Industrial Decarbonisation Frontiers Report

Life Cycle Assessment (LCA)

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 Life Cycle Assessment (LCA).

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Lead authors

Marcelle McManus
University of Bath

Contributing authors

Mark Scanlon
Energy Institute

Jasmin Cooper
Imperial College London

Isobel Marr
Heriot-Watt University

Huda Dawood
Teesside University

Xinyuan Ke
University of Bath

Amir Badiee
University of Lincoln

Clair Gough
University of Manchester

Lindsay-Marie Armstrong
University of Southampton

Alan Guwy, Jamie Massenet
University of South Wales

Executive summary

This report synthesises IDRIC’s research on Life Cycle Assessment (LCA), highlighting its essential role in supporting industrial decarbonisation. By evaluating full environmental impacts across the entire life cycle of decarbonised technologies and systems, LCA enables industry, policymakers and technology developers to make informed, sustainable decisions that avoid unintended consequences.

Key findings

Importance of comprehensive modelling
LCA is an essential tool to evaluate environmental impacts, across locations and over time, but inconsistent system boundaries and carbon accounting methods between sectors make it challenging to assess complex, multi-industry systems.

Sustainability and unintended consequences
LCA was used to assess a range of decarbonisation technologies and pathways. While these were highly effective in reducing greenhouse gas emissions, some were shown to cause unintended environmental impacts such as resource depletion or toxicity – highlighting the need for whole-system analysis.

Uncertainty and methodological challenges
A lack of standardised data, transparency and methodological consistency limits reproducibility and comparability of LCAs, especially for emerging technologies where life cycle inventory data is scarce or outdated.

LCA for emerging technologies
LCA is particularly impactful when applied early in the development of technologies; helping to guide design choices, assess trade-offs between decarbonisation and environmental impacts, and avoid locking in unsustainable practices.

Communication and collaboration
Strong engagement between industry, academia, NGOs and policymakers – through both in-person forums and online tools – helps to improve understanding of LCA results, which can lead to wider adoption and better-informed decision making.

Recommendations for industry

Embed LCA early in decision-making
Integrate LCA during the design and development stages of technologies and systems to enable proactive identification of trade-offs and ensure that sustainability is built in from the outset.

Enhance resource efficiency and circularity
Prioritise circular systems by reuse of industrial by-products, thus enabling reduction of waste treatment and significantly reducing environmental impacts.

Promote collaboration and transparency
Share data, case studies and methodologies across companies and clusters in order to improve consistency in LCA practices, build trust and enable coordinated decarbonisation strategies.

Encourage adoption of innovation
Leverage LCA to accelerate innovation in emerging technologies such as alternative carbon capture methods and circular production processes that can deliver both decarbonisation and environmental net gains.

Recommendations for policymakers

Enable improved data sharing and availability
Establish centralised, standardised LCA data repositories and incentivise transparent, high-quality data collection between industries. In some sectors, mandated sharing of life cycle data could be considered.

Enhance communication of results and address uncertainty issues
Support LCA reporting that includes uncertainty and sensitivity analysis to reflect the full range of potential environmental outcomes and improve trust in results.

Align cross-sector policy and regulation
Reduce double counting and omitting emissions data by standardising carbon accounting frameworks across sectors. Incentivise global net zero contributions, even if they cause a temporary increase in local emissions.

Support technology development with early-stage LCA
Make LCA a funded component of innovation grants, particularly for emerging technologies, to ensure sustainability is evaluated from the start and integrated through scale-up phases.

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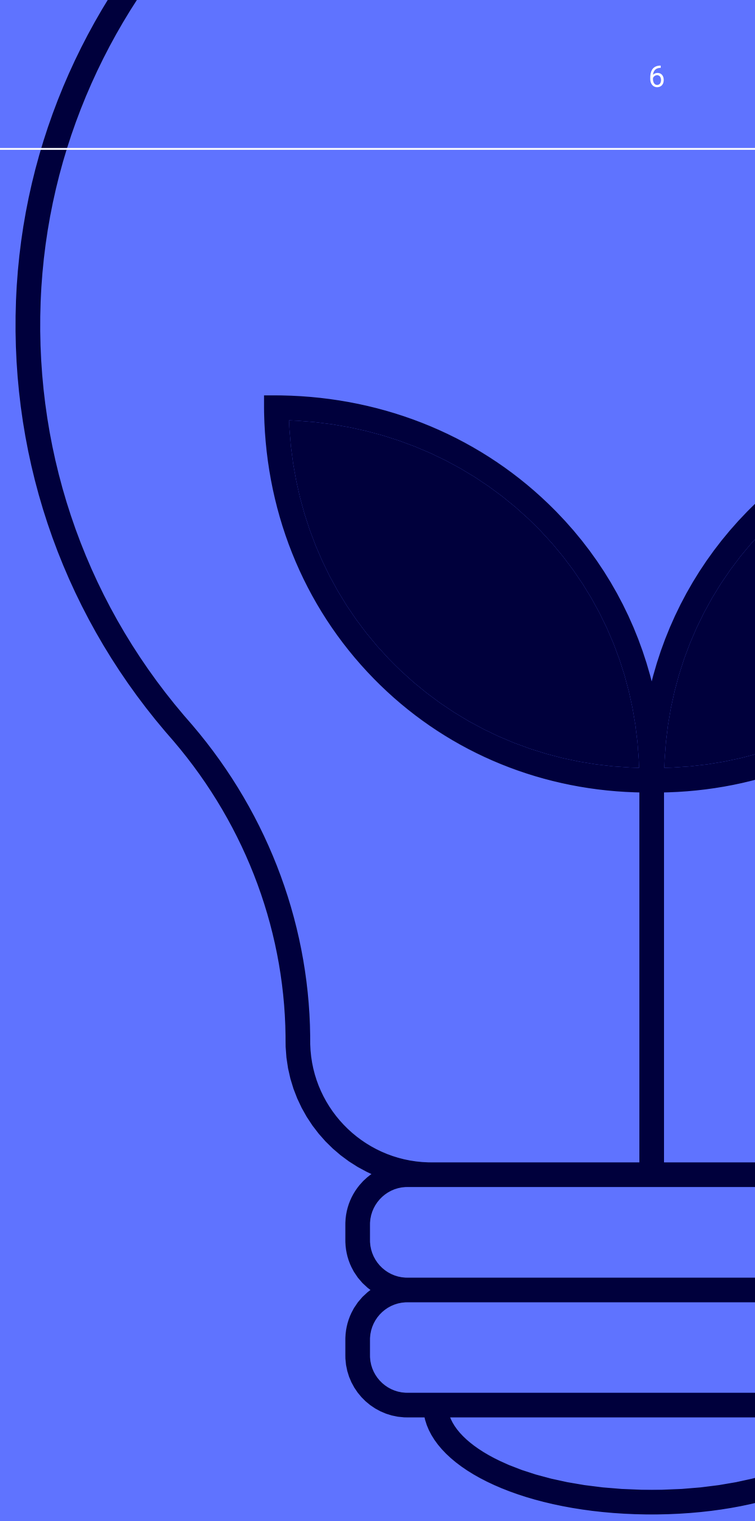
Introduction

