 and ISO 14044 standards, which outline the principles and requirements for conducting an LCA. The analysis includes four main stages: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation.

---

* Corresponding author: Muhammad Ahsan

2.2. Goal and Scope Definition

The goal of this LCA is to evaluate the environmental impacts of CCUS across its lifecycle. The scope includes CO_2 capture, transportation, utilization, and storage. The functional unit is defined as the capture and storage or utilization of one ton of CO_2.

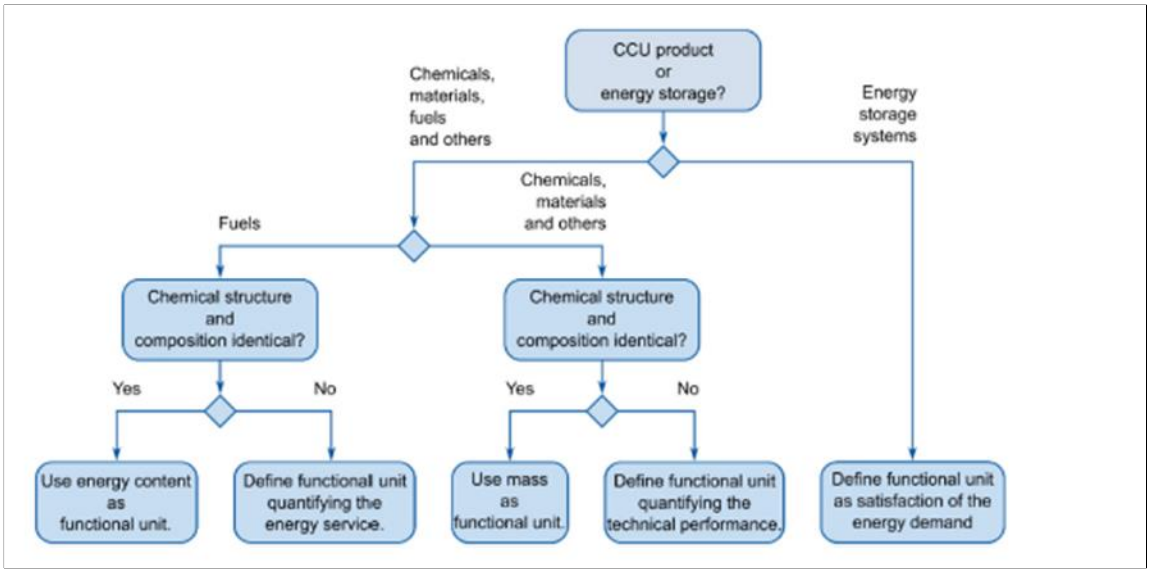

Figure 1 Decision Tree for selecting functional Unit for CCUS (Leonard Jan Muller et al 2020)

2.3. Inventory Analysis

Inventory analysis involves collecting data on inputs and outputs for each stage of the CCUS process. This includes energy consumption, raw materials, emissions, and other relevant factors.

2.3.1. CO_2 Capture

- Technologies: Post-combustion, pre-combustion, and oxy-fuel combustion.
- Inputs: Energy, chemicals (e.g., amines for post-combustion capture).
- Outputs: Captured CO_2, emissions, and waste products.

2.3.2. Transportation

- Methods: Pipelines, trucks, and ships.
- Inputs: Energy for compression and transportation.
- Outputs: Emissions from transportation vehicles.

2.3.3. Utilization

- Applications: Enhanced oil recovery (EOR), chemical production, and mineralization.
- Inputs: Energy, raw materials.
- Outputs: Products, emissions, and waste.

2.3.4. Storage

- Methods: Geological storage (e.g., saline aquifers, depleted oil and gas fields).
- Inputs: Energy for injection.
- Outputs: Emissions from injection operations, potential leakage.

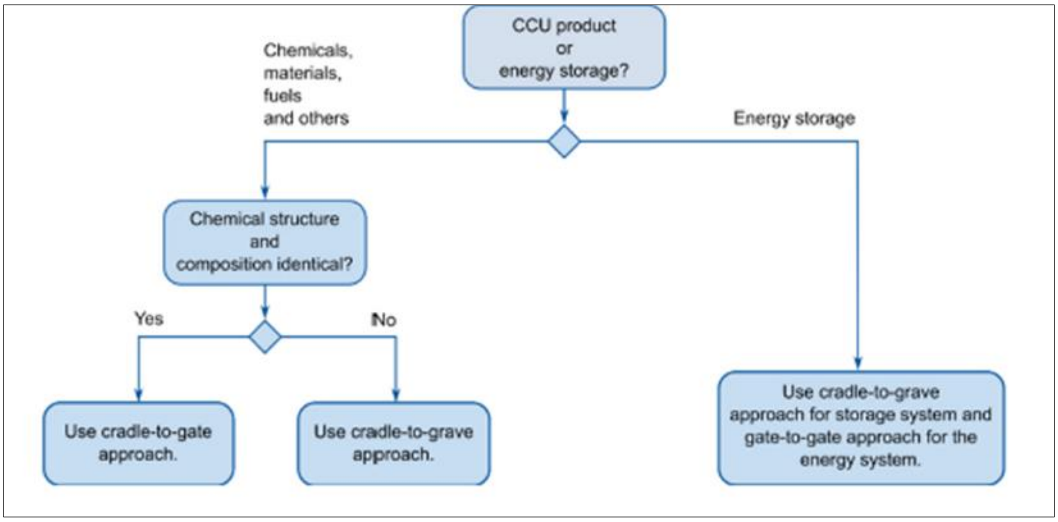

Figure 2 Decision Tree for selecting system boundary for CCUS (Leonard Jan Muller et al 2020)

