Industrial Decarbonisation Frontiers Report

Systems Planning and Decision-Making Tools

Since its launch in 2021, the Industrial Decarbonisation Research and Innovation Centre (IDRIC) has funded 100 projects, investigating and addressing the key dimensions of the whole system of industrial decarbonisation. This work has generated a vast body of knowledge, offering critical insights into the challenges we face in decarbonising and into the solutions – technical, economic and social – that are emerging. The *Frontiers Reports* series brings together all these insights to share with our industry and policy stakeholders.

Each report synthesises key findings from multiple projects conducted on a closely related theme, providing a comprehensive perspective on a specific aspect of industrial decarbonisation. Far more than simply research summaries, these reports translate academic insights into practical, evidence-based recommendations for our stakeholders. These recommendations are shaped by the expertise and evidence gathered by our research teams and are designed to support decision-makers in advancing their net zero goals.

The *Frontiers Reports* are anticipated to serve as catalysts for meaningful discussions between academia, industry, and policymakers on the most viable paths forward. We welcome constructive debate and are eager to support the implementation of recommendations that best align with our stakeholders' priorities and goals towards net zero.

This report brings together all IDRIC's research on Systems Planning and Decision-Making Tools.

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Executive summary

Effective systems analysis, planning and decision-making tools are central to accelerating industrial decarbonisation and enabling the UK's net zero ambitions.

This report synthesises key research conducted through IDRIC, exploring the development and application of integrated modelling, scenario planning, artificial intelligence (AI) tools and stakeholder-informed frameworks to support industrial clusters in designing and implementing robust, data-driven decarbonisation strategies.

Key findings

Integrated tools enable customised decarbonisation pathways
A range of simulation and modelling tools developed by IDRIC projects allow for tailored analysis of emissions, energy demands, infrastructure needs and cost implications across industrial clusters. These tools support both industry and policymakers in identifying viable, site-specific net zero strategies.

Infrastructure development must take a regional approach
Fuel demand modelling shows that switching from gas to electricity and hydrogen will significantly increase demand for the latter across industrial regions. Early upgrades to electricity networks, particularly in the West Midlands and West Yorkshire, are essential. Hydrogen infrastructure should be developed nationally but begin with regionally coordinated hubs.

Socio-economic modelling supports a just transition
Analysis of jobs and economic development across decarbonisation scenarios show the regional disparities in potential gains. Research using the Jobs and Economic Development Impact (JEDI)-UK framework model highlights how workforce development and local economic context must guide policy to ensure a fair and equitable transition.

Stakeholder input shapes effective strategies
Incorporating local industry and general public perspectives has led to the development of flexible, standardised planning frameworks that can be adapted to the requirements of different clusters. Research carried out in Tees Valley underscores the importance of social acceptance and political alignment in enabling carbon capture, utilisation and storage (CCUS) and other emerging technologies.

Advanced modelling supports technology innovation
Tools such as the PrISMa platform demonstrate how artificial intelligence (AI) tools and data-driven modelling can support material selection and cost-effective carbon capture. Other projects explored innovations like hyperspectral imaging for steel quality control and high-efficiency carbon capture for gas turbines, showing how targeted technological development can enhance emissions reduction.

Recommendations to industry

Enable comprehensive data accessibility and industry collaboration
Establish robust data-sharing frameworks between academia, industry and government to support real-time modelling and more accurate scenario planning.

Engage with local stakeholders
Collaborate with regional actors to align low-carbon solutions with local economic needs, share energy data and co-develop long-term sustainable decarbonisation strategies.

Integrate AI and systems planning tools for optimised decision-making
Invest in modular, adaptable modelling tools for selecting cost-effective technologies, conducting life cycle assessment and planning sector-specific decarbonisation pathways.

Optimise supply chain management and resource planning
Strengthen supply chains for specialised equipment and materials and assess national resource needs to avoid future bottlenecks in decarbonisation projects.

Accelerate workforce development and knowledge transfer initiatives
Launch targeted retraining and skills programmes in key areas like carbon capture and hydrogen. Prioritise knowledge retention in sectors with ageing workforces.

Recommendations to policymakers

Enable strategic place-based investment and master planning
Develop regional industrial decarbonisation strategies that reflect local infrastructure, industry composition and workforce needs, supported by targeted financial incentives.

Integrate industrial demand within broader energy system planning
Mandate collaborative planning between industrial clusters, energy networks and transport sectors. Encourage open data through incentives and support the deployment of integrated modelling tools.

Support sustained innovation and technology development
Provide long-term funding frameworks for critical technologies like CCUS, hydrogen and direct air capture, especially in regions with high deployment potential such as the industrial clusters.

Develop clear and actionable policy frameworks for industry adoption
Set sector-specific decarbonisation benchmarks and consider financial instruments, such as risk guarantees or low-interest loans to reduce investment barriers for high-cost technologies.

Moving forward

To deliver net zero, greater integration of industrial and energy systems planning is essential. Future modelling must incorporate real-time regional data, evolving supply chains and workforce trends. Scaling up decarbonisation will require continued collaboration between industry, academia and government, alongside targeted investments in AI driven tools, infrastructure and skills development. A socially equitable, economically viable transition depends on proactive, data-informed decision-making and transparent engagement at every level.

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Introduction

Reducing carbon emissions from industrial clusters worldwide is essential in the fight against climate change and plays a key role in the United Kingdom’s goal of reaching a net zero economy by 2050.

Reducing carbon emissions from industrial clusters worldwide is essential in the fight against climate change and plays a key role in the United Kingdom's goal of reaching a net zero economy by 2050. The UK's decarbonisation strategy targets a 78% reduction in emissions by 2035, compared to 1990 levels, with the ultimate goal of achieving net zero emissions by 2050.[1] In 2021, the industrial sector in the UK accounted for 12% of the country's total energy consumption, highlighting the necessity of industrial decarbonisation to meet net zero targets.[2] Whilst energy efficiency for industrial sectors remains a critical and cost-effective decarbonisation strategy, its impact appears to be limited, contributing 11% towards the 2050 emission reduction goal, compared to renewables (53%) and fuel switching (36%).[3] Therefore, it is imperative to combine various decarbonisation methods to effectively decarbonise the industrial sector.

The fragmentation of industrial decarbonisation frameworks increases the complexity of determining the essential steps for achieving effective industrial decarbonisation and transitioning to net zero emissions.[4]

Historically, energy system modelling was closed and proprietary, prioritising intellectual property rights. However, the imperative for decarbonisation has led to increased transparency in modelling methodologies and assumptions which provide essential input for implementing those changes.[5,6] A number of IDRIC's projects undertook holistic systems analysis and planning tools development to provide a nuanced understanding of the broad spectrum of mitigation options for decarbonising industrial clusters to realise set targets for reducing CO_2 emissions. In this report we assess their findings and key messages.

The fragmentation of industrial decarbonisation frameworks increases the complexity of determining essential steps for achieving effective industrial decarbonisation and transitioning to net zero emissions.

