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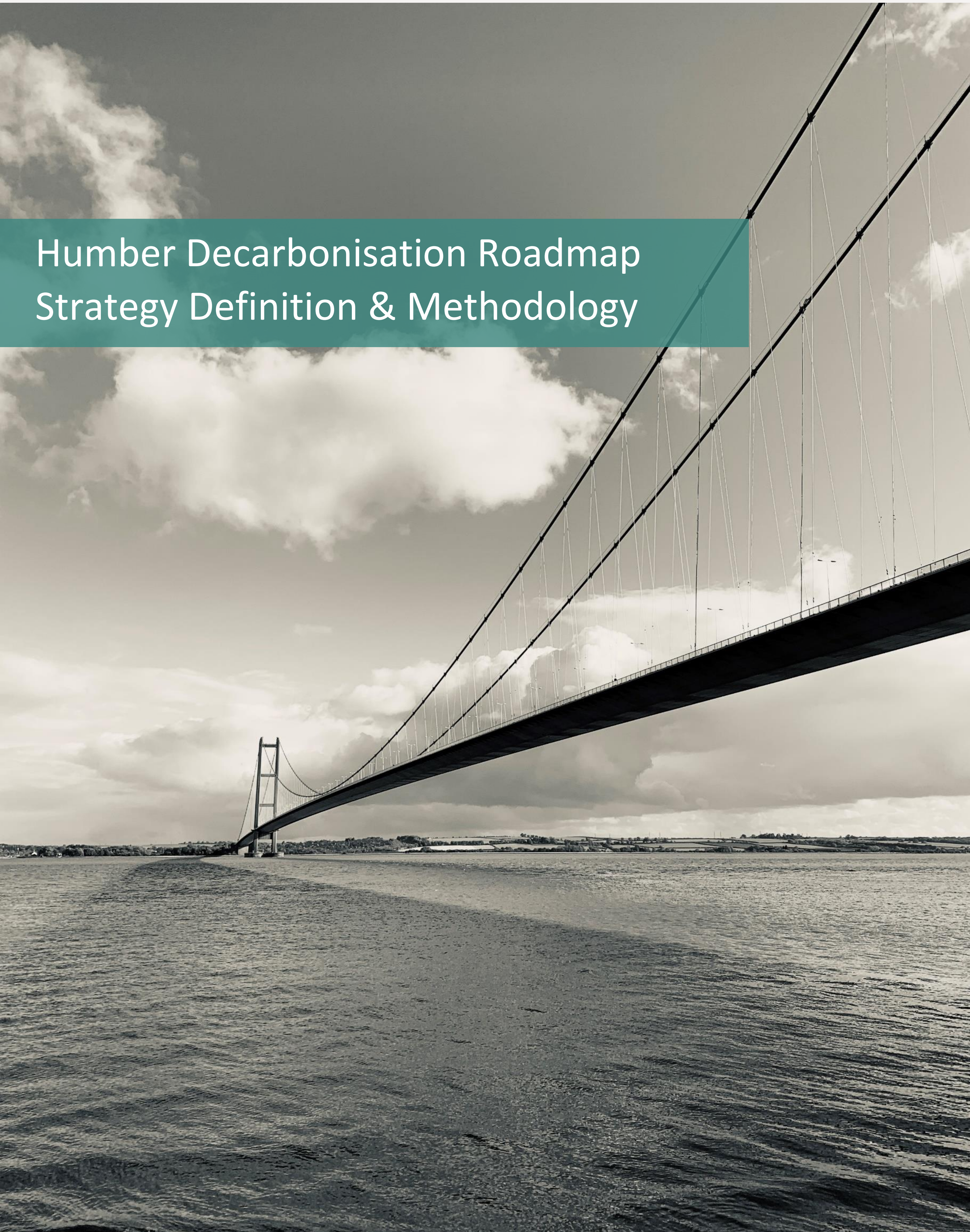
Humber Decarbonisation Roadmap
Strategy Definition & Methodology



Contents

1. Executive Summary

1.1 Scope of the Report

The scope of this report focusses on the Humber Industrial Decarbonisation Roadmap (HIDR) work package 4 (WP4). This relates to Systems Modelling. This considers the development of scope, outline approach and costs for Humber systems model in Phase 2. It draws on baseline scenario data from the HIDR Data project (WP1 & WP3), as well as the CATCH technical report which provides a high-level overview of technical options, costs and potential phasing (WP2).

The key question to be answered in Phase 2 is:

> What is the most effective way of delivering a net-zero industrial cluster in Humberside by 2040, taking into account the available resources, existing and future assets including those planned around the "ISCF Deployment" project[s], the geography of Humberside, industrial emissions, time, technology options and logistics networks? [1]

1.2 Context

The Paris Agreement was a significant landmark in the battle against climate change. Made by the UN Framework Convention on Climate Change (UNFCCC) at COP21 in December 2015, the Agreement's central aim is to strengthen the global response to the threat of climate change by keeping global temperature rises experienced this century to well below 2°C above pre-industrial levels. Following the Agreement, the UK became the first major economy to pass Net Zero emissions law on 27 June 2019, committing the UK to ending its contribution to climate change from all greenhouse gases (GHGs) by 2050. [2]

> **Net Zero** means that the UK's total greenhouse gas (GHG) emissions released to the environment would be **equal to or less** than the emissions the UK removed from the environment. [3]

1.3 Industrial Clusters

Clusters of large energy-intensive industries including those producing iron and steel, cement, chemicals, and oil refineries have naturally developed near ports and estuaries which provide abundant access to transport links, energy production and natural resources. These industrial clusters are significant contributors to both regional and national economies. However, due to their energy intensive nature they are also significant carbon emitters and contributors to climate change. [2] [3]

Over recent decades, the Humber Region has developed as a critical industrial cluster within the UK. Furthermore, the broad range of energy, industrial and manufacturing companies which have developed across region are now well positioned to offer decarbonisation opportunities. Proximity to the Humber estuary and the ports of Grimsby, Immingham, Goole and Hull provides import and export opportunities to Europe and beyond.

The Humber Industrial Cluster emits more CO_2 than any other industrial cluster; 30% more than the next largest. Total industrial emissions currently stand at 12.4 $MtCO_2e$ per year, or 13.9 tCO_2e for each Humber resident, more than twice the national average, according to the 2019 Humber Clean Growth White Paper. This arises mostly from the larger single point industrial or power generation sources. Data investigations during this project have revealed that emissions which also include medium and smaller emitters across industry sectors bring total industry emissions closer to 20 $MtCO_2e$ (see Appendix B), which matches the findings of the Data Project.

