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SIMULATING THE PATH TO NET ZERO IN AN UK INDUSTRIAL CLUSTER

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ABSTRACT

The decarbonisation of industrial clusters is central to the UK's net zero strategy. Located in southeast England, the Kemsley Industrial Cluster (comprising five firms) is the largest industrial cluster in the counties of Kent and Sussex, offering a critical opportunity for coordinated action. This study supports their decarbonisation-focused decision-making through a Monte Carlo simulation model. The model takes hourly energy use as input and simulates the potential impact of emerging decarbonisation technologies including hydrogen, and collaborative energy exchanges such as private wire electricity and shared steam flows. Key model outputs include emissions profiles and the overall energy balance. The model produces insights for six main decarbonisation scenarios over a 25-year horizon (2025–2050). Results suggest the cluster could reach net zero emissions by 2035 if carbon capture is implemented. This study develops a novel Monte Carlo model that captures inter-firm dynamics within industrial clusters, directly informing collaborative decarbonisation investment strategies.

1 INTRODUCTION

Industrial clusters pose both challenges and opportunities in the UK's transition to a low-carbon economy (DESNZ 2021). The Kemsley Industrial Cluster in North Kent—comprising a paper mill, plasterboard manufacturer, waste management firm, energy-from-waste facility, and biomass energy plant—has been designated a priority site under the UK's Local Industrial Decarbonisation Plan (GOV.UK 2025; Ansari et al. 2025). As the largest industrial cluster in the region, it plays a pivotal role in regional decarbonisation efforts.

Planning decarbonisation in such settings is inherently complex, shaped by diverse firm-level priorities, evolving regulatory and technological landscapes, and opportunities for collaboration through shared infrastructure. A range of green technology options are currently being considered by the cluster to replace fossil fuel where possible in their operations. These include electrification, green steam production, and the adoption of blue or green hydrogen. Carbon capture (CC) is also a key decarbonisation component for this cluster, particularly for hard-to-abate sectors such as energy-from-waste, though its deployment is constrained by each firm's infrastructure and technology readiness, with implementation not expected before 2035.

This paper introduces a Monte Carlo simulation model developed in close partnership with the five firms in the cluster. The model simulates the energy balance in the system and explores scenarios such as inter-company energy exchanges, particularly from the introduction of a private electricity wire linking the energy producers and energy consumers within the cluster and steam flows among some members of the cluster. Key outputs of the model include emissions profiles, allowing for assessment of the different decarbonisation technologies, and their impact over a period ending in 2050.

2 METHODOLOGY

The Monte Carlo simulation model was built in Excel with VBA, and consists of two layers:

1) Firm-Level Models: For each of the five participating firms, a Monte Carlo simulation model was developed, taking into account their operating schedules, internal energy use, production volumes, technology implementation feasibility, and emissions profiles associated with the fuels and materials used in their processes. The models run on an hourly basis, with embedded distributions based on 2023 production volumes. Operational uncertainties such as unplanned outages, seasonal fluctuations, and

pairwise process interdependencies are incorporated. Outages are randomised with VBA for each run using learnt patterns of historical data; seasonal fluctuations are captured through period-specific distributions; and pairwise interdependencies are modelled via linear regression. These individual models, validated by each of the firms, are then fed into the cluster-level model.

2) Cluster-Level Model: A joint simulation layer aggregates the five firm-level models and simulates system-level emissions and energy exchanges from private wire electricity and steam. It calculates annual greenhouse gas emissions across multiple scenarios, based on the rate and timing of technology adoption (e.g., electrification, carbon capture, hydrogen) by individual firms. The model outputs are the total electricity and steam generation and consumption, along with the overall balance across the full timeline and under various scenarios. Emissions include Scope 1, Scope 2, and Out of Scope (biogenic) and are reported as aggregated values for the entire cluster.

All results were collected using VBA, with 100 runs conducted for each year of significance across every scenario. Each batch of 100 runs takes about 15 minutes to complete on a laptop with an Intel Core i7 processor and 16 GB of RAM.

3 KEY FINDINGS AND CONCLUSION

The Monte Carlo modelling approach showed that the best scenario was Scenario 1 which included the steam exchange, as well as green hydrogen and carbon capture implementation. However, all scenarios performed well and showed the cluster reaching carbon negative emissions after 2035, as illustrated in Figure 1. Scenario results show that carbon capture is essential for the cluster to reach net zero emissions. It is the only feasible option for eliminating residual emissions from the energy-from-waste facility. While the biomass facility itself does not require capture to reach net zero—since it emits primarily biogenic CO_2—capturing those emissions could support the cluster in reaching net zero and enable further carbon removal beyond its remit.

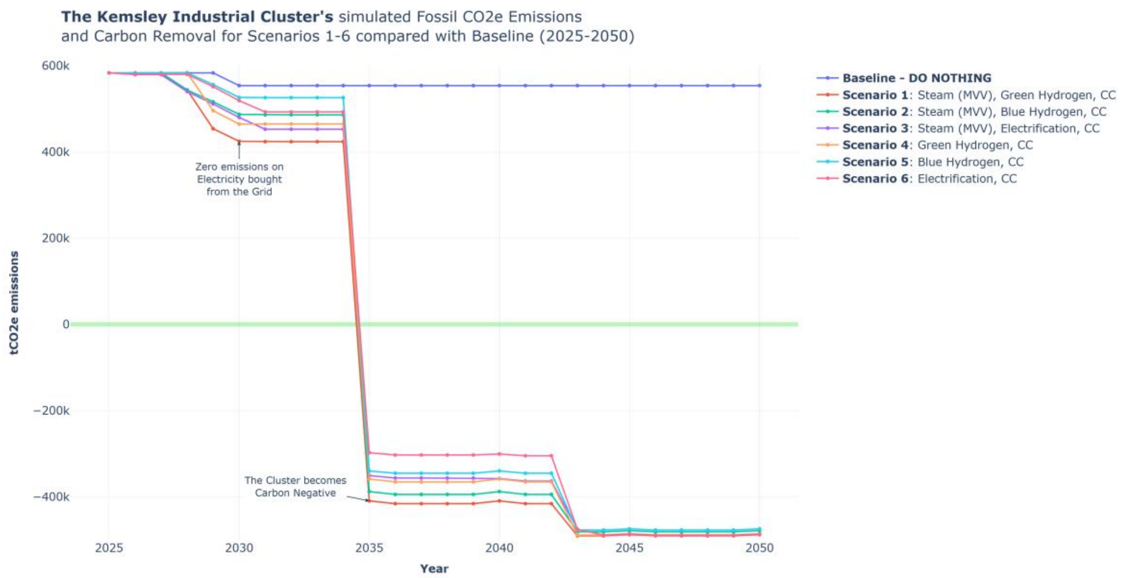

Figure 1: Scenario comparison of various decarbonisation paths for the Kemsley Cluster.

Future work could extend this method to other industrial clusters and integrate real-time data, enabling its use as a digital twin to support emission reporting and dynamic decarbonisation decisions.

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