Decarbonisation of industry is a complex challenge and understanding the full environmental impacts of products and systems – within an industrial context – is essential to meet our net zero carbon targets. There are many potential pathways to decarbonise industry, using different technologies, fuels and processes. However, to make the right choices, we need to understand their overall impact, not just in terms of carbon but also their broader effects on the environment.



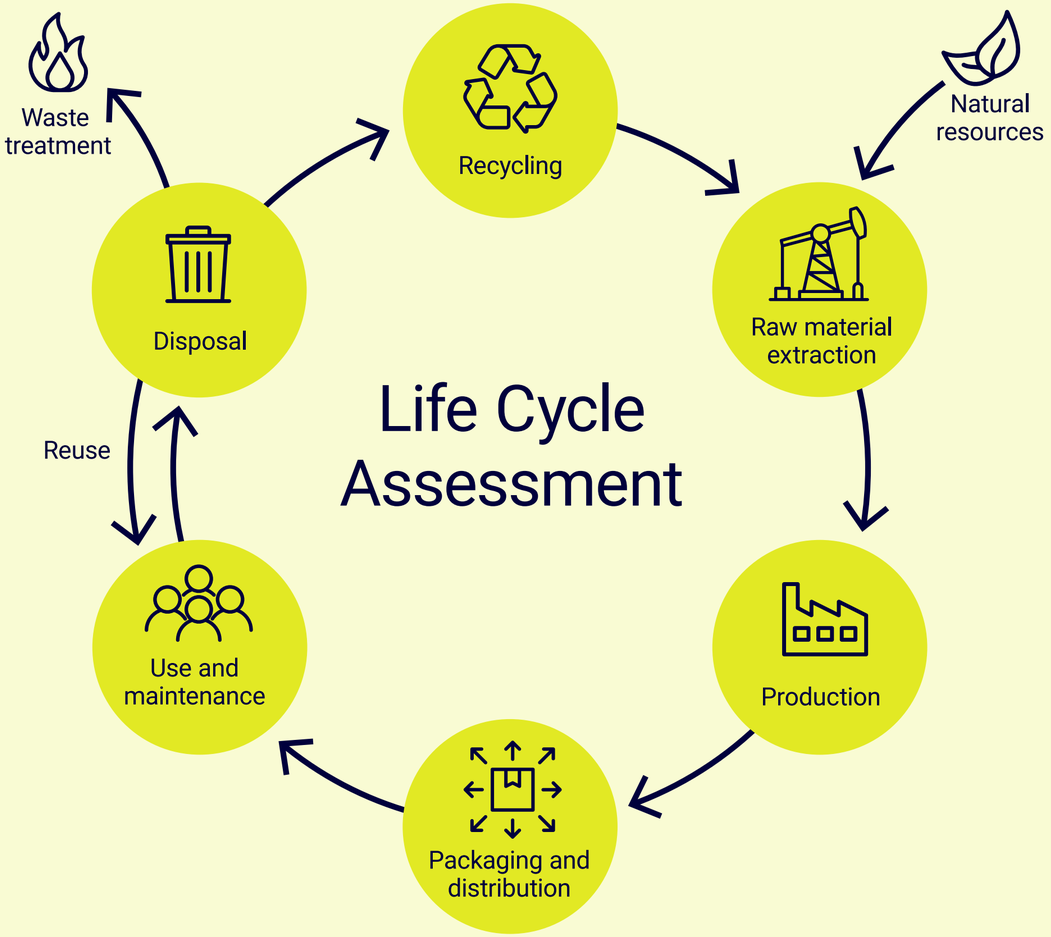


Figure 1

Life Cycle Assessment (LCA) evaluates the environmental impacts of a product, process, or service throughout its entire life cycle, from raw material extraction to end-of-life disposal.