1.4 Decarbonisation approaches

A brief overview of the technology options available to deploy in the Humber has been completed. Whilst not exhaustive these technology options provide a representative range that has been used to inform the data framework and ensure the methodology proposed suitably represents all technology options. There is no inherent structural bias towards one technology option or another. Also, given the fast-moving nature of technology solutions in this space, it is important the roadmap methodology is not constrained by a pre-defined list of established technology options and it is therefore able to robustly consider new and emerging technology options. The model should be a living entity which can be dynamically updated with the latest technology, policy and cost data, or any other data or parameters which change significantly over time.

1.5 Analytical Approaches Appraisal

An appraisal of a range of analytical approaches was carried out including qualitative, quantitative, semi-quantitative methods and systems modelling. Associated examples and application to the Humber Industrial Cluster were also explored. The appraisal concluded with a recommendation of prescriptive analytics modelling approach for Phase 2 (see section 1.8 and section 10.1).

A prescriptive analytics approach will allow the Roadmap team to ask questions about 'what should happen' in the future, taking into account interdependencies, possible uncertainties and step changes in technology which may occur. These will be modelled using constraint-based scenario analysis and sensitivity analysis. This will facilitate the development of an optimal roadmap to net zero with no regrets / least regrets visibility, as well as providing visibility of critical technology and infrastructure lead times and potential enablers or blockers.

1.6 Roadmap Methodology Definition

In section 7 we outline the technical requirements and structure of the recommended systems model approach. This will enable an accelerated start to Phase 2. We also provide advice and recommendations as to Delivery Partners, software acquisition approach and system model delivery costs.

1.7 Data Requirements

The data framework defines the data and datasets required for Phase 2. It is a framework for capturing data during stakeholder engagement, research or elicitation in Phase 2. This will provide the inputs to the model and model scenarios. Whilst the framework may look linear and two-dimensional in nature, it is capturing data for a multi-dimensional system with complex interdependencies and uncertainties. The data framework should remain flexible and dynamic to enable the capture of evolving or emerging datasets as work progresses into Phase 2.

A data gap analysis has been completed by comparing the data collected by the HIDR Data project against the Data Framework. Table 1 summarises each area of the data framework at a *data line* level.

Data Framework Area	Data Framework Data Lines	Collated by Data Project	Covered by Data Project with queries	Data Gaps (Phase 2 collection)
Energy Producers	32	16%	3%	81%
Industries	42	14%	0%	86%
Technology	23	0%	0%	100%
Transport and Storage	37	0%	0%	100%
Penalties and Incentives	13	0%	0%	100%

Table 1: Data Gap Analysis at 'data line' level

1.8 Analytical Model Recommendations

The Humber Decarbonisation Roadmap requires analysis of a complex industrial system including significant interdependencies and uncertainties. Therefore, it is recommended that a **quantitative, prescriptive analytics approach is taken**. This should include **constraint-based optimisation, scenario, sensitivity analysis and systems modelling**.

It is recommended that a mass balance model is used. Within a mass balance model, the flow of material, and associated resource, energy demand, economic impact and emissions produced is driven by forecast demand for products or services, which create a pull-effect through the value-chain.

It is recommended that the modelling approach in Phase 2 be tiered with a core model and optional model extensions.

Core model: This should model the decarbonisation roadmap within the Humber LEP region (North Lincolnshire, North East Lincolnshire, East Riding and Hull) and cover the six BEIS industries sectors (steel / iron, refining, chemicals, cement, glass, and paper).

It is also recommended that the core model include Drax, which lies close to the boundary of the Humber LEP due to the contribution it can provide towards Net Zero and the economics of CCS infrastructure through future plans for BECCS and hydrogen.

It is recommended that emissions from power stations be included where they are related to energy demand for industrial processes. This should apply whether the power stations are directly linked to industry (e.g. VPI Immingham) or not and they input power into the electricity grid (e.g. Drax).

Adopting this recommended core modelling approach will:

- Inform the optimal direction of the decarbonisation pathway, including system interdependencies and uncertainties.
- Enable the management of future risks and uncertainties.
- Enable the modelling of different objective functions and scenarios, e.g. time frame, cost, carbon level, etc.

Model Extension: Whilst the core model considers the modelling of the core complex system, in reality the Humber region is connected to other regions, clusters and national networks. Significant additional value could be obtained through extending the model in several ways.

- **Application to other industry sectors:** Analysis of other industry sectors should be carried out to determine baseline emission scenarios for the sector and include identification of significant point-source emitters. Analysis should enable prioritisation (phasing) of the decarbonisation of additional industry sectors, or individual point source emitters.
- **Power generators outside the Humber:** Inclusion of power generators outside of the Humber LEP region, e.g. to the south. The model extension could be used to determine whether additional value could be gained by using the CCS infrastructure to also capture emissions from power stations outside the Humber region.
- **Other projects and stakeholders:** Bringing in additional stakeholder interdependencies such as these to scenario modelling and sensitivity analysis will likely change value (cost benefit), timeline and phasing of technology and infrastructure as well as no regrets and least regrets decisions. There are possible links with:
  - Exporting of hydrogen (forecast in the 2030s) to support the South Yorkshire region’s hydrogen economy development.
  - Integration with regional and national gas hydrogen transition pathways, to support the decarbonisation of heat.
  - Integration with Teesside in terms of CCS pipeline and storage – creating links with neighbouring industrial cluster, including shared use of Endurance carbon storage facility in the North Sea.

2. Background

2.1 Decarbonisation

The Paris Agreement was a significant landmark in the battle against climate change. Made by the UN Framework Convention on Climate Change (UNFCCC) at COP21 in December 2015, the Agreement's central aim is to strengthen the global response to the threat of climate change by keeping global temperature rises experienced this century to well below 2°C above pre-industrial levels. [2]

Following the Agreement, the UK became the first major economy to pass Net Zero emissions law on 27 June 2019, committing the UK to ending its contribution to climate change from all greenhouse gases (GHGs) by 2050.

2.1.1 Why is this so important?

The impact of anthropogenic emissions on climate change since the time of the industrial revolution are now internationally accepted. Temperature evidence is available not only as a matter of record but is also corroborated through nature and ice core sampling. The earth has a natural rhythm of ice ages and interglacial periods which see temperatures fall and rise over long time periods. However, since the industrial revolution the observed trend in rising temperatures has been much steeper than expected, on a consistent basis, evidencing the effect emissions from human activities are having on the climate. Climate scientists and modellers have set the targets of limiting global temperature rises, which the Paris Agreement enacts, to minimise the impact of climate change and avoid a positive feedback loop. [4] [5]

2.1.2 Why now?

The earth is a complex system of sub-systems which all interact, are interdependent on each other and transfer flow on varying timescales. Some of these sub-systems include the atmosphere, ozone layer, the jet-stream, ocean current systems (such as El Nino and La Nina) and glacial systems. Accelerated warming due to the impacts of humans are causing rapid changes in these interconnected sub-systems. These in turn are causing changes in the observed climate and the frequency of extreme weather events. More significantly, rises in temperature in systems like the ocean or melting of glacial systems can themselves lead to the release of significant amounts of carbon dioxide and rising sea levels – resulting in a self-reinforcing, climate heating feedback loop. [4] [5]

