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Environmental impacts of CO_2-based chemical production: A systematic literature review and meta-analysis

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HIGHLIGHTS

- Overview of life cycle assessments concerning CO_2-based chemical production.
- Detailed review of methodological choices and technological differences.
- Methodological choices are functional unit, allocation method, and system boundary.
- Meta-LCA provides harmonized environmental impacts of CCU pathways.
- Formic acid produced via hydrogenation is a promising CCU pathway.

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ABSTRACT

Carbon capture and utilization (CCU) is perceived as a technology to mitigate climate change and conserve non-renewable resources, especially in the chemical industry. Numerous life cycle assessments (LCA) of individual CCU systems have been carried out. The goal of this review is to understand the environmental effects of CO_2-based chemical production comprehensively. In order to achieve this goal, a systematic literature review and a meta-analysis were conducted. 52 peer-reviewed articles were found that deal with LCA and CO_2-based chemical production. Amongst the case studies found, the methodological choices and technological parameters differ. The meta-analysis reveals that there is no CO_2-based chemical production technology that performs better in all analyzed impact categories (IC) compared to conventional production. Nevertheless, looking at the results from the meta-analysis, it has been found that the CO_2-based production of formic acid (FA) via H_2 is a promising CCU pathway. FA produced via hydrogenation performs better in 11 out of 15 ICs using the German grid mix as the electricity supplier and better in 14 out of 15 ICs using wind power as the electricity supplier compared to the conventional production. The global warming impact of FA production can be reduced by 95.01% when produced via CO_2 hydrogenation. The meta-analysis also unveils CCU technologies that are not favorable from an environmental perspective because CO_2-based kerosene and dimethyl carbonate (DMC) production lead to higher impacts in all ICs compared to conventional production. This study can inform decision-makers about the differences in published LCA studies on CCU and the harmonized environmental impacts of CO_2based chemical production.

1. Introduction

As countermeasures to climate change, several climate protection strategies exist. At United Nations Climate Change Conferences, main frameworks like the "1.5 °C-target" in the Paris agreement (2016) [1] have been resolved by the international community. In addition to political measures, technical measures have been developed [2]. Within these technical measures, the improvement of energy efficiency and the implementation of renewable energies play an essential role [3]. One of the emerging technical measures is carbon capture and storage (CCS). CCS is applied, for instance, to the operation of existing fossil power plants to reduce their impact on climate change [4,5]. This end-of-pipe technology aims to reduce CO_2-emissions through the technical separation of flue gases and the permanent storage in underground deposits [5,6]. The more recent idea is to use the captured CO_2 rather than storing it. This approach is called CCU [7,8]. CCU is seen as a climate mitigation option leading to deep emission reductions in energy-intensive industries, which are required to limit global warming to 1.5 °C by the Intergovernmental Panel on Climate Change (IPCC) [9]. Kätelhön et al. (2019) [10] investigated the climate mitigation potential of

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