2.4. Impact Assessment

The impact assessment phase evaluates the potential environmental impacts associated with each stage of the CCUS process. Key impact categories include:

- **Global Warming Potential (GWP)**: Measures the impact of greenhouse gas emissions.
- **Energy Consumption**: Evaluates the energy required for capture, transportation, utilization, and storage.
- **Resource Depletion**: Assesses the use of raw materials and natural resources.
- **Emissions and Pollutants**: Includes CO_2, NO_x, SO_2, and other pollutants.

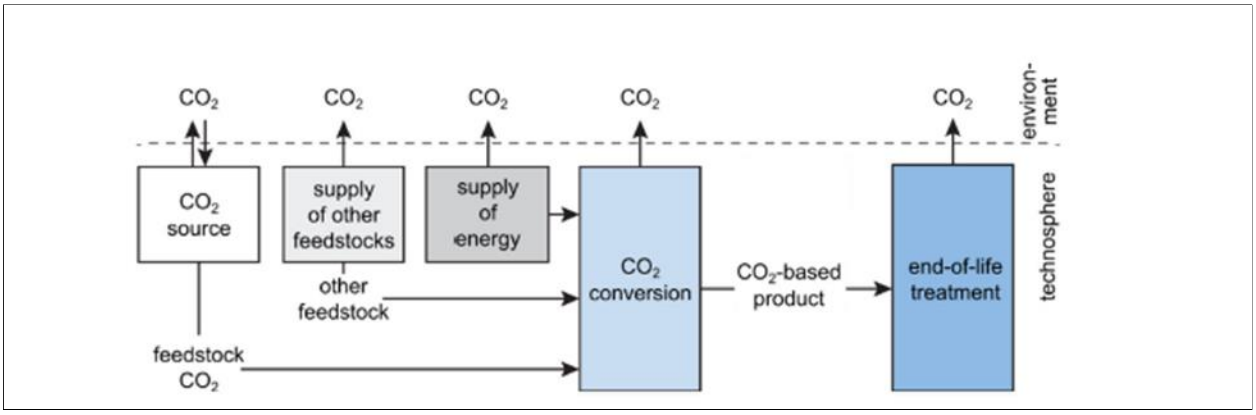

Figure 3 Schematic life cycle of CCU technologies span from the CO2 source, supply other feedstocks and energy to the end-of-life treatment. In all life cycle stages, environmental impacts should be considered adopted from von der Assen et. Al. (2013)

2.4.1. Interpretation

The interpretation phase involves analyzing the results to draw conclusions about the overall environmental impact of CCUS. Sensitivity analysis is conducted to assess the influence of different variables on the results.

3. Results

3.1. CO_2 Capture

The capture stage is energy-intensive, with significant variations depending on the technology used. Post-combustion capture requires large amounts of energy for solvent regeneration, while pre-combustion and oxy-fuel combustion technologies have different energy profiles and efficiencies.

3.2. Transportation

Transportation of captured CO_2, especially via pipelines, is relatively efficient but still contributes to emissions. The distance and method of transportation significantly influence the overall environmental impact.

3.3. Utilization

Utilization of CO_2 in applications like EOR can provide economic benefits and offset some environmental impacts. However, the net environmental benefit depends on the specific application and its lifecycle emissions.

3.4. Storage

Geological storage is a critical component of CCUS, with the potential to sequester large amounts of CO_2. The environmental impact is largely dependent on the risk of leakage and the energy required for injection.

4. Discussion

4.1. Benefits of CCUS

CCUS has the potential to significantly reduce CO_2 emissions from industrial sources and power generation. It can also contribute to the circular economy by utilizing CO_2 as a feedstock for various products.

4.2. Limitations and Challenges

The main challenges of CCUS include high energy consumption, potential CO_2 leakage from storage sites, and the economic feasibility of large-scale deployment. Further research and technological advancements are needed to address these issues.

4.3. Sensitivity Analysis

Sensitivity analysis highlights the importance of improving capture efficiency and reducing energy consumption in the CCUS process. Advances in transportation and storage technologies can also enhance the overall sustainability of CCUS.

5. Conclusion

This LCA provides a comprehensive evaluation of the environmental impacts of CCUS. While CCUS offers a promising solution for reducing CO_2 emissions, its overall sustainability depends on technological advancements, economic viability, and effective risk management. Policymakers and industry stakeholders must consider these factors when promoting CCUS as a climate mitigation strategy.

Compliance with ethical standards

Disclosure of conflict of interest

No Conflict of interest to be disclosed. The paper has been presented at 2024 Low Carbon Technology Conference.

References

[1] ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework.

[2] ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines.

[3] Rubin, E. S., et al. (2015). "The Cost of CO_2 Capture and Storage." International Journal of Greenhouse Gas Control, 40, 378-400.

[4] Budinis, S., et al. (2018). "An Assessment of CCUS Costs, Barriers, and Potential." Energy Policy, 120, 673-682.

[5] Boot-Handford, M. E., et al. (2014). "Carbon Capture and Storage Update." Energy & Environmental Science, 7(1), 130-189.