According to the 2018 UK Clean Growth Strategy, around $13.5 trillion public and private funding is required on an international scale between 2015 and 2030 to meet the aims of the Paris Agreement. In the UK, it is estimated that the entire low carbon economy could grow by 11% during this period - a rate of four times the underlying economy growth rate, delivering £60 - £170 billion of export sales. [6]

Some of the key areas contributing to UK emissions are shown in Figure 1. At a high level, opportunities to reduce these emissions are listed below:

- **Business and industry (25%):** Industrial decarbonisation and commercial buildings.
- **Power (21%):** Delivering a clean, smart, flexible power grid.
- **Transport (24%):** Moving to low carbon transport and infrastructure.
- **Natural resource (15%):** Enhancing benefits and value. Including agriculture, land, waste and resource management.
- **Homes (13%):** Improving energy efficiency of homes and low carbon heating.
- **Public sector (2%):** Public sector targets.

Business and industry is a key sector, contributing 25% of all UK emissions. In relation to the Humber Industrial Cluster (HIC), it is likely that some elements of power linked to industry will also need to be included in the industrial decarbonisation roadmap (see Appendix B). For example, VPI Immingham power station feeds Phillips 66 and Total Lindsey oil refineries as well as supplying electricity to the national electricity grid. There may also be some elements of natural resource emissions to be associated with industry. For example, Easington is a critical UK gas terminal site and Drax power station uses biomass, which is brought in via the ports of Immingham, Hull, Liverpool and from the north east.

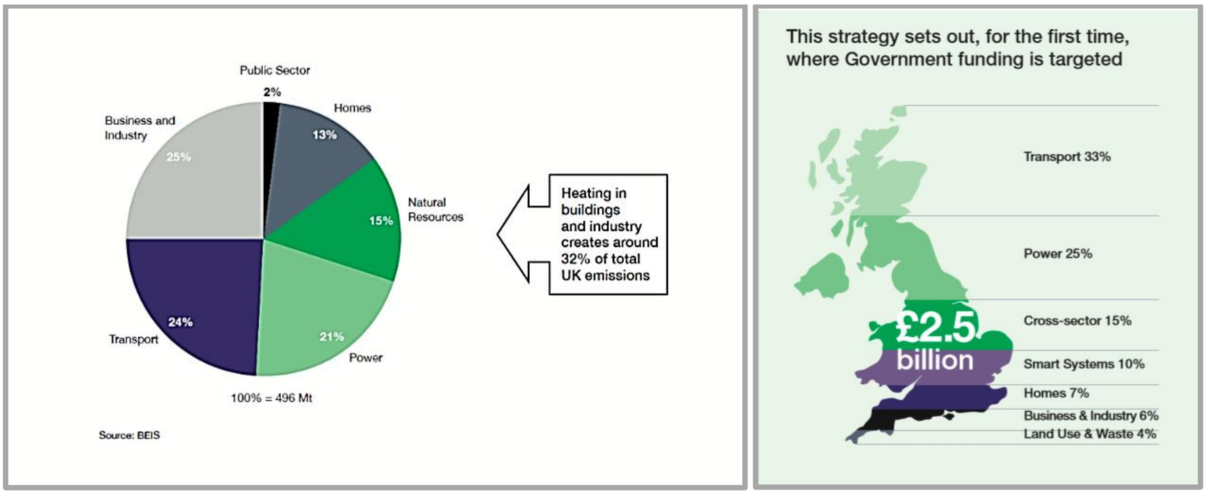


Figure 1: UK emissions (2015) and spend (2015-2021) by sector, 2018 UK Clean growth Strategy [2]

Figure 1 also shows the split of funding targets BEIS attributes in the 2018 UK Clean growth Strategy for the period 2015-2021. There is a discrepancy between funding amount (expenditure) and emissions for the industrial sector. This lack of correlation combined with the presence of a cross-sector government funding allocation of 15% indicates BEIS' intention that the decarbonisation of industry will require a whole-systems, or integrated, approach. A whole-systems modelling approach to developing a decarbonisation roadmap for the HIC is one of the options described and evaluated in Section 6.

2.1.3 What does Net Zero mean?

Net Zero means that the UK's total greenhouse gas (GHG) emissions released to the environment would be **equal to or less** than the emissions the UK removed from the environment. [3]

The Committee on Climate Change (CCC) provides independent analysis on climate change science, economics and policy, as well as monitoring the progress made in reducing emissions and achieving carbon budgets and targets. They anticipate that by 2050 not all sources of GHGs will be eliminated. In the UK, current models predict that from 2050, 75-175 million tonnes of carbon dioxide equivalent ($MtCO_2e$) will need to be removed each year using carbon capture, utilisation and storage (CCUS) to achieve and maintain net zero. [3] [7]

Achieving Net Zero in the HIC will require a range of technology development pathways in combination, for example:

- Elimination of GHG emissions processes, which may include the use of green hydrogen production for power and industrial process.
- Reduction and utilisation or storage of GHG emissions, using CC(U)S.
- Where GHG emissions cannot be eliminated or captured, the use of negative GHG emissions technologies, such as Bio-Energy with CCS (BECCS) could be used. BECCS removes more carbon through the cultivation and CCS phases than it releases through the burning phase. Direct Air Capture and Carbon Sequestration (DACCS) is an additional but emerging negative emissions technology which could also be deployed in the Humber region. It uses sorbents to absorb CO_2 from the air after which they can be either permanently stored or used. This process is analogous to the way plants absorb CO_2 during photosynthesis. [8]

- Natural carbon sequestration: It is well known that carbon dioxide is taken in by trees and plants during photosynthesis. However, other less well-known natural sequestration processes exist. Land management practices, such as applying organic material, e.g. biochar, to soils or agricultural land can increase their propensity to absorb carbon. Marine and coastal ecosystems also store carbon in the form of calcium carbonate. If these ecosystems are damaged it decreases the amount of carbon they are able to store. Therefore, good environmental management of these areas will maximise carbon storage, on top of other ecosystem benefits. [9]

As not all emissions are likely to be eliminated by 2050 and the CC(U)S process is less than 100% efficient, negative emissions processes such as BECCS and DACCS will have an important role to play in balancing the Net Zero equation. The extent to which negative emissions technology systems will play a role in the HIC decarbonisation pathway will be determined in the Phase 2 project roadmap (development of the HIC decarbonisation roadmap). This does not preclude that other novel technologies may emerge, nor that trading mechanisms like the Emissions Trading System (ETS) may be used at a regional level within the UK to meet the UK Net Zero 2050 target. [3]