Source: Adapted from Swiss Federal Office for the Environment (BAFU) (2022)

Technologies cannot exist in isolation – they interact with infrastructure, supply chains and other industries. A system-wide approach is therefore necessary to understand how adopting a particular technology affects the bigger system. This includes looking at both direct impacts within the immediate system (known as the system boundary) and indirect effects (such as how the technology influences other parts of the economy and environment). Without this broader perspective, we risk making choices that seem beneficial in one area but cause problems elsewhere. This is why a life cycle perspective is essential for effective decarbonisation.

Life Cycle Assessment (LCA) is a method for evaluating the environmental impacts of a product, process, or service throughout its entire life cycle, from raw material extraction to end-of-life disposal (Figure 1). It is a powerful tool that supports the design of long-term strategies to mitigate greenhouse gases (GHGs), making its use crucial for decarbonisation. The use of LCA enables industry, policymakers and technology developers in their decision-making in a variety of areas, such as screening for alternative technologies, pinpointing the specific stages of a process where the most significant environmental impacts are occurring (hotspot identification) and contributing data to enable the production of more sustainable solutions.

LCA is used as the basis for calculating carbon footprints, pinpointing the carbon-intensive stages of a product's life and identifying opportunities for reduction. When used effectively, it helps identify problematic parts of supply chains, reduce unintended consequences, prevent double carbon-counting and carbon leakage or burden shifting (i.e. the indirect transfer of emissions elsewhere, rather than their absolute removal/avoidance)

Despite LCA being identified as a critical tool to enable effective decarbonisation, there is still a lack of consistent data available for both novel and existing materials, leading to an inability to reliably compare results. Encouragingly however, efforts to address uncertainty and sensitivity, and improve data collection and sharing, are rapidly improving the ability to access and process data. Alongside data availability, there are issues with methodological consistency, with different industrial sectors using differing conventions for system boundaries and carbon measurement.

Achieving net zero requires consistency in data and methods, which can be applied both locally and globally. The availability of robust, reliable data, along with standardised methods and tools is essential across supply chains, sectors and international borders.

Research findings

Life Cycle Assessment (LCA) is a critical tool in the path towards industrial decarbonisation. IDRIC's projects have applied LCA in numerous case studies, supporting the design and development of emerging technologies, providing information for potential scenario development and selection, and evaluating the impacts of existing technologies to help identify next steps for reducing carbon emissions.

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

Project ID	Project name
MIP 1.3	Life cycle analysis framework for industrial decarbonisation
MIP 1.6	Unintended consequences? Life cycle comparison of UK industrial decarbonisation pathways
MIP 2.6	Integrated assessment of BECCS in context: environmental, policy, regulatory and social factors
MIP 3.1	A smart decision modelling (SDM) tool for industrial cluster decarbonisation
MIP 5.2	The VFA factory for decarbonisation
MIP 6.1	Accelerating the deployment of cost-competitive advanced carbon capture technologies for industrial decarbonisation
MIP 7.1	Environmental impacts of the large-scale deployment of a hydrogen energy system
MIP 8.4 / IA 4.4	Where to locate new bioenergy with carbon capture and storage? A natural capital approach
MIP 8.5	Bio-balance
MIP 8.7	Up-scaling on-site CO_2 utilisation for decarbonisation of dispersed cement sector: a novel route to reliable net-zero concretes
MIP 8.8	Creating a carbon framework for a decarbonised circular economy
FF 2-2	Determining optimum pyrolysis conditions for biochar to be used as metallurgical coal replacement – in support of deep decarbonisation of large UK industrial emitters based within the Humber cluster

The projects covered a wide range of applications, using LCA to:

- Assess decarbonisation pathways for ammonia, cement, methanol and steel production.
- Evaluate biomass supply chains and land-use strategies for bioenergy with carbon capture and storage (BECCS).
- Compare the use of biochar with metallurgical coal for the steel industry.
- Explore the environmental impacts of hydrogen production, utilisation, transmission and application as an energy vector.
- Assess carbon capture and utilisation (CCU) opportunities, exploring the conversion of industrial wastes into valuable products.

The LCA work carried out by IDRIC varies in terms of the range of environmental impacts addressed. Many studies have focused primarily on greenhouse gas (GHG) emissions – an understandable emphasis in decarbonisation efforts. However, studies that considered all commonly explored environmental impacts highlighted that while decarbonisation pathways often reduce emissions, they can introduce other unintended environmental consequences, such as resource depletion or toxicity increases. The work does not suggest that decarbonisation always results in these negative outcomes, rather that we need to be mindful of these potential issues. Using full LCA early in the technology development process can enable us to optimise nascent systems – leading to the creation of truly transformative systems, which not only help achieve net zero but also support broader sustainability goals.

LCA is an essential tool to evaluate environmental impacts, across locations and over time, but inconsistent system boundaries and carbon accounting methods between sectors make assessing complex, multi-industry systems challenging.

Importance of comprehensive modelling

A critical message from across all projects was the importance of comprehensive modelling. LCA is an essential tool to help evaluate environmental impacts at multiple spatial and temporal resolutions, meaning it can assess how impacts vary depending on location (spatial resolution) and over time (temporal resolution). It can also be used to help determine costs and some social impacts, helping decision-makers understand how sustainability trade-offs evolve over time and across different regions.

Effective LCAs require the integration of diverse methods to capture both detailed insights (e.g. to help understand where exactly where impacts occur within a particular product or system) and broad overviews which can help identify patterns between systems or products. However, the use of different system boundaries and carbon accounting methods is common across different sectors. This leads to challenges when working with complex systems, especially when these cross industrial sectors and disciplines.