1 CCC (2020). Reducing UK emissions: 2020 Progress Report to Parliament.

2 Ngwaka, U., Khalid, Y., Ling-Chin, J., et al. (2023) Industrial cluster energy systems integration and management tool. Energy Conversion and Management, 297: 117731. doi:10.1016/j.enconman.2023.117731.

3 Mier, M. and Weissbart, C. (2020) Power markets in transition: Decarbonization, energy efficiency, and short-term demand response. Energy Economics, 86: 104644. doi:10.1016/j.eneco.2019.104644.

4 Ogwumike, C., Akponeware, A., Oyewole, A., et al. (2024) Transitioning or tinkering at a net-zero economy? Introducing an assessment framework for industrial cluster decarbonisation in the United Kingdom. Energy Research & Social Science, 110: 103459. doi:10.1016/j.erss.2024.103459.

5 Pfenninger, S., DeCarolis, J., Hirth, L., et al. (2017) The importance of open data and software: Is energy research lagging behind? Energy Policy, 101: 211–215. doi:10.1016/j.enpol.2016.11.046.

6 Beltramo, A., Leonard, A., Tomei, J., et al. (2024) Data governance and open science in energy planning: A case study of the Kenyan ecosystem. Energy Research & Social Science, 118: 103821. doi:10.1016/j.erss.2024.103821.

Research findings

Modelling tools allow us to analyse a wide range of scenarios, providing insights that can inform and guide both industry and policymakers in making data-driven, future-oriented decisions.

Ten IDRIC projects contributed to this report. They are referred to by their project IDs throughout.
→ See further information.

Project ID	Project name
MIP 1.1	An integrated energy system planning tool for net zero industrial clusters
MIP 1.7	An integrated framework for levelled up and low carbon industrial clusters
MIP 2.1	Development of an open-source toolkit to design and evaluate the performance of low carbon infrastructure for industrial clusters
MIP 2.3	Systems, infrastructure and technologies for providing low-carbon fuels
MIP 3.1	A Smart Decision Modelling (SDM) tool for industrial cluster decarbonisation
MIP 6.1	Accelerating the deployment of cost-competitive advanced carbon capture technologies for industrial decarbonisation
MIP 9.2	Industrial clusters and whole energy system modelling
FF 3-4	Comprehensive Assessment of Post-Combustion Capture Options (CAPCCO)
FF 3-11	Reducing blast furnace emissions with hyperspectral imaging
FF 4-1	Assessing the feasibility of implementing CO_2 capture and utilisation in Quorn mycoprotein process

The IDRIC projects described in this report used systems analysis and integrated modelling for a variety of research objectives that range from exploring infrastructure development needs for decarbonisation using spatial mapping, for assessing socio-economic needs and evaluating emissions, costs and energy consumption reduction for various scenarios. Focusing on the use of modelling for technology development, IDRIC's projects looked at steel and cement sector case studies and carbon capture, utilisation and storage (CCUS).

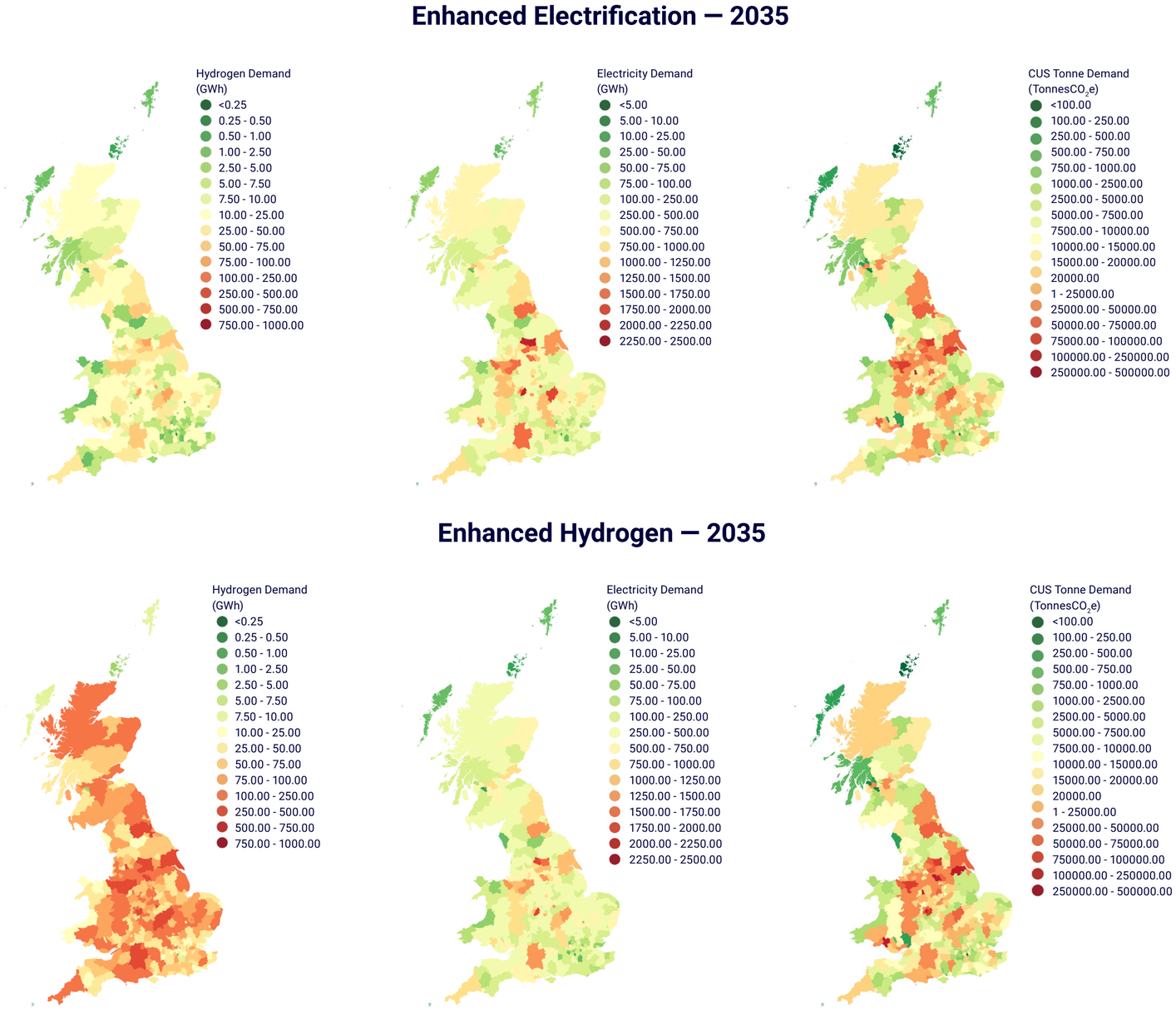
Infrastructure development and regional approach

Geographic data and a fuel demand model were used to understand the range and scale of energy vectors and infrastructure needed for industrial decarbonisation in IDRIC project MIP 2.3. A scenario-based approach explored fuel demand. Initial findings showed that when industrial gas demand switches, it leads to an increase in electricity and hydrogen demand. The electricity demand increased in all regions by 50-70% of existing gas demand; and hydrogen demand ranged from 8-37% of existing gas demand, predominantly near Merseyside, Humberside and other major industrial conurbations (West Midlands, West Yorkshire) (Figure 1). Demand for CCUS was noted as consistent across various fuel switch scenarios and is primarily tied to the cement and brick industries. Furthermore, research demonstrated that electricity upgrades must take place in 2020s, prioritising the West Midlands and West Yorkshire.[7] Hydrogen infrastructure may be required nationally, but planning laws should facilitate regional/local agglomeration to hydrogen hubs starting in the early 2030s. CCUS and biomass should be targeted at geographically constrained sites and rural areas.