2.2 Industrial Clusters Decarbonisation

Clusters of large energy-intensive industries including those producing iron and steel, cement, chemicals, and oil refineries have naturally developed near ports and estuaries which provide abundant access to transport links, energy production and natural resources. These industrial clusters are significant contributors to both regional and national economies. However, due to their energy intensive nature they are also significant carbon emitters and contributors to climate change. [2] [3]

Within the UK as a whole industry accounts for:

- £150 billion Gross Value Add (GVA) to the UK economy.
- 1.5 million jobs.
- Export of goods and services worth £320 billion.
- 25% of GHG emissions, with 66% of these (17%) coming from energy-intensive industries. [10]

The largest six industrial clusters in the UK, recently mapped by the Industrial Clusters Mission, have energy-intensive industries with emissions of 33.2 $MtCO_2e$/yr (*Figure 2*). Manufacturing companies within industrial clusters often use the same infrastructure and resources, e.g. supply chains and workforce. The challenge of decarbonising industry seeks to leverage the scale and interdependencies of these industrial clusters to create collaboration opportunities and find cost-effective solutions. [11]

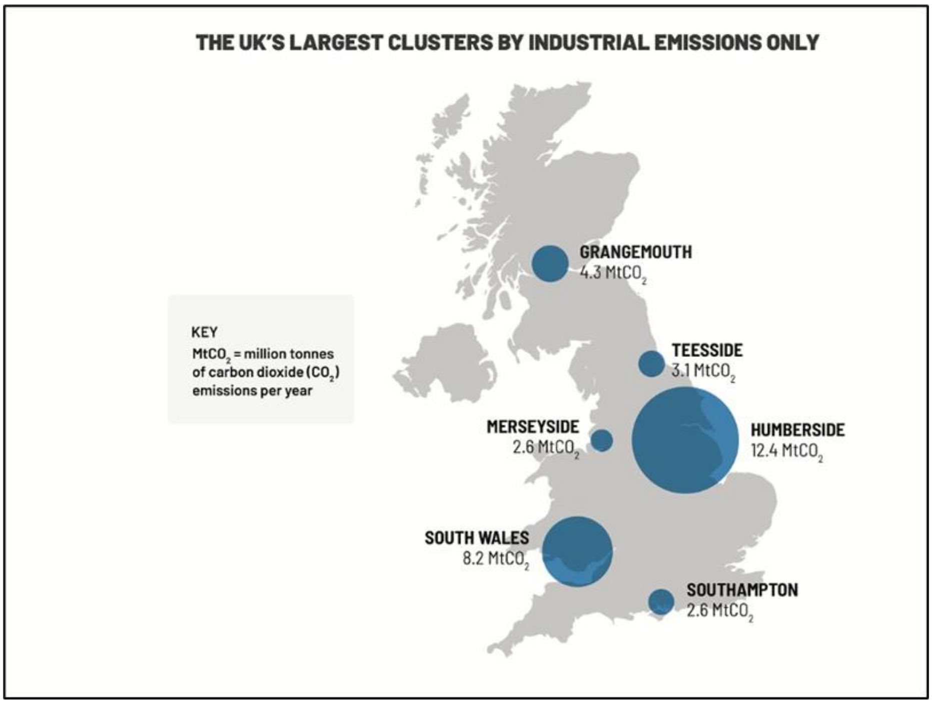


Figure 2: UK's largest industrial clusters by emissions [5]

2.2.1 What is the investment?

The Clean Growth Strategy announced £2.5 billion funding for national programmes to accelerate clean growth. There are various funding initiatives and programmes that Humber-based industries can benefit from, including:

- The Industrial Decarbonisation programme.
- The Industrial Heat Recovery Support (IHRS) programme.
- The Industrial Energy Efficiency Accelerator (IEEA).
- The Industrial Fuel Switching Market Engagement Study.
- The Carbon Capture and Usage (CCU) Demonstration Programme.

The Industrial Decarbonisation programme is funded by £170 million from the Industrial Strategy Challenge Fund (ISCF) which is expected to be matched by funding of up to £261 million from industry. This project is funding this project to identify and define a Humber decarbonisation roadmap strategy and methodology. [11], [12]

2.2.2 What is the challenge?

This Industrial Decarbonisation challenge aims to accelerate the cost-effective decarbonisation of industry by developing and deploying low-carbon technologies. It also aims to enable the deployment of infrastructure at scale by the mid-2020s. [11], [12]

The key aims of the challenge are:

- To boost the competitiveness of key industrial regions and drive inward investment, creating and protecting jobs for a low-carbon global economy with growing low-carbon export markets.
- To support delivery of the Clean Growth Grand Challenge and the Industrial Clusters Mission, which has set an ambition to establish **at least one low-carbon industrial cluster by 2030** and **the world's first Net Zero carbon industrial cluster by 2040**. This will help place the UK at the vanguard of clean growth to a greener future, by driving the technologies, services and markets to produce low carbon industrial products.

- Enable detailed designs and demonstration of industry-scale technologies and shared infrastructure for the cost-effective deep decarbonisation of at least one industrial cluster.
- Produce Roadmaps and feasibility studies for Net Zero industrial clusters.
- Enable sustainable industrial clusters knowledge creation and sharing function, including the creation of a joint industry, government, and academic-led research programme. [11], [12]

3 Definition, objectives & scope

3.1 Definition

This project report relates to work package 4 of the Phase 1 of the Humber Industrial Decarbonisation Roadmap (HIDR) project.

3.2 Objectives

The objectives of work package 4 of the HIDR Phase 1 project are to provide:

1. A detailed evaluation of the possible methodological approaches to developing a Humber decarbonisation roadmap in Phase 2 and recommendation of best overall approach.
2. Definition of the data and datasets that will be needed in Phase 2, including a data gap analysis.
3. Definition of how the Humber decarbonisation roadmap will be constructed in Phase 2 (following recommended best overall approach).
4. Identification of how outputs of Phase 2 activities will achieve desired Phase 2 Project outputs.
5. Definition of key technical requirements of Phase 2 roadmap methodology.

3.3 Scope

Phase 1 was split into two sub-projects, one led by CATCH (supported by Business Modelling Associates (BMA) on work package 4) which concentrated on the HIDR Strategy Definition and Methodology (HIDR Roadmap Project), and a second led by the Humber Local Enterprise Partnership (LEP) in conjunction with Element Energy which concentrated on data gathering and baseline scenarios (HIDR Data Project). The context of the scope of this project against these other projects can be seen in Appendix A.

The rest of this report will focus on the work package 4 (WP4) part of the HIDR Roadmap Strategy and Definition project led by CATCH in conjunction with Business Modelling Associates (BMA), which is focussed on the definition of systems modelling approach to enable the development of the roadmap strategy. More specifically, this includes the development of scope, outline approach and costs for the Humber systems modelling in Phase 2.

CATCH is an industry led partnership supporting the process, energy, engineering and renewable industries in Yorkshire and the Humber.