Supply chains play a significant role in environmental impacts, and decarbonising supply chains amplifies the benefits of broader decarbonisation efforts. Despite this, detailed and spatially explicit analysis of transportation is often missing from systems, and IDRIC project MIP 2.6 found this was of particular significance within the BECCS supply chain. Research identified critical differences within common standards and policies regarding allocation methods, the use of uncertainty and how temporal issues are accounted for. Projects MIP 8.8, MIP 2.6 and others produced research which highlights that transparency in the choice of methodologies (Figure 2), along with transparent and robust carbon accounting, are essential for enabling informed decision-making among policymakers and industry leaders.

Source		ISO 14040 & 14044	Techno-Economic Assessment & Life Cycle Assessment Guidelines for CCU	Life Cycle Assessment of Circular Systems	Responsible Steel International Standard	Whole life carbon assessment for the built environment	PEFCR
Primary Considerations	ALCA						
	CLCA						
	Economic Allocation						
	Mass Allocation						
	Energy Allocation						
	Sub-division of System						
	System Expansion						
	Circular LCA						
	CCUS						
Temporal	Dynamic Inventory						
	Dynamic Characterisation Factors						
	Delayed Emissions						
Regionalisation	Regionalised LCA						
Data Quality Analysis	Uncertainty Analysis						
	Sensitivity Analysis						
Comments		[1]	[1,2,3,4,5]	[6]	[6]	[6]	[1]
References		ISO 14040, 2006 ISO 14044, 2006	Langhorst, 2022	ICCA, 2022a, 2022b	ResponsibleSteel, 2022	RICS, 2017	EC, 2017

Figure 2

Summary of LCA Guidelines, showing the extent to which six key LCA related policies and standards mention and describe critical parts of LCA methodology, such as attributional and consequential LCA (ALCA & CLCA), and how carbon capture and utilisation (CCU) is considered. The lack of detail across many of these guidelines indicates the uncertainty in approaches that can be encountered by LCA practitioners, and highlights where some discrepancies in results may occur. MIP 8.8

Table adapted from A. Pinto, L. McDonald et al, (2024), Improving life cycle assessment for carbon capture and circular product systems, The International Journal of Life Cycle Assessment 29 (3), 394-415

Mention & describe
Mention only
Do not mention

Sustainability, unintended consequences and circular economy

Circular practices, such as reusing industrial by-products, CCU, or biochar production, are central to reducing waste and enhancing environmental sustainability. IDRIC's research has demonstrated significant environmental benefits from circular approaches. For example, in IDRIC project MIP 5.2 the production of volatile fatty acids (VFAs) from waste materials was found to have eight times lower global warming potential compared with traditional methods, along with other positive environmental impacts across 12 impact categories. For more information on IDRIC's research in this area, please refer to our Frontiers Report on Circular Economy.

However, there are instances where decarbonisation can have unintended consequences. For example, project MIP 1.6 found that the use of the sorbent monoethanolamine (MEA) used to capture carbon dioxide, within CCS processes, increased ecotoxicity impact. To reduce this, alternative carbon capture processes can be considered, such as calcium looping. This highlights why whole-system analysis is critical: without it, we risk unintended consequences i.e. solving one problem while unintentionally creating another.

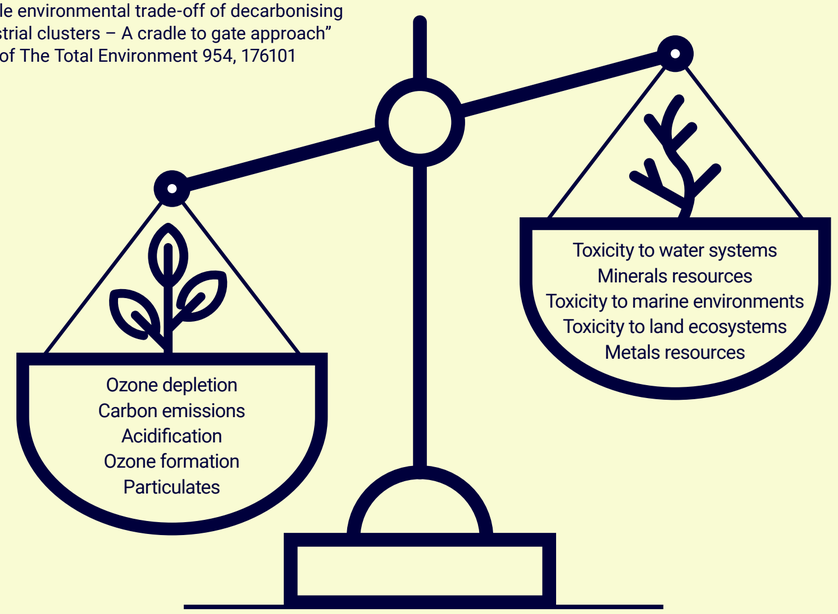
Full LCAs are needed in addition to the subset of carbon accounting in order to fully identify any unintended consequences resulting from GHG reduction strategies. Whilst intuitively we might think decarbonisation or circular systems always have a lower environmental impact, it may not be the case in every situation. We therefore need to ensure a critical assessment is carried out before major changes are made in order to optimise environmental benefits. Early identification of the impacts is key to minimisation and mitigation, ahead of any large-scale deployment.

IDRIC's work has shown that even in relatively well studied systems, like hydrogen, there are significant gaps in detail from across their life cycle. In project MIP 7.1, a comprehensive review of LCA methodologies was applied across the hydrogen value chain, including production, transmission and end-use stages. It showed a significant drop off in understanding of the environmental impact of the end-use of the fuel, compared with the production. This highlights that even when we know and understand a supply chain, the full environmental impacts have not always been calculated.