7 ESE 0033 (2024). Written evidence submitted to UK parliament.

Figure 1

Preliminary results from MIP 2.3, modelling demand levels for hydrogen, electricity, and CCUS in 2035 with differing electrification and hydrogen scenarios.



Energy system planning

Simulation tools were developed to enable industrial clusters to plan net zero decarbonisation routes. Scenario-based analysis allows a systematic evaluation of emissions, costs and energy efficiency to support simulation of the proposed decarbonisation pathways. The tools delivered in project MIP 1.1 empower industries to assess tailored decarbonisation pathways, enhancing their efficiency and cost management. Using the tools, policymakers could gain a better foundation for regulating, aligning incentives with cluster-specific energy demands and setting carbon reduction goals. Improved decision-making ensures targeted and practical net zero strategies.

Socio-economic assessment

A just transition demands that the economic benefits of decarbonisation and technology deployment are shared fairly, including for communities that have historically relied on high-carbon industries. Therefore, systems modelling techniques were applied to assess the socio-economic impacts of decarbonising industrial clusters in the UK in project MIP 1.7. Using the Jobs and Economic Development Impact (JEDI)-UK framework, the analysis focused on quantifying Gross Value Added (GVA) and job creation across various sectors in response to a range of decarbonisation pathways, including post-CCS, steam methane reforming (SMR) and autothermal reforming (ATR) technologies (Figure 2).

Key findings show that the direct and indirect impacts of decarbonisation vary significantly across regions, with certain regions like the Humberside showing the highest potential economic returns. The project highlighted the importance of considering regional economic dependencies when planning for industrial decarbonisation, revealing that spillover effects across regions are substantial. The modelling also identified that sectors such as machinery/electrical equipment, professional services and utilities will play a critical role in job creation and economic growth. The analysis demonstrated the link between regional policy, technology deployment and workforce development, offering a robust, data-driven framework for both industry stakeholders and policymakers.

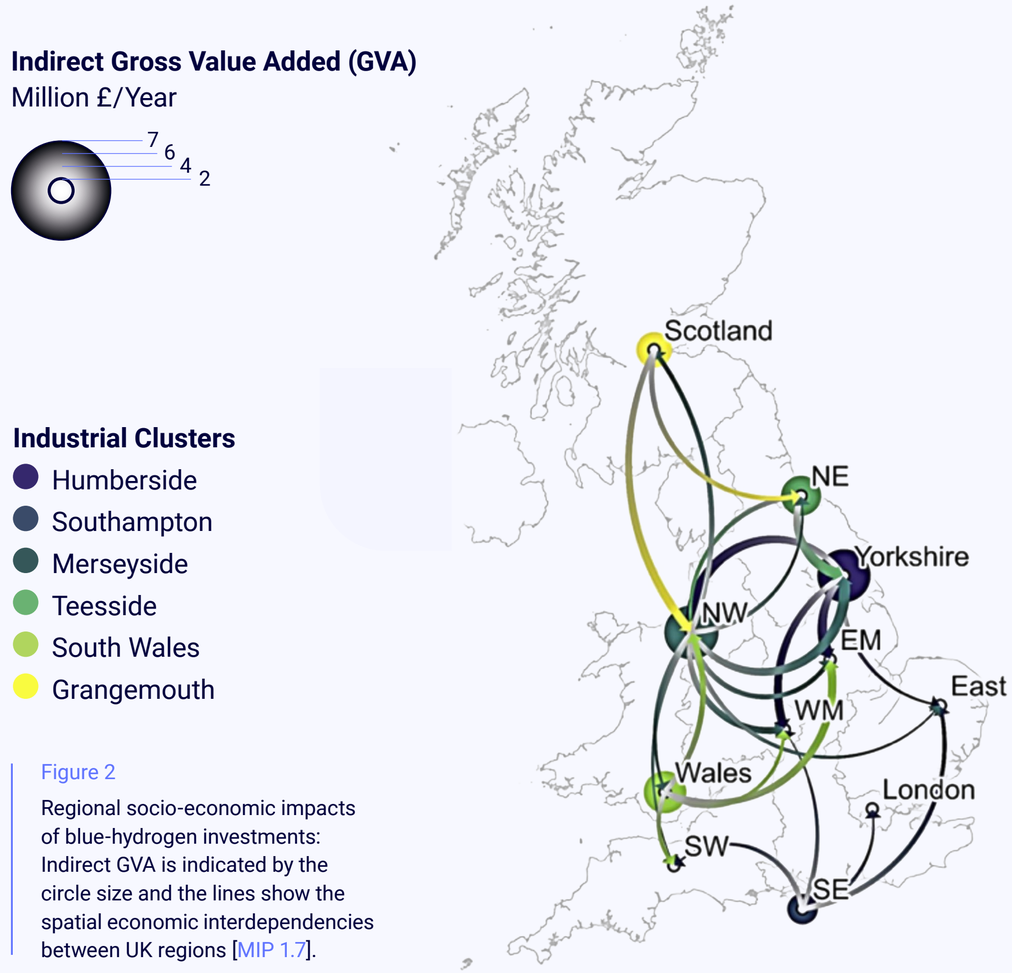


Figure 2

Regional socio-economic impacts of blue-hydrogen investments: Indirect GVA is indicated by the circle size and the lines show the spatial economic interdependencies between UK regions [MIP 1.7].

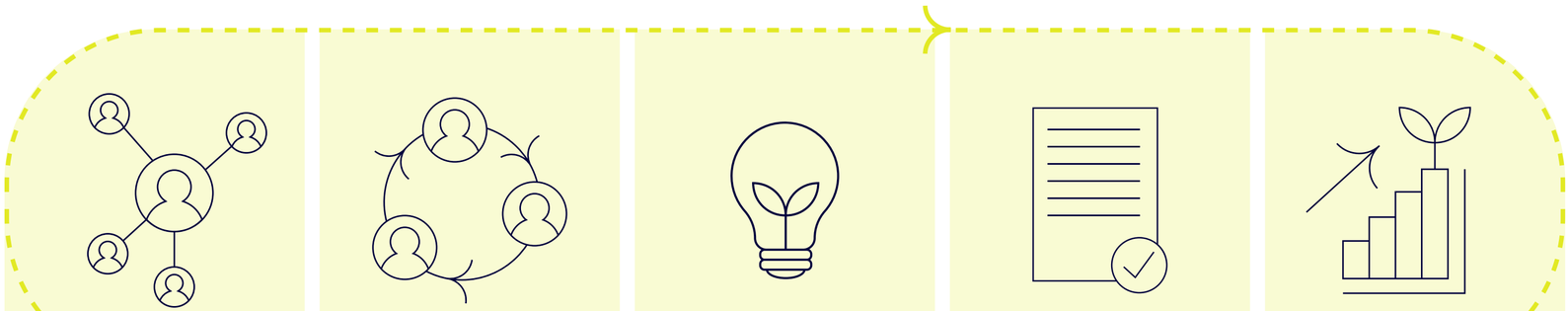
Analysis by project MIP 1.7 demonstrated the link between regional policy, technology deployment and workforce development, which offers a robust and data-driven framework for both industry stakeholders and policymakers.