BMA are a Yorkshire based company specialising in analytics and systems modelling methodologies, consultancy and supporting software. BMA's systems models are used by UK and international clients to support long term challenges such as energy decarbonisation and water resilience through their investment and strategic planning processes.

3.3.1 HIDR Roadmap Project WP 4 Report Objectives

The key question to be answered in Phase 2 is:

> What is the most effective way of delivering a net-zero industrial cluster in Humberside by 2040, taking into account the available resources, existing and future assets including those planned around the "ISCF Deployment" project[s], the geography of Humberside, industrial emissions, time, technology options and logistics networks? [1]

To enable this question to be answered in Phase 2, this report has the following objectives:

- Provide an understanding of the pros and cons of using a model led approach versus alternative approaches to achieving the Phase 2 project objectives. i.e. to objectively reflect on whether a model led approach is the best way forward (including legacy options), taking into consideration the level of funding that will be available.

- Definition on the organisation of data inputs to the level of detail needed to enable a potential accelerated start i.e. what data will be needed and in what form(s). This is likely to include definition of “industry sector” and how power plants located in Humberside are/are not included, sub sectors (e.g. pharmaceuticals, personal care, food, refining) and perhaps even sub sectors to sub sectors (e.g. fish processing, meat processing etc within food).
- Definition on how the Roadmap methodology/model would be constructed. To include (as appropriate):
    - Modules structures and optimisation/sensitivity capabilities.
    - Modelling environment and whether there are benefits to using open-source or other licensed languages.
    - Options for who might deliver a model in the Phase 2 Project.
    - Cost estimations and implications (what can be achieved in a Phase 2 project for what costs).
    - Assessment of risks and mitigations.
- Identifying how the outputs from the Phase 2 activities (e.g. modelling) will achieve the desired Phase 2 Project outputs including key sensitivities.
- Defining key technical requirements for model (e.g. modelling environment, data input structure to the level of detail needed to enable a potential accelerated start, technical on how it will be written and what is needed).

4 The Humber Industrial Cluster

4.1 Overview

Over recent decades, the Humber Region has developed as a critical industrial cluster for the UK. Furthermore, the broad range of energy, industrial and manufacturing companies which have developed across region are now well positioned to offer decarbonisation opportunities. Proximity to the Humber estuary and the ports of Grimsby, Immingham, Goole and Hull providing import and export opportunities to Europe and beyond.

Specifically, the Humber Industrial Cluster has the following characteristics:

- Two of the UK's four oil refineries producing a third of the UK's fuel output.
- One of the UK's two integrated steelworks.
- The second largest chemical cluster in the UK, with two major chemical regions at Saltend Chemicals Park and South Humber Bank.
- Has one of the largest concentrations of food manufacturing and cold storage in the UK.
- Handles a third of UK coal and biomass imports.
- Receives a fifth of UK gas imports.
- Produces a sixth of UK electricity.
- Three of the world's largest wind farms, with the largest in the world currently under construction.
- Has 20 operational onshore wind farms.
- Is a hub for offshore wind manufacture and servicing.
- A key port and logistics hub, which contributes £2.5bn GVA to the UK economy.

The HIC covers four local authorities: Hull, East Riding, North East Lincolnshire and North Lincolnshire [13], [14]

4.1.1 Energy Consumption and Economic Impact

The Humber Industrial Cluster (HIC) is one of the UK's leading industrial regions. Industry in the region has developed and grown around the Humber estuary and deep-water ports which facilitate the export and import of goods and services. Energy-intensive industries such as oil refineries, petrochemicals, and steel manufacturing account for around a fifth of the Humber's GVA and a tenth of jobs. [15]

There is 4.4 GW of installed electrical capacity in the region – the majority powered by fossil fuels. However, the region is a prime location for the development of renewable energy with Dogger Bank, set to be the largest wind farm globally when commissioned, which is expected to be delivered in phases between 2023-2025. There is currently 0.6 GW of installed renewables capacity in the core Humber region, as defined by the HIDR Data project, see Appendix B. This increases to 1.1 GW for the broader region. If planned and under-construction projects are also included the totals in the core and broader regions increase to 1.6GW and 6.2 GW respectively. More detail is provided in Appendix D. [16]

4.1.2 Emissions

The HIC emits more CO_2 than any other industrial cluster; 30% more than the next largest. Total emissions currently stand at *circa.* 20 $MtCO_2e$ per year. This arises largely from single point industrial or power generation sources.

A more in-depth analysis of the Humber Industrial Cluster can be found in Appendix C.

4.1.3 Classification of Industry

This section provides more detail about the industries within the Humber Industrial Cluster (HIC). Before going on to describe the technologies that are available to decarbonise industry, it is important to define the term *industry* and understand the key industries which operate within the Humber Cluster. This will enable decarbonisation options to be contextualized.

Industry can be classified into four types:

Primary: Primary Industry involves the acquisition or extraction of raw materials. For example, metals and coal are mined, oil drilled from the ground, foodstuffs farmed, and fish trawled.

Secondary: Secondary Industry plays a key role in driving the economy of a country. It uses the materials from Primary Industry with a focus on producing goods through manufacturing, engineering, and assembly processes, Figure 3. For example, converting raw materials into components, including production of chemicals, plastics, oil refinery, food processing, personal care products, steel making; as well as product assembly such as housebuilding and train parts.

Tertiary: Tertiary Industry can be linked to both Primary and Secondary industries and involves the provision of a service. For example, rail transport, road transportation or shipping services, healthcare, investment specialists, digital technology, and port services, Figure 3.

Quaternary: The Quaternary Industry involves research and development industries. For example, pharmaceutical research, university research, statisticians, data collectors or software experts. [17]