Figure 3

Environmental Trade Offs MIP 1.6

Adapted from J. Cooper & A. Hawkes (2024)
"Life cycle environmental trade-off of decarbonising UK industrial clusters – A cradle to gate approach"
Science of The Total Environment 954, 176101



Uncertainty and methodological challenges

Whilst LCA is a highly powerful tool, there are still methodological and data-associated challenges with its use which need to be addressed. Our research has highlighted that these include:

- Limited reproducibility of an LCA, or even the re-use of technology information within an LCA, due to the lack of transparent Life Cycle Inventory (LCI)* datasets or lack of details on process' mechanisms, kinetics, or where estimates have been made.
- Generic LCI data is typically relatively old, meaning it is not the most accurate or representative when modelling emerging technologies.
- Lack of transparency in the LCI, whether deliberately (e.g., to protect commercially sensitive information) or not, makes replication of the study challenging and in turn limits the future applications of the LCA in question, such as using it for an upstream process in another LCA (see project MIP 8.8 for more detail).
- Temporal and spatial uncertainties in LCA modelling create challenges that require continuous refinement, whilst the diversity of methodologies in LCA can cause discrepancies in decision-making. This necessitates the creation of frameworks for consistency and alignment across regions and sectors (see project MIP 8.8 for more detail).

* The LCI is the result of detailed accounting of all the material and energy flows (inputs and outputs) associated with a product, process, or activity throughout its life cycle.

LCA for emerging technologies

IDRIC has used LCA for the assessment and optimisation of emerging technologies, such as sorbent-based direct air carbon capture (DAC) (project MIP 6.1 and BECCS (projects MIP 2.6 and MIP 8.4. In project MIP 8.7, comparative LCA has been proven effective for assessing the scalability of novel mineral carbonation processes for producing low-carbon construction materials, highlighting the need for balanced optimisation between sustainability and material performance. While many industries and businesses recognise LCA as an extremely valuable tool for decarbonisation, its acceptance and application vary by sector.

IDRIC's research found that the most challenging yet impactful applications of LCA are for emerging technologies, where it has the most potential to shape product and process design to achieve both decarbonisation and environmental net gain. For example, project MIP 8.4 identified that formulating an effective land-use strategy for BECCS delivery could potentially meet multiple priorities, such as tree planting, improving natural capital (specifically biodiversity) and economic resilience to UK farmers growing these crops.

Using a life cycle-based framework to identify and evaluate trade-offs at this early stage has significant advantages in ensuring sustainable technology deployment. Nevertheless, at this early stage the levels of uncertainty are higher, for example, because results are sensitive to any processes changes as technologies and systems develop. It is critical to be fully transparent about this to aid decision-making.

Communication and collaboration

Effective communication and collaboration are critical to the successful widespread adoption of LCA. Collaboration between industrial clusters, academic researchers, NGOs and governments is integral to advancing decarbonisation technologies.

Investment in tools, such as the interactive visualisation platforms developed by IDRIC projects MIP 6.1 and MIP 3.1, can facilitate the communication of LCA research findings to industry and policy stakeholders, aiding their decision-making. Similarly, workshops or other stakeholder engagement and knowledge exchange activities, can allow the sharing of academic LCA findings, fostering collaboration and supporting policy development. This engagement between academics and these stakeholders can both drive change in individual processes and enable policy mechanisms for cross-sectoral change.

Carbon accounting can be complex, especially for complex systems that cover national and international boundaries, and for which impacts and benefits might be felt over decades – but that should not prevent action. Industry can play a pivotal role in driving transparent, standardised approaches to ensure accelerated progress toward net zero by collaborative data sharing, being transparent with data and methodology, and working across sectors to create case studies.

Recommendations to industry

Based on IDRIC's work on Life Cycle Assessment (LCA), we make the following recommendations to industry to enable them to understand the full environmental impacts of different decarbonisation pathways, to assess trade-offs and to move forward with the most effective strategies to meet net zero goals, whist minimising unintended environmental consequences.

Key recommendations

1 **Embed LCA early in decision-making**
Integrate LCA during the design and development stages of technologies and systems to enable proactive identification of trade-offs and ensure that sustainability is built in from the outset.

2 **Enhance resource efficiency and circularity**
Prioritise circular systems by reuse of industrial by-products, thus enabling reduction of waste treatment and significantly reducing environmental impacts.

3 **Promote collaboration and transparency**
Share data, case studies and methodologies across companies and clusters in order to improve consistency in LCA practices, build trust and enable coordinated decarbonisation strategies.

4 **Encourage adoption of innovation**
Leverage LCA to accelerate innovation in emerging technologies such as alternative carbon capture methods and circular production processes that can deliver both decarbonisation and environmental net gains.

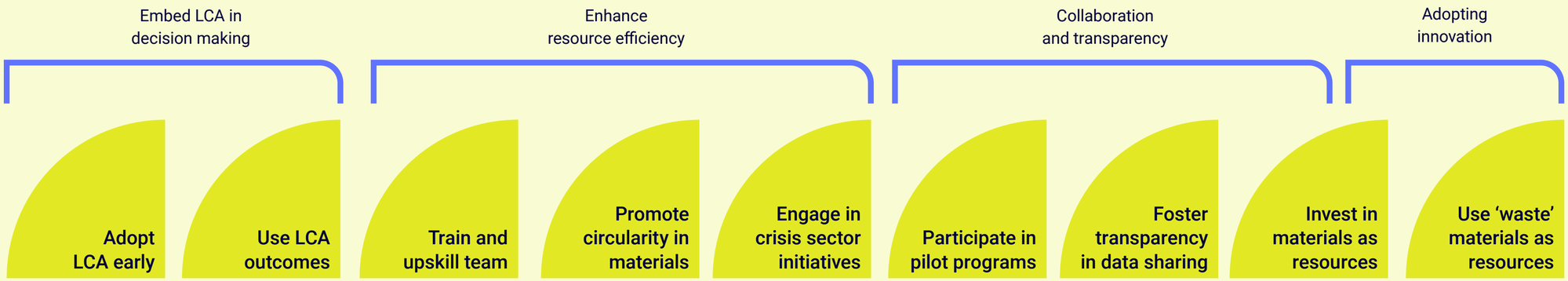


Figure 4

Themes Identified for incorporating LCA into industrial approaches.

