Clustering CO_2 capture in industrial districts: a multi-criteria comparison of blue hydrogen vs. post-combustion options

Hard-to-abate manufacturing sectors remain a significant challenge for achieving deep decarbonization targets, as a major share of their CO_2 emissions originates from intrinsic process chemistry and the need for live flames, rather than from energy demand alone (Martinez-Castilla, 2024).

While current decarbonization investments are largely directed toward large-scale emitters such as cement and steel plants, other sectors, such as ceramic tile manufacturing, glassmaking, and secondary metal foundries, account for a relevant fraction of European industrial CO_2 emissions. These sectors typically consist of small or medium-sized plants, with annual emissions in the range of 10-100 ktCO_2, a scale that makes the standalone deployment of carbon capture solutions economically and technically challenging. At the same time, such plants are often geographically clustered within industrial districts, where the spatial proximity between plants may enable shared infrastructure and economies of scale.

Multiple options for clustering exist (Berghout et al., 2015; Lee et al., 2025) and for investment decisions at the industrial district level it is relevant to assess which option is preferable across economic, environmental, and social dimensions.
This work evaluates three alternative routes of clustering carbon capture at an industrial district scale, as sketched in Fig. 1a: (i) centralized pre-combustion capture via blue hydrogen production in a dedicated steam methane reforming (SMR) facility equipped with CO_2 capture (IEAGHG, 2017) and subsequent H_2 distribution to industrial plants; (ii) centralized post-combustion CO_2 capture, where each plant sends their flue gas to a single carbon capture facility via amine scrubbing; (iii) distributed post-combustion CO_2 capture with centralized solvent regeneration, where each plant is equipped with an absorption module and lean/rich amine solution is sent back and forth to a single amine regeneration facility. These configurations are benchmarked against option (iv), fully distributed post-combustion CO_2 capture, where each plant is retrofitted with a complete capture system. SMR and amine scrubbing are selected as reference technologies due to their high technology readiness level.

The assessment is based on a multi-criteria framework encompassing all three pillars of sustainability (Zanobetti et al., 2025). In addition to economic performance and environmental benefits associated with net CO_2 abatement, social sustainability is addressed through the inclusion of process safety, which is considered as a proxy for societal acceptability of innovative technologies and can be quantified since early stages of their lifecycle. In particular, inherent safety indicators are applied to quantify the potential for accidental scenarios (fire, explosions, toxic releases).

The comparative assessment is performed on a representative industrial cluster, the so-called "Ceramic District" of Sassuolo (Northern Italy), which hosts approximately 80% of the Italian ceramic tile production. Here, more than 30 plants, with individual CO_2 emission rates ranging from 5 to 100 kt CO_2 per year, are placed within a radius of less than 10 km (see Fig. 1b), making the district an interesting testbed for the assessment of clustered carbon capture options.

Plant-specific data were retrieved from the EU ETS registry and environmental permitting documents. Realistic pipeline networks for the transportation of the fluids in Fig. 1a were defined accounting for local constraints. Mass and energy balances, as well as equipment sizing, for each configuration in Fig. 1a were determined through Aspen HYSYS simulations. A sensitivity analysis was conducted to assess the influence of key parameters, including electricity price and carbon intensity, topology of the capture and distribution networks, and the degree of electrification of the capture process.

Preliminary results show that clustered configurations outperform fully distributed capture across all the sustainability domains. Among post-combustion carbon capture options, option (iii) emerges as the most favorable configuration. Pre-combustion capture via blue H_2, option (i), can further reduce costs, but at the expense of higher potential safety-related impacts.