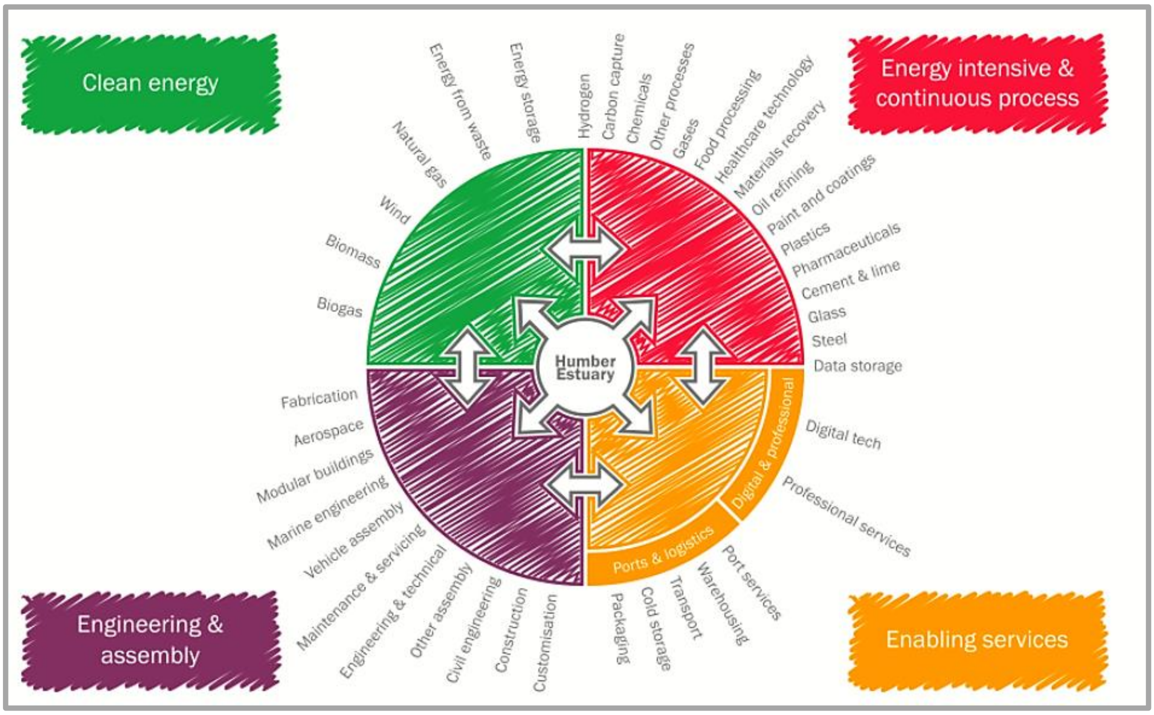


Figure 3: The Humber's blueprint for an Industrial Strategy: Sectors [18]

The competitive challenge is to decarbonise key industrial regions with large, energy-intensive industrial plant. For the Humber, key decarbonisation opportunities lie within the Primary and Secondary industry sectors where energy-intensive industries operate directly, but also within the Tertiary Sector when considering transportation services and supply chains related to these industries. All Industry levels will be important in developing and deploying decarbonisation infrastructure and technology on the path to low carbon and net zero targets in the Humber. The Quaternary Industry will also play a key role in the research and development of innovation and emerging technology and infrastructure.

4.2 Energy-Intensive Industries

Industrial clusters are areas densely populated with industry, often energy-intensive industrial companies. These can be categorised into the following areas [10]:

- Iron and Steel
- Oil refining
- Chemicals
- Glass
- Paper
- Cement

Figure 4 and Figure 5 are taken from the Carbon Trust, Study of the Humber Energy Intensive Industries Cluster (March 2018) for the Humber LEP. These visuals provide an illustration of the number and distribution of the *large emitters* in the Humber region, largely clustered around the coast and estuary. However, some key emitters are absent such as Drax power station. This is because Carbon Trust Study uses Humber and Humber & Yorkshire representations which may be different from the requirements of this project, and Drax does not lie within their defined Humber & Yorkshire region. Nevertheless, they are useful visual guides for Phase 1 of this project. Revised data and updated visualisations may for example be inputs to phasing of key CC(U)S infrastructure scenarios and sensitivity analysis in Phase 2. [19]

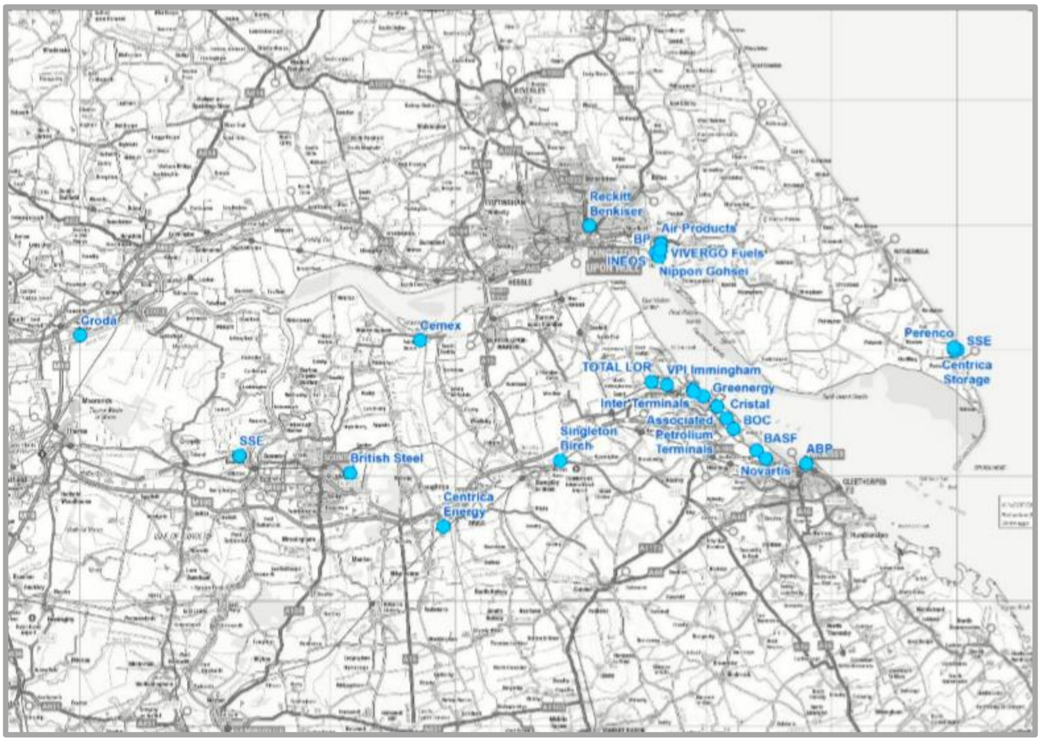


Figure 4: Energy-intensive industries [17]

Figure 5: Heat map of energy-intensive emitters [17]

If not carefully managed, decarbonisation of the HIC could cause a serious economic shock or destabilisation of the regional economy. There are however opportunities to grow the economy in a managed and stable way during the transition to a low carbon future. There will be inherent challenges and risks associated with decarbonisation. Competition and collaboration will need to be considered throughout the process at a regional and national level. For example, the transition to a low carbon future for energy-intensive industries may mean that the workforce of the Humber in 2050 looks quite different from the one in 2020. The transition path for this is likely to include activities such as: natural ingress / egress, redeployment, re-training and upskilling. [13]

Whilst providing an opportunity to contribute to climate change and a greener future, decarbonisation is also a major economic opportunity for the Humber region and the UK, given that the Humber estuary is a gateway to European and international trade. Globally and within the UK, low carbon sectors are growing significantly faster than the wider economy. The Humber is a prime location for the development and deployment of a range of renewable energy and future fuel technologies given its coastal location and proximity to a large port complex and both active and depleted gas fields. [13]

5 Approaches for Industrial Decarbonisation

To provide a robust and unbiased evaluation of all approaches to industrial decarbonisation of the Humber, the methodology to develop a roadmap must be able to simultaneously consider a wide range of technology options. The challenge is balancing the ability to draw into the methodology deep expertise from a range of domain experts whilst maintaining a broad and unbiased approach that considers all technology options on a 'level playing field'. Therefore, is it important that we develop a methodology that has no inherent structural bias towards one technology option or another. To this end we have compiled a brief overview of the technology options available to deploy in the Humber. Whilst not exhaustive these technology options provide a representative range that has been used to inform the data framework and ensures the methodology proposed will suitably represent all technology options. Finally, given the fast-moving nature of technology in this area, it is important the roadmap methodology is not constrained by a pre-defined list of established technology options and is able to robustly consider new and emerging technology options. The model should be a living entity which can be dynamically updated with the latest technology, policy and cost data, or any other data or parameters which change significantly over time.