Industry and stakeholder perspectives

The key performance indicators and approaches to reach decarbonisation targets of individual cluster projects and strategies can vary extensively from one industrial site and cluster to another and from region to region across the world. Therefore, in project MIP 3.1, stakeholder and industry perspectives were analysed to develop a standard framework that can be adapted to the requirements of other industrial clusters' strategies (Figure 3).

Figure 3

Industrial decarbonisation assessment framework developed by project MIP 3.1.[8] The framework recognises the importance of stakeholder engagement, data-driven decision-making, and the integration of appropriate decarbonisation technologies to achieve meaningful and sustainable industrial decarbonisation.



Potential Stakeholders

- Identifying, listing, and contacting key Teesside cluster stakeholders and partners
- Identifying and agreeing stakeholders' operations and support level
- Identifying and agreeing stakeholders' tasks and activities

Stakeholders Communication, Engagement & KPIs

- Conducting and implementing communication approach: consultations, interviews, workshops, questionnaires
- Defining engagement process, reviews, timeline and meeting schedules
- Defining tasks, activities, roles, and responsibilities in the context of KPIs

Decarbonisation Technologies Definition

- Defining policies, new and emerging technology
- Defining decarbonisation technologies strategy for effective emission abatement
- Defining new approaches for emissions reduction

Data Collection

- Data collection via UK LA database, literature, agencies, industry specialists
- Data collection approach, data collection roles and accountabilities, and data collection storage defined
- Data preparation and pre-processing defined

System Evaluation Process

- Descriptive analytics
- Diagnostic analytics
- Predictive analytics
- Prescriptive analytics

Use of modelling tools for technological development

Project MIP 6.1 aims to find the optimal sorbent/process combination for a particular carbon capture process. As we can potentially use millions of possible scenarios, AI-driven models can expedite material discovery. The PrISMa (Process-Informed design of tailor-made Sorbent Materials) platform is used to evaluate the performance of a sorbent. PrISMa seamlessly integrates density functional (DFT) calculations and molecular simulations, process design, technoeconomics, and life cycle assessment to arrive at a holistic evaluation. Figure 4 shows how this PrISMa platform is integrated into an AI-driven materials design cycle.

Focusing on blast furnaces for the steel industry, the potential of hyperspectral imaging for the real-time analysis of molten pig iron can offer significant advancements to industrial decarbonisation. Through project FF 3-11, this technology has been shown to provide a pathway to online chemical analysis, enabling early detection of impurities that compromise steel quality and is therefore a practical route to reduce CO_2 emissions by minimising reprocessing due to impurity-driven steel defects. Moreover, this approach could be adapted for broader applications across the foundation industries, including combustion analysis and real-time monitoring in high-temperature processes.

Globally, 99% capture for a combined cycle gas turbine plant will be required to deliver climate change mitigation targets.[8] Modelling results from project FF 3-4 showed that changes in process conditions could achieve up to 99% carbon capture levels in amine post-combustion capture (PCC) plants for combined cycle gas turbine flue gases.

8 Michailos, S. and Gibbins, J. (2022) A Modelling Study of Post-Combustion Capture Plant Process Conditions to Facilitate 95–99% CO_2 Capture Levels From Gas Turbine Flue Gases. Frontiers in Energy Research, 10. doi:10.3389/fenrg.2022.866838.

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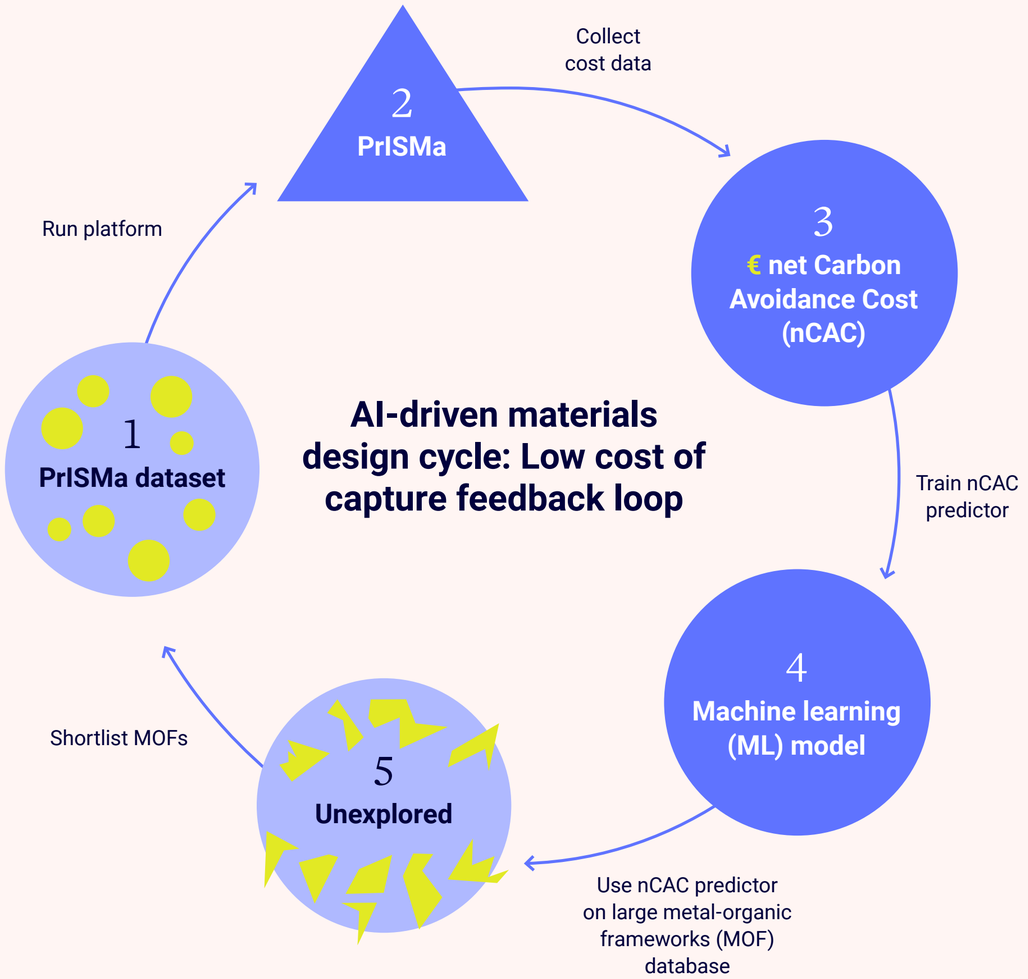


Figure 4

An AI-driven materials design cycle to obtain more top-performing materials. The PrISMa platform is used to evaluate the performance of a material in terms of the net Carbon Avoidance Cost (nCAC). As this evaluation requires state-of-the-art density functional (DFT) calculations and molecular simulations, a shortcut machine learning (ML) model is made that directly predicts the nCAC from the crystal structure. With this shortcut ML model, a database of 30,000 metal-organic frameworks (MOFs) is evaluated. Now, only the top-performing materials are evaluated by the PrISMa model. These data enable us to enhance the ML model's ability to predict top-performing materials.