Embed LCA early on in decision-making

Incorporating LCA at the earliest stages of design and process development embeds sustainability into novel processes and products and enables real-time adjustments to be made. By doing this we can avoid unintended consequences and ensure we maximise environmental benefits.

Effectively integrating LCA requires training and investment to equip the workforce with the necessary skills to understand and implement LCA within industrial processes. Simple decision-support tools, such as a multi-criteria decision tools and framework developed by IDRIC project MIP 3.1 have been designed to support industrial clusters in planning their decarbonisation strategies, incorporating environmental, economic and social factors. For more information on IDRIC's decision making tools, please refer to our Frontier's Report: Systems Planning and Decision Making Tools.

In project MIP 8.4, a cross-sectorial policy roundtable discussing the barriers to BECCS implementation found it was critical that decision makers directly engaged with the financial markets to enable transparency and robust regulation of the BECCS technologies. Communicating LCA results transparently is critical – not just for internal decision-making but also for building trust with consumers, stakeholders and regulators by demonstrating environmental responsibility.

Enhance resource efficiency

IDIRC's LCA research shows that efficient circular systems can reduce environmental impacts by a factor of two to eight compared with conventional methods. Using "wastes" as a resource enables the reduction of waste treatment, as well as creating new value chains and preparing industry for a time when we have de-fossilised and will require carbon from alternative sources.

To achieve this, we need to invest in optimising supply chain logistics to reduce the environmental impacts associated with raw material transport. This is especially relevant when future raw materials may be more geographically dispersed and sourced from sites that were traditionally viewed as waste streams and have no history of supplying raw materials and creating value.

For more information on IDRIC's research in this area, please refer to our Frontiers Report on Circular Economy.

Incorporating LCA at the earliest stages of design and process development embeds sustainability into novel processes and products, and enables real-time adjustments to be made.

Promote collaboration and transparency

It is clear that no one sector or industry can achieve net zero alone. To create sustainable materials and systems, a substantial improvement in meaningful cross-sector collaboration is required. Encouragingly, this is already happening in many of the UK's industrial clusters, where we are beginning to see successful synergies in logistics sharing and coordinated investment, as well as materials sharing. However, while evidence shows shared systems are environmentally beneficial, there are still numerous blockers. This includes how each actor is rewarded – carbon accounting as it stands doesn't always financially reward the groups of companies working together to reduce carbon – for their contributions.

Expanding participation in pilot programs and demonstrators that embed LCA will help create case studies that validate their feasibility and quantify their environmental benefits. Results from these demonstrators should be shared widely, with the aim to foster transparency, emphasise feasibility and environmental benefits and provide a robust evidence base to justify further adoption.

Industries should develop relationships with local communities affected by their projects as early as possible in the process. Not only will this encourage trust and transparency, it also allows a better understanding of the opportunities and risks for the community and enables local people to input meaningfully into project design.

Encourage adoption of new innovations

Investing in green technologies is critical to the success of industrial clusters and achieving UK and international net zero targets. By using LCA approaches, IDRIC's research has highlighted that, for example, innovation is particularly impactful in the following areas:

- Exploration and adoption of the use of alternative chemicals for the carbon capture processes (as part of CCS) to reduce unintended environmental consequences.
- Prioritising the use of industrial by-product and waste streams for processes like mineral carbonation and biomass conversion, reducing reliance on raw materials.

In order to create sustainable materials and systems, a substantial improvement in meaningful cross-sector collaboration is required.

Recommendations to policymakers

Developing strong policies for the use and development of Life Cycle Assessment (LCA) will be critical in achieving national and global net zero targets. IDRIC's work has identified four key areas for policy development.

Key recommendations

1 **Enable improved data sharing and availability**
Establish centralised, standardised LCA data repositories and incentivise transparent, high-quality data collection between industries. In some sectors, mandated sharing of life cycle data could be considered.

2 **Enhance communication of results and address uncertainty issues**
Support LCA reporting that includes uncertainty and sensitivity analysis to reflect the full range of potential environmental outcomes and improve trust in results.

3 **Align cross-sector policy and regulation**
Reduce double counting and omitting emissions data by standardising carbon accounting frameworks across sectors. Incentivise global net zero contributions, even if they cause a temporary increase in local emissions.

4 **Support technology development with early-stage LCA**
Make LCA a funded component of innovation grants, particularly for emerging technologies, to ensure sustainability is evaluated from the start and integrated through scale-up phases.

Enable improvements in data sharing and availability

LCA relies on high-quality, comprehensive inventory data to accurately assess environmental impacts, so poor availability of data is a critical issue for all industrial decarbonisation stakeholders. Even when life cycle inventory data is available, it is often not shared by industry due to concerns about competitiveness and proprietary processes.