As shown in the Committee on Climate Change's Net Zero Report, 2019 (Figure 6) the key abatement options for industrial decarbonisation are [20]:

- Resource efficiency and product substitution.
- Energy efficiency.
- Carbon Capture and Storage.
- Carbon Capture and Utilisation.
- Fuel switching.
  - Bio-energy with CCS (BECCS).
  - Biomass.
  - Hydrogen.
  - Electrification.

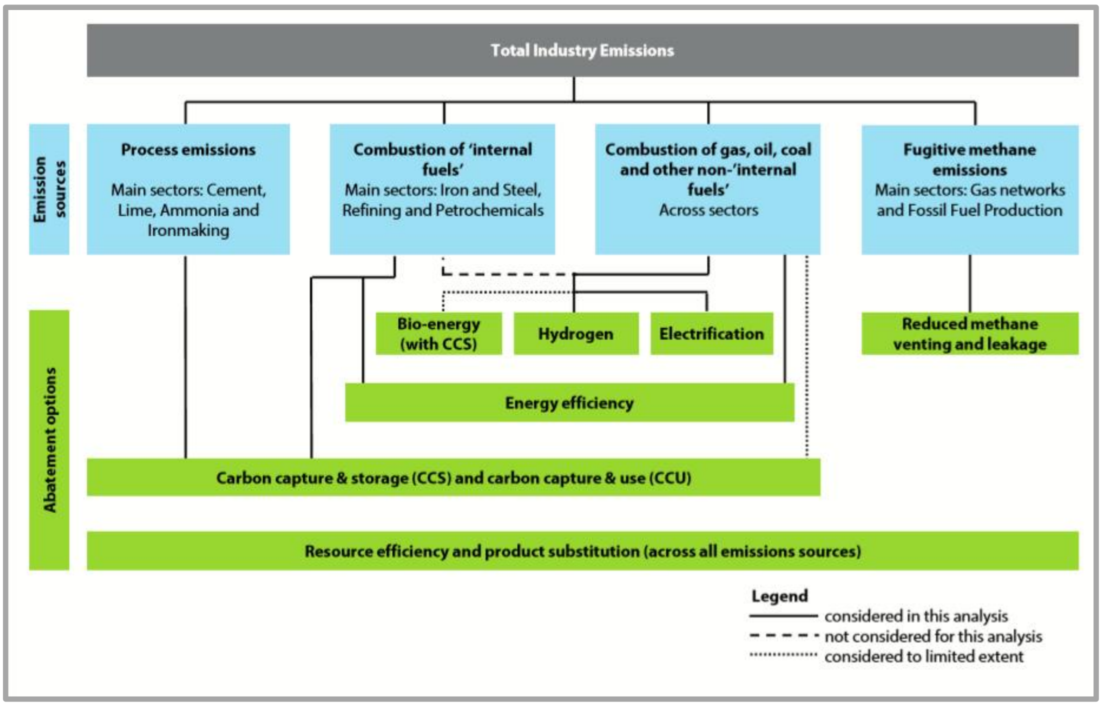


Figure 6: Abatement options for industrial decarbonisation [20]

5.1 Energy Efficiency

This includes aspects of using energy more efficiently and reducing the flow of materials throughout the system. For example, in the steel industry, advances have already been made to improve the efficiencies of blast furnaces. In future there is also the potential to increase the amount of steel produced from recycled materials in electric arc furnaces (EAF) if the supply and value chain support this, see Section 13.1.4. This would enable a lower carbon future and a more circular economy. Energy efficiency options will be industry specific by nature and will impact industrial processes, costs, products, and profitability. It will therefore be essential to engage with the industries and industry experts to elicit the necessary data in Phase 2. [20]

5.2 Carbon Capture

Carbon Capture and Storage (CCS) involves three steps:

- **Capture:** The separation and capture of CO_2 from other gases produced at large industrial process facilities (Figure 7), e.g. coal and natural-gas-fired power plants, steel mills, cement plants and oil refineries. Carbon capture technologies can be grouped into three main categories: Pre-combustion; Oxy-combustion; and Post-combustion. [17]
- **Transport:** Once captured, the CO_2 is compressed and transported via pipelines, trucks, ships, or other methods to a suitable site for permanent geological storage.
- **Storage:** CO_2 is injected into deep underground rock formations, usually at depths of one kilometre or more. This includes depleted hydrocarbon reservoirs, non-potable saline aquifers or disused coal mines or un-mineable coal seams. [21]

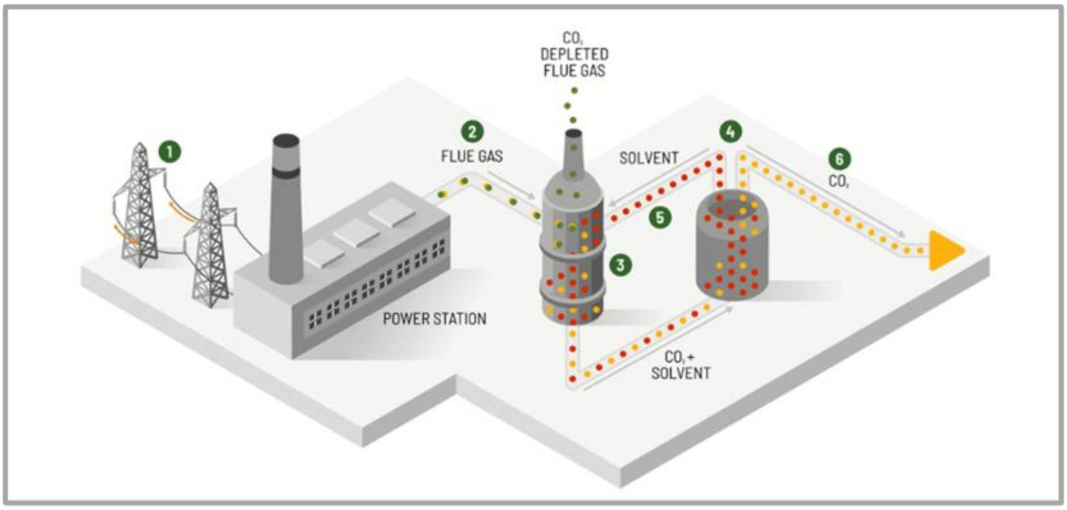


Figure 7: Carbon Capture [22]

