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AN OPEN-SOURCE TOOLKIT TO DESIGN AND EVALUATE NET-ZERO PATHWAYS FOR INDUSTRIAL CLUSTERS

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Why a Tool for Clusters?

- Decarbonization of industrial processes is essential to meet climate goals
- Focusing on industrial clusters instead of single sites can help aid the decarbonization by leveraging synergies and with economies of scale
- Explore new insights for industrial decarbonization

Cluster Definition

- A cluster consist of sites of industrial scale processes within geographical proximity (similar location) which can share the same infrastructure
- Initial focus on the industrial sectors of steel & iron mills, refineries, cement production, and CCGT power plants

Problem Statement – Interventions to Decarbonize Industrial Processes

Example:

Base Process → **Intervention** → **Intervened Process**

Base Process	Intervention	Intervened Process
• Steel Plant	• Install MEA CC • Use hydrogen • Slag carbonation	• Steel Plant w/ MEA CC • Steel Plant injecting H_2 • Steel Plant injecting H_2 w/ MEA CC • Steel Plant with slag carbonation

Decarbonization is driven by technological interventions, changing the incumbent processes. The toolkit incorporates a portfolio of interventions. Each intervened process is quantified based on a detailed process models

The optimal design and transformation of a cluster is expressed by:

1. **WHICH** technologies or distribution options should be installed?
2. **WHAT SIZE** should the installation be?
3. **WHERE** should these technologies be installed?
4. **WHEN** should/can these technologies be installed?

Solving the Problem – Optimal Pathway Development

Following a Resource Technology Network (RTN) formulation, the problem is defined through the use, production, transport, storage, import, and emission of resources. Base and intervened processes are described by their conversion factors between resources.

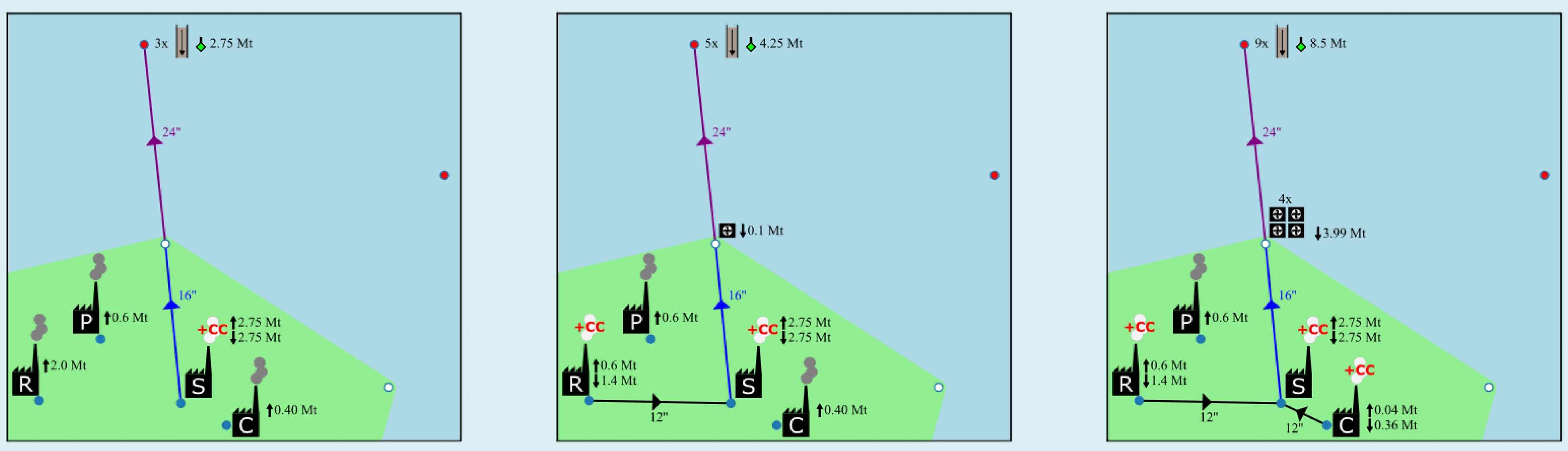
A pathway towards a desirable cluster design consists of multiple investment rounds. Within each round (WHEN), the three points WHICH, WHAT SIZE, and WHERE are solved. Finding the optimal solution requires an optimizer to solve a Mixed-integer linear programming (MILP) problem. The toolkit breaks the problem down into two steps.

1) **Snapshot**: optimal solution of cluster design
2) **Backcasting**: accounting for path-dependencies and lock-in effects by starting from the snapshot solution of the final investment round and working backwards in time.

approach	round 1	round 2	round 3
single investment	**S30** snapshot w/ 30% emission reduction	**S50** snapshot w/ 50% emission reduction	**S100** snapshot w/ 100% emission reduction
backcasting	**BS30** backcasted snapshot w/ 30% emission reduction ←	**BS50** backcasted snapshot w/ 50% emission reduction ←	**S100** snapshot w/ 100% emission reduction

Example Results – CCS Network Design for a Hypothetical Cluster

- Assuming three investment rounds, with different emissions targets
- Allowing the installation of Carbon Capture technology, Direct Air Capture Plants, CO2 transport network, and injection and storage technologies.
- Cluster consisting of:
    - Refinery (R)
    - CCGT Power Plant (P)
    - Steel Mill (S)
    - Cement Plant (C)



(a): round 1 - 30% CO_2 reduction (b): round 2 - 50% CO_2 reduction (c): round 3 - 100% CO_2 reduction

Insights from the Tool

Economic	• Cost metrics • Cluster CAPEX and OPEX • Primary resource consumption
Environmental	• Per unit material consumption rates • Key pollutant emissions and reduction metrics • LCA indicators
Geographic	• Infrastructure and upgrade requirements • Demand and storage for energy • CO_2 reservoir effects
Technical	• Reliability, Safety and risk analysis • Energy intensity metrics • Technology readiness levels
Social	• Integration with low-carbon alternatives • Social costs of CO_2 emissions
Policy	• Regulation and incentivisation • Demand and storage for energy • Carbon pricing

Acknowledgment

We would like to acknowledge that this work was supported by the UKRI ISCF Industrial Challenge within the UK Industrial Decarbonisation Research and Innovation Centre (IDRIC) award number: EP/V027050/1

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