Recommendations to industry

Research findings highlight several specific recommendations and areas for further investigation to support the transition to net zero industry.

Key recommendations

1 **Enable comprehensive data accessibility and industry collaboration**
Establish robust data-sharing frameworks between academia, industry and government to support real-time modelling and more accurate scenario planning.

2 **Engage with local stakeholders**
Collaborate with regional actors to align low-carbon solutions with local economic needs, share energy data and co-develop long-term sustainable decarbonisation strategies.

3 **Integrate AI and systems planning tools for optimised decision-making**
Invest in modular, adaptable modelling tools for selecting cost-effective technologies, conducting life cycle assessment and planning sector-specific decarbonisation pathways.

4 **Optimise supply chain management and resource planning**
Strengthen supply chains for specialised equipment and materials and assess national resource needs to avoid future bottlenecks in decarbonisation projects.

5 **Accelerate workforce development and knowledge transfer initiatives**
Launch targeted retraining and skills programmes in key areas like carbon capture and hydrogen. Prioritise knowledge retention in sectors with ageing workforces.

In general, advanced modelling tools development and validation should be helped through robust data-sharing agreements and cross-sectoral collaboration.

Likewise, there is a need to undertake whole energy systems analysis that encompass technology development, deployment, infrastructure planning, workforce training, while considering regional socio-economic strengths and needs to achieve net zero targets both nationally and globally (Figure 5).

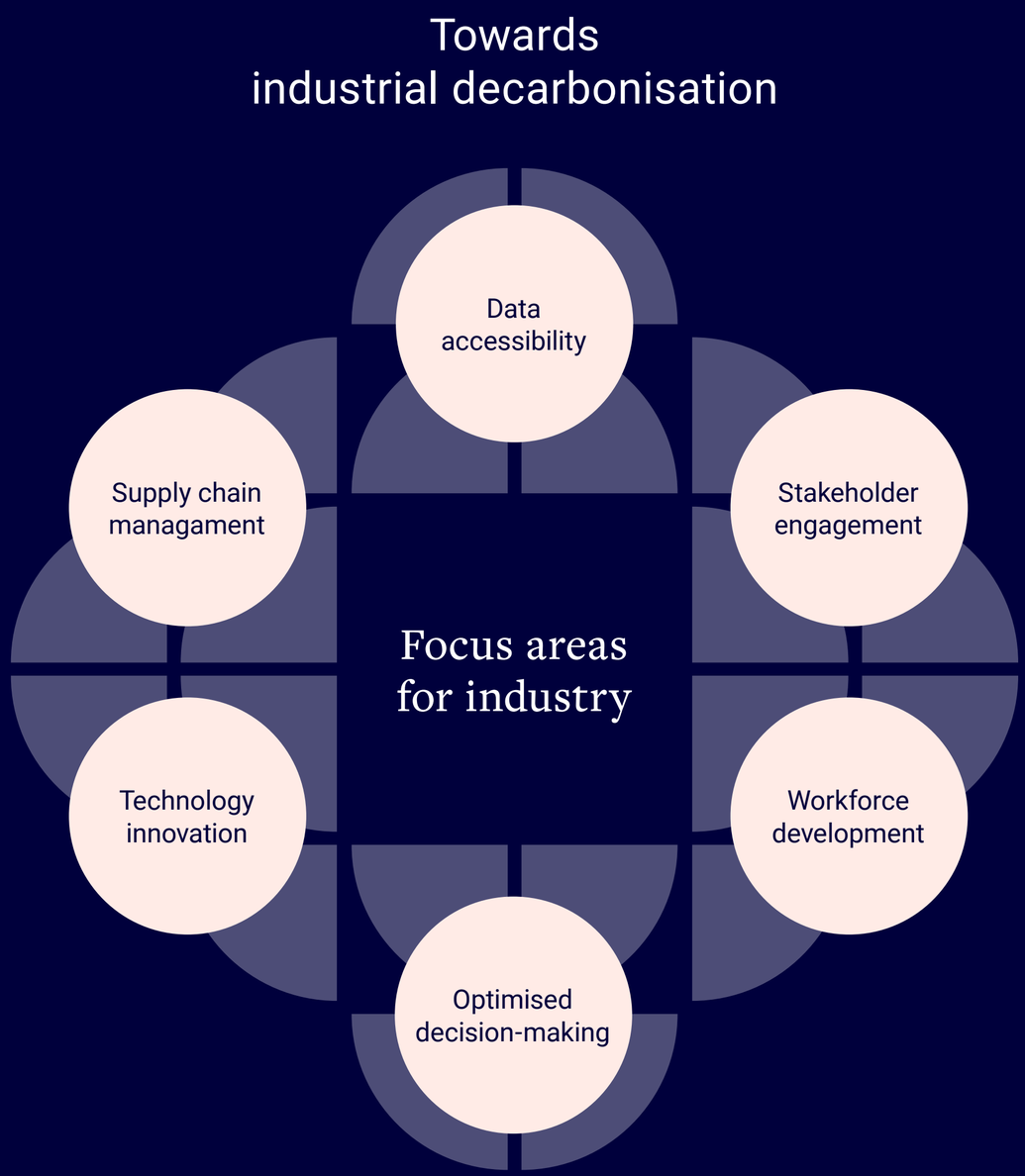


Figure 5
Recommended areas of focus for industry.