To overcome this, centralised repositories could be developed to facilitate access to standardised, potentially harmonised and verified datasets. Incentives could be provided for those who invest in high-quality data collection and sharing practices, encouraging a change in data collection and sharing culture.

In some sectors, mandated sharing of life cycle data could be considered. This may be particularly beneficial in sectors where shared resources and complex supply chains mean that access to regulated data is critical to the successful decarbonisation of the entire sector, as well as the success of a particular industry or business. The development of sustainable aviation fuels is a good example of this.

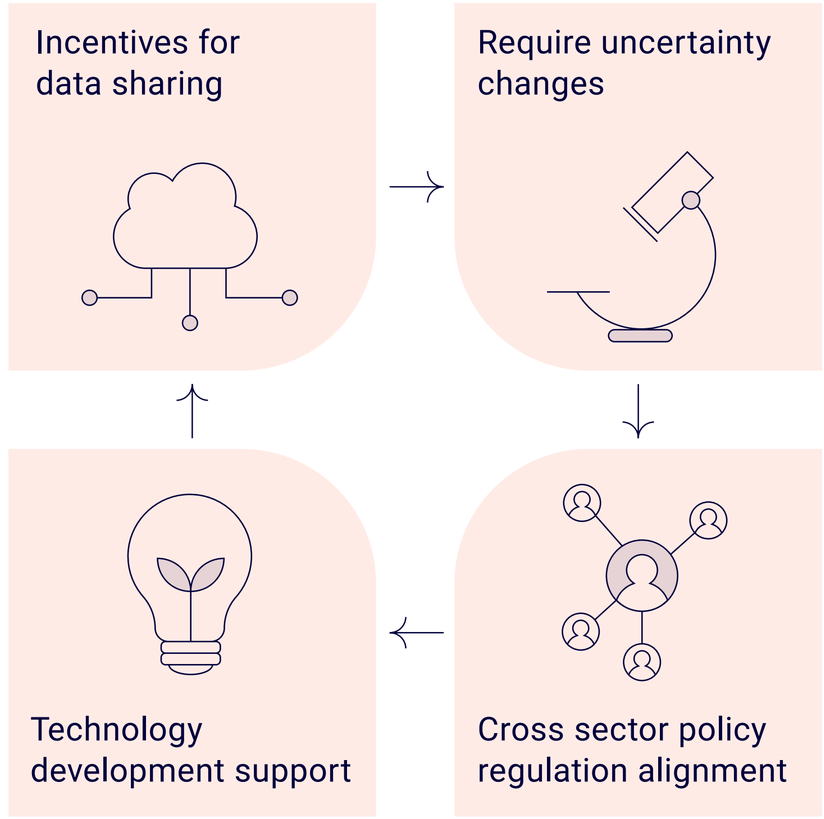
Enhance communication of results and address uncertainty issues

Effective communication of LCA results is crucial for their uptake and use in decision-making. However, when single-number results are provided for a process or system, the validity of the results can be questioned. Similarly, these single numbers do not represent wider systems or potential outliers, meaning critical environmental impacts might be missed or miscalculated.

Therefore, the use of uncertainty and sensitivity analysis within LCA should be incentivised. This move away from single-number results reflects the range associated with inventory data relating to, for example, spatial or temporal differences, as well as inherent uncertainty associated with early-stage data for emerging technologies.

Figure 5

Key areas for policy development identified.



> Centralised repositories could be developed to facilitate access to standardised, potentially harmonised, and verified datasets. Incentives could be provided for those who invest in high-quality data collection and sharing practices.

Align cross-sector policy and regulation

Whilst LCA is underpinned by ISO standards and various policy guidance, significant variation in approaches still exists, particularly across sectors, leading to issues with double counting and emission omissions. With complex supply chains and the potential of carbon to be used several times in a circular system, this is critical to standardise. Carbon accounting frameworks – as a precursor to full LCA methodology – should be harmonised across sectors to avoid these issues.

LCA should be used as a foundational tool for designing and evaluating decarbonisation policies to ensure balanced environmental trade-offs.

Whilst net zero targets at both a national and local level – such as within an industrial cluster – are critical to mobilising decarbonisation, they can sometimes disincentivise action for global carbon reduction. Therefore, we need policies that incentivise global net zero contributions, even if they cause a temporary increase in local emissions, for example when setting up new low-carbon infrastructure.

Support technology development

Most of the industries IDRIC has engaged with were fully aware of the benefits the use of LCA could bring. However, the cost and time required to undertake LCA often acts as a barrier.

To overcome this, we recommend funding early-stage LCA through innovation grants. This could become a funded, mandatory component of research and development grants for emerging technologies. The data provided by these studies could then help to drive the centralised data collection repositories previously described.

Industry should engage with government to clarify their needs, particularly regarding Monitoring, Reporting and Verification (MRV) of the emerging technologies. Government in turn, will require scientific expertise and mechanisms to de-risk business models for new technologies to encourage widespread adoption.

IDRIC's research also indicated that the provision of platforms – and associated funding mechanisms –to support industries working collaboratively on resource optimisation and circular economy practices, can accelerate the transition to low environmental impact industrial processes.

Whilst net zero targets at both a national and local level are critical to mobilising decarbonisation, they can sometimes disincentivise action for global carbon reduction.

Moving forward

To accelerate industrial decarbonisation in a way that supports long-term environmental resilience, future research should focus on the provision and collection of transparent and robust life cycle data for existing and nascent technologies.

There should be stronger incentives for integrating LCA into early-stage development and a particular focus on downstream technologies, value chains and materials used in emerging sectors such as CCS technologies, BECCS and hydrogen storage.

