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# Life Cycle Assessment of BECCS systems: critical review of life cycle inventories

Sibylle Duval--Dachary[a,b,c]*, Amandine Pastor[b,c], Sandra Beauchet[a], Daphné Lorne[a], Thibault Salou[b,c], Arnaud Helias[b,c]

[a] *IFP Energies nouvelles, 1 et 4 avenue de Bois-Préau, 92852 Rueil-Malmaison, France*
[b] *ITAP, Univ Montpellier, INRAE, Institut Agro, Montpellier, France*
[c] *Elsa, Research Group for Environmental Lifecycle and Sustainability Assessment, Montpellier, France*

**Abstract**

To limit global warming to 1,5°C by the end of the century, all scenarios considered in the 2018 IPCC report [1] include carbon dioxide removal technologies (CDR). Among the contemplated CDR are bioenergy carbon capture and storage (BECCS) systems, composed of three consecutive stages: biomass production, followed by biomass energy conversion process (heat, power or biofuels) and $CO_2$ capture, and finally $CO_2$ transport and storage. The $CO_2$ emitted and captured in the biomass energy conversion process was initially removed from the atmosphere by photosynthesis during the biomass growth. Therefore, BECCS systems can theoretically generate negative emissions. However, BECCS systems also consume energy and chemicals, that can lead to additional emissions of greenhouse gases or other types of pollution, as acidification or human toxicity [2]. Thus, the negative emissions potential of a BECCS system needs to be confirmed from a life cycle perspective, along with the risk of problem shifting from climate change to another impact category. To achieve this, life cycle assessment (LCA) is the suitable, and standardized [3,4], method. Life cycle assessment on BECCS are essential to support the large-scale deployment of industrial CCS deemed necessary by the European Union (EU) to achieve its climate neutrality target by 2050 [4]. Several reviews of LCA on BECCS systems have already been published [5–10], focusing only on LCA results and methodology. However, an essential part of conducting an LCA is the collection of all the data to build the life cycle inventory (LCI). The LCI regroups all the emissions to the environment and all the materials and energy consumed during the life cycle of the system under study. Thus, this review will focus on inventory data used in LCA of BECCS.

The objectives are to discuss the relevance of inventory data regarding current technologies, to identify missing or outdated data and to provide default inventory values when possible. To this end, Web of science and Scopus databases were used to search scientific articles on bioenergy, LCA and carbon capture and storage (CCS). Ninety-seven articles were published after 2015 on these topics. Thirty-five were LCA on BECCS and thus considered relevant for this review. This state-of-the-art indicates that some technological bricks are more studied than others. Thus, the biomass-to-power conversion technologies studied were mainly combustion (16 articles), gasification (10 articles) and fermentation (5 articles). Another example is the $CO_2$ transport. When $CO_2$ transport is mentioned (20 articles), only two options are considered: pipeline (19) and ship combined with pipeline (1). The results of this review also include data uncertainty or variability, and data production method (simulation, measures…), when available. For instance, monoethanolamine (MEA)-based capture is the preferred $CO_2$ capture process (20 articles). The inventory data used to model MEA-based $CO_2$ capture in these twenty LCA of BECCS is

* Corresponding author. Tel.: +3-314-752-6340, *E-mail address: sibylle.duval-dachary@ifpen.fr*

mostly based on simulation results, often coming from the work of Rao and Rubin 2002 and 2006 [11,12]. To assess their relevance, these data are compared with measurement from pilot plants [13].

Finally, a main outcome is an inventory of all the LCI data provided in the 35 LCA of BECCS. When enough data is available, synthesis inventory tables are provided for each process involved in the life cycle of BECCS: biomass production (energy wood, agricultural residues…), conversion technology (combustion, gasification….), $CO_2$ capture (MEA…), transport and storage. These inventory tables will facilitate the comparison of BECCS systems. In fact, the objectives of performing an LCA of BECCS are various, as for example, biomasses comparison, or a comparison of several options for $CO_2$ capture. Different objectives lead to contrasting system boundaries, hypothesis, and modelling choices. By completing inventories or replacing certain modelling choices, the summary tables will allow similar assumptions and system boundaries to be maintained from one LCA on BECCS to another. Thus, the environmental performance of BECCS systems could be compared without the biases, constraints and modelling choices made to describe the technical systems. Nonetheless, additional data from industrials will still be needed to ensure the robustness and relevance of these inventories compared to current technologies.

*Keywords:* Life cycle assessment (LCA); Life cycle inventory (LCI); Bioenergy with carbon capture and storage (BECCS); Negative emissions technologies

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