Enable comprehensive data accessibility and industry collaboration

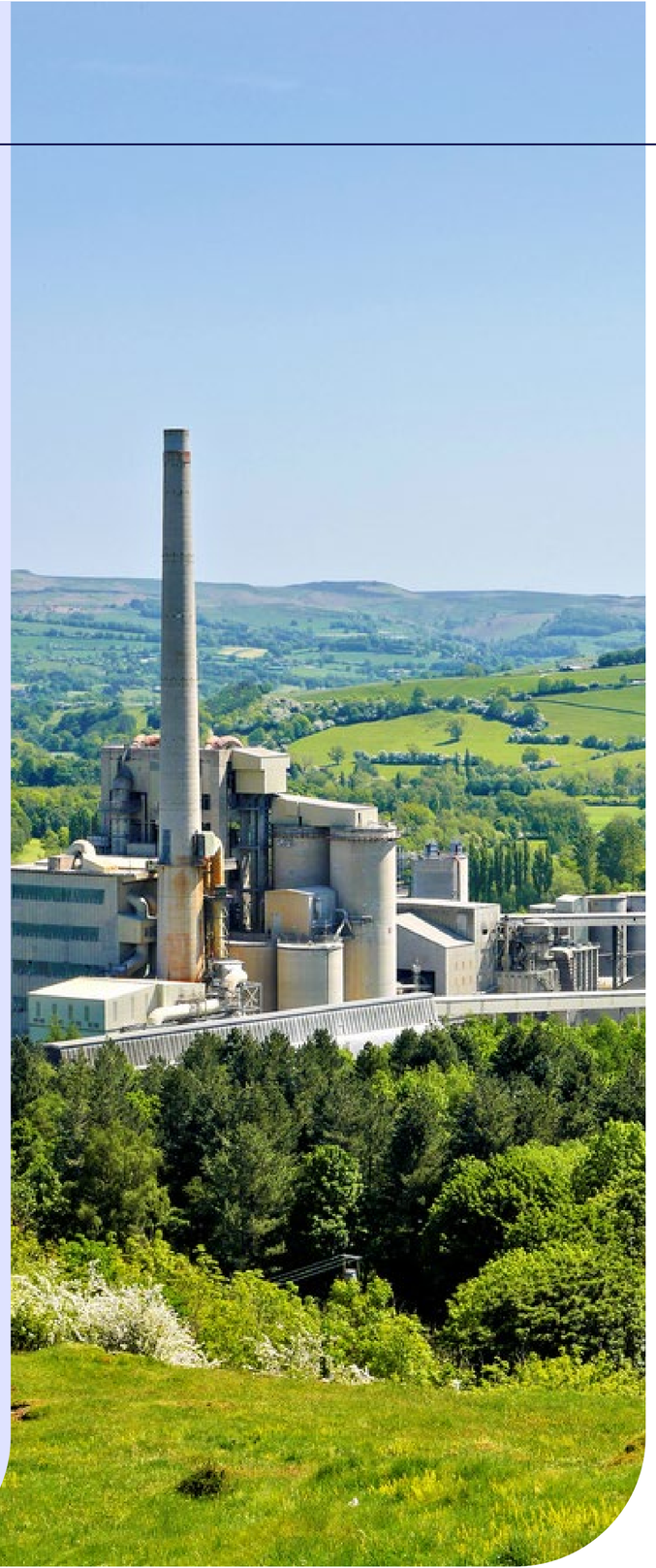
There is a clear need for robust data-sharing frameworks between academia, industry and government, enabling access to real-time, high-fidelity data on industrial operations, emissions and resource usage. This can improve the accuracy of decarbonisation models and allow organisations to carry out scenario planning, enabling them to make better-informed decisions. Furthermore, there also needs to be stronger collaboration between academia and industry to facilitate knowledge sharing and make data more 'discoverable' or avoid unintended consequences of using one dataset across different scenarios and models.

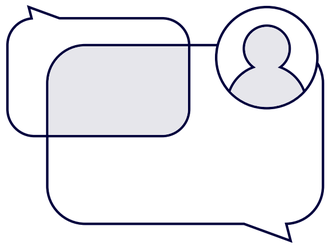
Standardised data-sharing agreements should be developed, potentially facilitated by government mandates, to make aggregated data available while ensuring privacy and competitive protections.

Engage with local stakeholders and international partners

We recommend that industry engages with local stakeholders to share data on energy use, to ensure low-carbon solutions are deployed in alignment with regional economic needs and to develop decision-making tools to foster long-term sustainability. Furthermore, cross-sector collaboration between clusters, industry bodies and policymakers is essential to build knowledge for creating scenarios with viable decarbonisation technology options. Aligning industrial decarbonisation strategies with regional economic strengths and weaknesses can increase local opportunities for growth.

Establishing partnerships to share best practices and data will accelerate adoption and reduce costs. Internationally, industries could leverage technology development and innovation to meet global sustainability targets and remain competitive in a low-carbon economy.





Integrate AI and systems planning tools for optimised decision-making

Industries should explore AI-based decision-making tools for decarbonisation planning. Artificial intelligence tools, such as the PrISMa platform used in IDRIC's research, proved essential in selecting optimal materials and processes for carbon capture. AI applications for life cycle assessment and technoeconomic analysis should be expanded to other decarbonisation technologies.

Modular decision-making tools allow industry-specific adaptation, making them versatile across sectors and responsive to technological advances. Industries should explore the development of modular systems that can be adapted for use across multiple industries, such as steel, cement and dispersed industries, to improve cost-effectiveness in the selection of decarbonisation solutions.

System planning and decision-making tools would help industries customise their decarbonisation strategies, for instance, incorporating electrified heating solutions, optimising renewable integration, storing energy and switching to alternative fuels. Emphasising the use of dynamic tools for resource allocation and cost-benefit analysis will enhance strategic energy management within industrial clusters.

Optimise supply chain management and resource planning

Scaling decarbonisation technologies requires robust supply chains, with adequate resources for specialised equipment (e.g. heat exchangers, pumps). We recommend that supply chain resilience programmes which prioritise decarbonisation needs are established, with funding to **support specialised manufacturing capacity for essential equipment**. Future decarbonisation projects will depend on specific resources and materials, potentially causing bottlenecks if supplies are insufficient or uncertain.

Industry with potential government support, should consider undertaking national assessments of critical material needs for decarbonisation, establishing contingency plans for shortages in essential resources like rare metals or components for carbon capture and hydrogen technologies.

Accelerate workforce development and knowledge transfer initiatives

Transitioning industries to decarbonisation pathways will need a workforce skilled in emerging technologies. A significant skills shortage is approaching, posing a potential barrier to achieving a sustainable industrial sector.[9] Projects identified the need for specialised training, particularly in carbon capture, hydrogen technology and advanced instrumentation. Retraining and skills development should be prioritised in industry, especially for workers in high-carbon sectors, to ensure a just transition. This can help manage job displacement while filling new job roles created in low-carbon industries.

Regional training programmes and apprenticeships should be established to build a decarbonisation-ready workforce. These programmes could be funded by industry-government partnerships and may include targeted reskilling for areas with retiring workforces.

As technologies shift, there's a risk of losing specialised knowledge essential to smooth transitions. For example, training workers to undertake grid upgrades safely should be a priority to ensure reinforcement deadlines are met, as grid upgrades are likely to become even more difficult to resource. A proactive approach to knowledge transfer will maintain continuity and reduce inefficiencies.

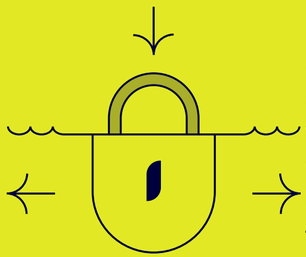
Industry and clusters should explore implementing knowledge retention programmes that focus on training younger workers in skills traditionally held by retiring employees in sectors like steel and cement. This could be facilitated by sector-specific training academies or mentorship programmes.