Pilot projects with embedded LCA and techno-economic assessments are required to understand the impact of emerging technologies beyond the lab scale. This should then be followed by the integration of LCA throughout further scale-up phases to ensure continued environmental benefits are realised.

Standardised carbon accounting frameworks should be further developed to ensure fair GHG reductions, as well as the ability to compare and add complex supply systems into novel and existing technologies. Fair and transparent incentives to create circular processes within industrial clusters, with mechanisms that reward global carbon reduction efforts over localised targets, must be developed and adopted.

To enable the successful implementation of all the above, collaboration between policymakers, industry and LCA practitioners will be vital.

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	Researchers	
MIP 1.3	Life cycle analysis framework for industrial decarbonisation	Marcelle McManus ◣, Linda Newnes, Ariane Pinto, Lewis McDonald, Sam Cooper	University of Bath
MIP 1.6	Unintended consequences? Life cycle comparison of UK industrial decarbonisation pathways	Adam Hawkes ◣, Jasmin Cooper	Imperial College London
MIP 2.6	Integrated assessment of BECCS in context: environmental, policy, regulatory and social factors	Clair Gough ◣, Sarah Mander, Diarmaid Clery, Muir Freer, Abhilasha Fullonton, Lisa Bell	University of Manchester
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, Tony Roskilly, Andew Smallbone	University of Durham
MIP 5.2	The VFA factory for decarbonisation	Alan Guwy ◣, Rhys Jones, Jaime Massanet-Nicolau	University of South Wales
		Marcelle McManus, Ariane Pinto, Lewis McDonald	University of Bath
MIP 6.1	Accelerating the deployment of cost-competitive advanced carbon capture technologies for industrial decarbonisation	Susana Garcia ◣, Charithea Charalambous	Heriot-Watt University
MIP 7.1	Environmental impacts of the large-scale deployment of a hydrogen energy system	Martin Maeso ◣, Mark Scanlon, Toni Needham, Amaia O'Reilly	Energy Institute
MIP 8.4 / IA 4.4	Where to locate new bioenergy with carbon capture and storage? A natural capital approach	Lindsay-Marie Armstrong ◣, Gail Taylor ◣	University of Southampton
		Brett Day; UC Davis: Caspar Donnison	University of Exeter
MIP 8.5	Bio-balance	Marcelle McManus ◣, Ariane Pinto, Lewis McDonald, Rebecca Rowe, Iain Donnison	University of Bath
MIP 8.7	Up-scaling on-site CO_2 utilisation for decarbonisation of dispersed cement sector: a novel route to reliable net-zero concretes	Xinyuan Ke ◣, Mohamed Katish, Vahiddin Alperen Baki, Brian Ding	University of Bath
		Susan Bernal, Alice Macente	University of Leeds
		Phil Renforth	Heriot-Watt University
MIP 8.8	Creating a carbon framework for a decarbonised circular economy	Marcelle McManus ◣, Linda Newnes, Ariane Pinto, Lewis McDonald, Jose Luis Hernandez Galvan	University of Bath
		Jonathan Radcliffe, Alok Choudhary, Taofeed Ilb Mohammed, Neha Metha, Thomas Fender	University of Birmingham
FF 2-2	Determining optimum pyrolysis conditions for biochar to be used as metallurgical coal replacement – in support of deep decarbonisation of large UK industrial emitters based within the Humber cluster	Amir Badiee ◣, Louis Mitchell, Souvik Roy, Aliyu Aliyu, Joe Howe	University of Lincoln

Project ID	Project name	Outputs	
MIP 1.3	Understanding public responses to industrial decarbonisation in insecure times	Synergy between industry and agriculture	Journal
		Improving life cycle assessment for carbon capture and circular product systems	
MIP 1.6	Unintended consequences? Life cycle comparison of UK industrial decarbonisation pathways	A life cycle assessment study of UK decarbonised ammonia, cement, methanol and steel for emission insetting	Journal
		Life cycle environmental trade-off of decarbonising UK industrial clusters – A cradle to gate approach	
MIP 2.6	Integrated assessment of BECCS in context: environmental, policy, regulatory and social factors	Co-deployment of bioenergy with carbon capture and storage in the UK: Growth or gridlock?	Journal
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 5.2	The VFA factory for decarbonisation	A review of carboxylate production and recovery from organic wastes	Journal
		Production of volatile fatty acids by anaerobic digestion of biowastes	
		Improving life cycle assessment for carbon capture and circular product systems	
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	
MIP 8.4 / IA 4.4	Where to locate new bioenergy with carbon capture and storage? A natural capital approach	Land-use change from food to energy	Journal
		Expert workshop gives a reality check on bioenergy with carbon capture and storage (BECCS): trust, demand and collaboration are critical	Report & video
MIP 8.5	Bio-balance	Synergy between industry and agriculture	Journal
MIP 8.7	Up-scaling on-site CO_2 utilisation for decarbonisation of dispersed cement sector: a novel route to reliable net-zero concretes	Comparative life cycle assessments of laboratory and Pilot-scale Mechanochemical processes for producing carbonated mineral products as cement substitutes	Journal
MIP 8.8	Creating a carbon framework for a decarbonised circular economy	Carbon accounting	Policy brief
		Towards a unified carbon accounting landscape	Journal
FF 2-2	Determining optimum pyrolysis conditions for biochar to be used as metallurgical coal replacement – in support of deep decarbonisation of large UK industrial emitters based within the Humber cluster	Determining optimum pyrolysis temperature for biochar to be used as metallurgical coal replacement	Webinar

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