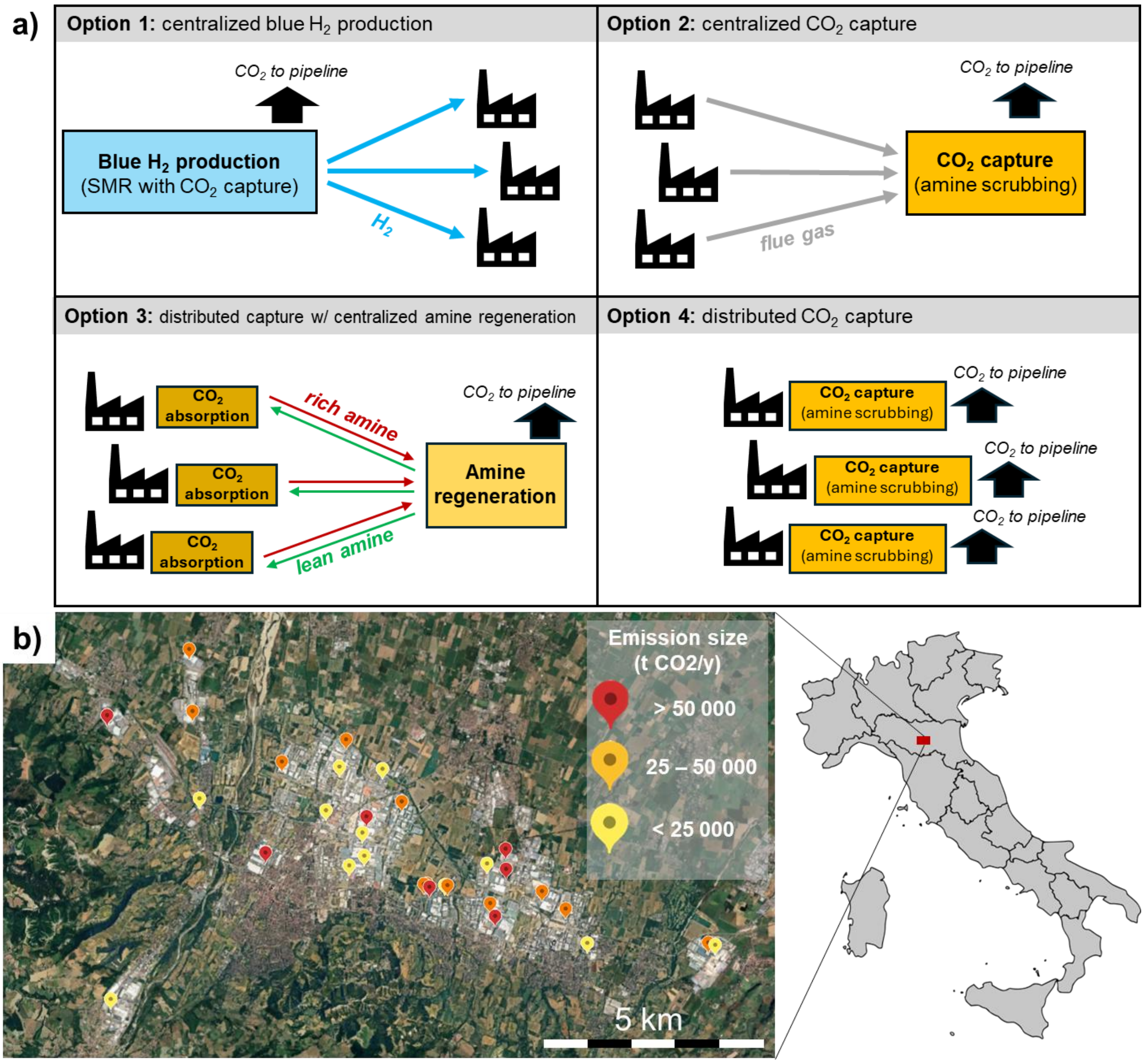

Figure 1 *a) Considered options for the application of carbon capture at the industrial district level, b) the "Ceramic District" considered as case study.*

Beyond the specific case study, the proposed methodology is general and transferable to other industrial clusters, providing a robust decision-support tool for sustainability-oriented technology screening and investment prioritization. Generally, the number of serviced industrial plants and their relative distances result as key discriminants in determining the preferred clustering strategy.

References

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