9 Sovacool, B.K., Bazilian, M.D., Kim, J., et al. (2023) Six bold steps towards net-zero industry. Energy Research & Social Science, 99: 103067. doi:10.1016/j.erss.2023.103067.

Technology recommendations by sector

Steel sector
As the industry shifts away from blast furnaces, electric arc furnaces offer an efficient decarbonisation pathway. However, they require precise control of scrap materials and high-quality metrology. We recommend industry supports advanced metrology and instrumentation research and development for electric arc furnaces to enable accurate, efficient decarbonisation in the steel industry.

Measurement tools
Accurate measurement tools are necessary not only for process efficiency but also for regulatory compliance. Industrial sector should establish standards and develop advanced monitoring tools in emissions reporting, ensuring accurate, traceable emissions reduction.



Carbon capture, utilisation and storage (CCUS)
UK industry should integrate CCUS as part of a balanced strategy for emissions reduction, especially in hard-to-abate sectors. Industries outside of clusters can benefit from CCU, which offers economic opportunities through CO_2 utilisation for products like polymers and methanol. To address high costs, we recommend exploring public-private partnerships that leverage both government incentives and private investment, reducing financial risks for early adopters.

Recommendations to policymakers

Based on the research findings, recommendations are made for policymakers to support the decarbonisation of industry sector (Figure 6).

Key recommendations

1 **Enable strategic place-based investment and master planning**
Develop regional industrial decarbonisation strategies that reflect local infrastructure, industry composition and workforce needs, supported by targeted financial incentives.

2 **Integrate industrial demand within broader energy system planning**
Mandate collaborative planning between industrial clusters, energy networks and transport sectors. Encourage open data through incentives and support the deployment of integrated modelling tools.

3 **Support sustained innovation and technology development**
Provide long-term funding frameworks for critical technologies like CCUS, hydrogen and direct air capture, especially in regions with high deployment potential such as the industrial clusters.

4 **Develop clear and actionable policy frameworks for industry adoption**
Set sector-specific decarbonisation benchmarks and consider financial instruments – such as risk guarantees or low-interest loans – to reduce investment barriers for high-cost technologies.

Figure 6
Recommended areas of focus for policymakers.

Enable strategic place-based investment and master planning

Policymakers should ensure that national decarbonisation goals are supported by regional strategies that account for local industry composition and workforce needs. This can improve the feasibility of achieving net zero by tailoring policy to regional strengths. Targeted financial incentives could be introduced to encourage the deployment of technologies in regions with the highest potential for positive economic and employment impacts.

Different industrial clusters, especially dispersed industries, have their own infrastructure needs and decarbonisation challenges. Dispersed industries are responsible for 55% of emissions in the UK and may not have access to increased power, hydrogen production facilities or CO_2 transport.

Tailored master planning at a local or regional level can optimise resources, prioritise infrastructure needs and align investments with regional economic and workforce capacities and weaknesses. Therefore, we recommend the formation of regional master plans that integrate industrial decarbonisation with existing infrastructure, socio-economic profiles and workforce development needs. Regional government bodies or cluster-specific task forces could oversee these efforts.

Integrate industrial demand within broader energy system planning

A holistic approach is needed, to consider the interactions between industry-specific needs and the broader national energy system. This holistic approach can be developed on the basis of robust data and scenarios. Industry hesitancy in sharing proprietary data can be mitigated with incentives or funding conditional upon data accessibility. Introduction of financial incentives, such as tax breaks or funding support, for industries that con-tribute to wider access and also open-access data initiatives, focusing on emissions and decarbonisation technologies could be considered.

IDRIC projects highlighted that successful decarbonisation relies on more than a single technology or sectoral approach. Holistic approaches have multi-sector collaboration, including energy, transport and industry, as part of their decarbonisation pathways.

Policies mandating integrated decarbonisation strategies across sectors are required. This might include joint planning between energy networks, transport and industrial clusters to align timelines, infrastructure and funding. We recommend policymakers fund the deployment of system planning and decision-making tools, identifying areas of top priority for incentives. Regulatory frameworks can encourage data-driven, cluster-specific pathways and integrate decarbonisation considerations to maximise the outcomes of research and development.

Support sustained innovation and technology development

Decarbonisation initiatives require long-term commitment beyond the typical funding cycles. Consistent government support can help stabilise investments, foster industry confidence and allow research and development to evolve with the technology. Policymakers should consider implementing decade-spanning support frameworks for key decarbonisation projects, potentially including long-term funding mechanisms or tax incentives tied to emission reductions.

Both CCUS and hydrogen were identified as critical components in achieving net zero, especially for sectors like cement and steel. Hydrogen and direct air capture were also deemed essential due to limited biomass availability. We recommend **targeted funding and policy incentives for CCUS and hydrogen integration in cement and steel are developed.** Direct air capture could be incentivised where biomass feedstocks are limited.

A coordinated national CCUS strategy could prioritise regions like Tees Valley, where industrial clusters and supportive local governments create ideal conditions for early deployment and demonstrable success. For the UK Government, it is essential to develop incentives that reduce financial risk for industries adopting CCUS. This can include tax breaks, subsidies and blended funding models to make CCUS technology more financially viable. A UK-wide approach to carbon market stabilisation could help enable industries to benefit from predictable pricing and investment returns in captured CO_2 markets.

Local governments, especially those within established industrial clusters, should work closely with national bodies to streamline permitting processes and support regional partnerships. Local authorities also have an important role in driving public awareness initiatives that can address public concerns around CCUS, positioning it as a key player in a sustainable future. Internationally, examples from the US and Middle East emphasise the value of cohesive policies, market support and funding support that align industrial decarbonisation with job creation, regional economic growth. This in turn incentivises both private and public investment for infrastructure development (e.g. for pipeline construction and maintenance).

Develop clear and actionable policy frameworks for industry adoption

Mandating carbon capture and emissions standards across high-emission industries, with benchmarks for CCS, hydrogen use and other technologies, can drive standardisation and consistent reductions. Policymakers should set sector-specific decarbonisation benchmarks for 2030 and 2040. This might include enforcement through carbon taxes or emissions credits, emerging themes during workshop).

Similarly, decarbonisation technologies come with high financial risk, slowing uptake by industry. Financial instruments such as risk guarantees or low-interest loans could de-risk investment. Government could consider establishing a “decarbonisation risk fund” offering low-interest loans or partial investment guarantees for companies implementing high-cost technologies and infrastructure upgrades. Transparent communication by policymakers is necessary to maintain public acceptance, particularly focusing on the benefits and uses of high-cost technologies, that can accelerate adoption.

→ For more information, please read IDRIC’s Frontiers Report on Green Finance and Economic Considerations.

Moving forward

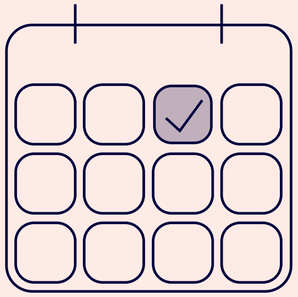
Systems planning and decision-making tools are crucial as they inform both industry and policymakers to make data-driven, future-oriented decisions. Therefore, to accelerate industrial decarbonisation, further efforts should focus on expanding systems modelling to include more granular, region-specific data on supply chains, labour markets and technological performance.

There is a need for more detailed, real-time data on regional economic dependencies and sector-specific decarbonisation potentials to enhance the accuracy of future modelling. Further development of accessible and scalable simulation tools is crucial.

Further research is needed on how to align the development of skills and workforce training programmes with emerging technological needs, ensuring that workers can easily transition into new roles within the low-carbon economy. Collaboration with local leaders, educational institutions and industry can help establish a strong talent pipeline, enabling a skilled workforce for carbon capture, utilisation and storage and related technologies, large infrastructure projects and electricity grid upgrade. Industry-wide training initiatives will also be critical to ensure workforce readiness for adopting advanced monitoring technologies.

In addition, there is a growing case for the use of artificial intelligence and machine learning algorithms to inform industrial decarbonisation. Modelling tools can be used to compare projected electricity demand with regional and local headroom figures and use this to develop a roadmap for grid upgrades at a national scale. Machine learning algorithms can allow learnings from one region to be incorporated into the development plan of others.

Policymakers should work with the energy sector and with industry to consider the implications for infrastructure and pathways for implementation. Policies can provide



a framework for regional infrastructure planning to support fuel switching and grid resilience, assessing possible future scenarios for industrial decarbonisation. Increased collaboration between stakeholders, alongside advancements in technology adoption, policy integration and cross-sector communication to align decarbonisation strategies would expedite progress towards net zero. Policymakers and industry leaders should collaborate to address barriers to decarbonisation through targeted funding, tax incentives and pilot programmes.

Greater attention needs to be given to the social and equity impacts of decarbonisation, particularly on vulnerable communities. Public perception and stakeholder engagement are crucial to ensure broad acceptance of low-carbon transitions. For example, achieving social acceptance of carbon capture, utilisation and storage will require policies that prioritise transparency, community input and local benefits. These policies should align deployment with regional economic goals and create a pathway for sustainable, community-centered growth.

Contributing projects

IDRIC projects included in this report

IDRIC ran three complementary strands of projects:

1 In-depth research projects embedded within nine Multidisciplinary Integrated Programmes (MIPs), each programme tackling a key challenge or pathway for industrial decarbonisation;
2 Shorter-term Flexible Fund (FF) projects designed to rapidly address emerging or urgent opportunities identified directly by industrial clusters;
3 Impact Accelerator (IA) projects aimed at maximising the impact of existing IDRIC projects.

Projects discussed within the report are referred to by their project ID.

◗ — Principal investigator

Project ID	Project name		
MIP 1.1	An integrated energy system planning tool for net zero industrial clusters	Janie Ling-Chin ◗, Anthony Paul Roskilly, Yousaf Khalid, Andrew Smallbone, Ugochukwu Ngwaka	Durham University
		Huda Dawood, Nashwan Dawood, Faisal Siddiqui, Ruben Pinedo-Cuenca	Teesside University
MIP 1.7	An integrated framework for levelled up and low carbon industrial clusters	Niall Mac Dowell ◗, Nadine Moustafa, Mai Bui	Imperial College London
MIP 2.1	Development of an open-source toolkit to design and evaluate the performance of low carbon infrastructure for industrial clusters	Nilay Shah ◗, Anna Korre, Zhenggang Nie, Naveed Tariq, Shyamaladevi Sivakumar	Imperial College London
		Mijndert Van der Spek, Till Strunge, Arezoo Azimi	Heriot-Watt University
MIP 2.3	Systems, infrastructure and technologies for providing low-carbon fuels	Jonathan Radcliffe ◗, Thomas Fender	University of Birmingham
MIP 3.1	A Smart Decision Modelling (SDM) tool for industrial cluster decarbonisation	Nashwan Dawood ◗, Huda Dawood, Ruben Pinedo-Cuenca, Fathi Abugchem, Chris Ogwumike, Faisal Siddiqui, Adepeju Oyewole	Teesside University
		Sumit Roy, Janie Ling-Chin, Anthony Paul Roskilly, Andrew Smallbone	Durham University
MIP 6.1	Accelerating the deployment of cost-competitive advanced carbon capture technologies for industrial decarbonisation	Susana Garcia ◗, Charithea Charalambous	Heriot-Watt University
MIP 9.2	Industrial clusters and whole energy system modelling	Paul Guest ◗, Matthew Joss	Energy Systems Catapult
FF 3-4	Comprehensive Assessment of Post-Combustion Capture Options (CAPCCO)	Stavros Michailos ◗	University of Hull
		Jon Gibbins, Abby Samson, Mathieu Lucquiaud	University of Sheffield
FF 3-11	Reducing blast furnace emissions with hyperspectral imaging	Jon Willmott ◗, Matthew Hobbs	University of Sheffield
FF 4-1	Assessing the feasibility of implementing CO_2 capture and utilisation in Quorn mycoprotein process	Dawid Hanak ◗, Nashwan Dawood, Gari Harris, Kumar Patchigolla, Diana Feliciano, Ellis Marshall	Teesside University

Project ID	Project name	Outputs	
MIP 1.1	An integrated energy system planning tool for net zero industrial clusters	Industrial cluster energy systems integration and management tool	Journal
MIP 2.1	Development of an open-source toolkit to design and evaluate the performance of low carbon infrastructure for industrial clusters	Finding least-cost net-zero CO_2e strategies for the European cement industry using geospatial techno-economic modelling	Journal
		Toolkit to design and evaluate the performance of low carbon infrastructure	Webinar
MIP 2.3	Systems, infrastructure and technologies for providing low-carbon fuels	Industrial energy infrastructure for a decarbonising Britain	Webinar
MIP 3.1	A Smart Decision Modelling (SDM) tool for industrial cluster decarbonisation	Transitioning or tinkering at a net-zero economy? Introducing an assessment framework for industrial cluster decarbonisation in the United Kingdom	Journal
MIP 6.1	Accelerating the deployment of cost-competitive advanced carbon capture technologies for industrial decarbonisation	A data-science approach to predict the heat capacity of nanoporous materials	Journal
		Shedding light on the stakeholders' perspectives for carbon capture	
		How to decarbonise our energy systems	
		A robust framework for generating adsorption isotherms to screen materials for carbon capture	
		A holistic platform for accelerating sorbent-based carbon capture	
FF 3-4	Comprehensive Assessment of Post-Combustion Capture Options (CAPCCO)	A modelling study of post-combustion capture plant process conditions to facilitate 95–99% CO_2 capture levels from gas turbine flue gases	Journal
		Conceptual design and thermodynamic investigation of novel energy and fuel generation systems from municipal waste coupled with carbon capture and storage	
		A performance modelling study for zero fossil CO_2 stack operation and solvent thermal reclaiming in post-combustion capture industrial applications	

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