Many organisations such as the CCC and the Intergovernmental Panel on Climate Change (IPCC) agree that 2050 climate targets cannot be reached without the use of CCS. UK net-zero scenarios involve aggregate annual capture and storage of 75-175 $MtCO_2e$ in 2050, which would require a major CO_2 transport and storage infrastructure, servicing at least five clusters and with some CO_2 transported by ships or heavy goods vehicles. The methodology and modelling can be used to test CCS alongside other technology and other infrastructure options and availability to determine optimal decarbonisation transition pathways based on desired outcomes and constraints. [3]

Some industries such as steel, cement, refining chemicals, glass, and ceramics all emit CO_2 as part of a chemical process required in production. *Currently*, CCS is the only technology option that would enable deep decarbonisation for these industries.

CCS also provides the following opportunities:

- Enables the production of bulk low-carbon (blue) hydrogen.
- Facilitates trade markets for the UK. There are the potentials for the use of oil, gas and coal to be continued to be used within an energy mix with CCS and this may be driven by global energy prices.
- A technology that is proven both in the UK and internationally, with a long-term safety record. It has been applied in a wide range of industries since 1972.
- It will service the economy through infrastructure (new asset base or repurposing of existing asset bases), generation of value and provision of jobs.
- Enables negative emissions when used with biomass (BECCS) – this is important when working towards net-zero in an industrial cluster as this provides a balancing offset where not all anthropogenic emissions are able to be completely eliminated or removed by other means such as CC(U)S.
- It provides a middle ground between renewables, which have associated endemic factors of availability and variability, and the high costs of nuclear power. [21]
- Utilisation of captured carbon dioxide in beer, bioplastics, construction materials and animal feedstocks.

5.3 Fuel switching

5.3.1 Biomass

Biomass describes a range of materials including: oil crops; starch crops; sugar crops; forestry crops (e.g. wood pellets), energy crops (e.g. Miscanthus); agricultural wastes and waste from municipal solid wastes, commercial and industrial (C&I) wastes and construction and demolition (C&D) wastes. [17]

Biomass can be combusted to heat steam producing energy, for example wood pellets are combusted in four of Drax power station's generators which have been converted to biomass from coal. Biomass can also be used as a feedstock to produce chemicals and fuels, e.g. for transport. For example, Greenergy in Immingham produce a waste-based biofuel. [17] [23]

Biomass can also be used in combination with CCS, Section 5.3.2.

5.3.2 Bio-energy with Carbon Capture and Storage (BECCS)

The 2019 CCC Net Zero Report concluded that biomass should only be used in industrial applications with CCS in the long-term. Using CCS in conjunction with Bio-energy can result in a negative emissions process as fewer emissions are released from the environment than are removed. In the Phase 2 project, it will be important to understand any other constraints relating to the cultivation, transportation and environmental land management opportunity cost relating to the raw biomass material or feedstock requirement. [20]

Drax power station currently aims to have CCS on one biomass unit by 2027, rolling out to all biomass units between 2028 and 2035 with a view to producing a net negative 16 $MtCO_2e$/yr. [24]

5.3.3 Hydrogen

Hydrogen is used in oil refineries in the hydro-cracking process, see Section 13.1.3. and can be used as an alternative fuel in other industries for process heating and power generation, replacing natural gas, or other hydrocarbon-based fuels. Hydrogen is also a product of the refining process. Therefore, there is a supply and demand balance as to whether refineries have enough self-supply of hydrogen and have surplus to export to other industries, or whether they require more than they produce and therefore need additional imports.

Crude oils are getting heavier. Combined with the trend for lighter products, such as gasoline, butane and gas which require greater desulfurisation, it is likely that oil refineries will require more hydrogen in the future, increasing the likelihood that the hydrogen they produce will not be sufficient for their needs and they may become more reliant on hydrogen imports. Within the Humber region, these hydrogen imports may come from green hydrogen (produced by renewable energy and electrolysis), or blue hydrogen (by steam methane reformation, auto thermal reformation or thermal partial oxidation and CCS). [20]

The 2019 CCC Net Zero Report noted that hydrogen also has the technical potential to reduce emissions from most forms of industrial combustion and that low-carbon hydrogen has a unique role to play in reducing emissions from direct firing processes,*Table 2*. That is, where the flame and subsequent combustion gases need to come into direct contact with the material or product being produced. This includes furnaces, such as those used in steel manufacturing and glass manufacturing processes (see Appendix B). This again presents significant opportunity for the use of hydrogen in the Humber. [20]

The Hy-Impact Series, Study 4 assessed the potential for hydrogen use by industry and power in the Humber and Yorkshire region. It determined that the Humber region presents a strong opportunity for the use of hydrogen in both industry and power. It forecast hydrogen production demand of 1.6 GW (13 TWh/yr) in 2030 across 45 industry sites; and up to 18 GW_e (20-165 TWh/yr) in 2030 across 9 existing and 6 new power generation facilities. [25]

Process driven by	Process type	Suitable duel switching technologies	Key sectors relying on these processes
Direct Heating	Low temperature	Electric heaters, hydrogen heaters	Vehicles, other smaller manufacturing sectors
	High Temperature	Solid biomass combustion, hydrogen heaters, electric kilns / furnaces, radio frequency heating, electric plasma gas heaters	Glass, Ceramics, other non-metallic minerals
Indirect Heating	Low temperature (including space heating)	Solid biomass boilers, hydrogen boilers, electric boilers, electric heaters, heat pumps, microwave heaters	Vehicles, other smaller manufacturing sectors
	High Temperature	Electric heaters, hydrogen heaters (hydrogen replacing gas burners)	Refining, Petrochemicals & Ammonia
	Steam	Solid biomass boilers, hydrogen boilers, electric boilers, heat pumps, in limited applications	Food & drink, Paper, Chemicals

Table 2: Industrial heat processes and suitable fuel switching technologies [20]

5.4 Emerging Technologies

The model methodology outlined in Section 7**Error! Reference source not found.** should not be constrained to the technologies detailed in this section (5), but should be designed in such a way as to be able to incorporate emerging technologies and new technologies which may arise in the future. This will ensure the methodology is not unduly biased towards more established technology options.

5.5 High-level Costs

The 2019 CCS Net Zero Report details the cost estimates in *Table* 3. Robust and accurate cost data will be critical to developing a roadmap using a methodology underpinned by prescriptive analytics. This will allow the full benefit of complex mathematical optimisation to be levered and ensure that the developed roadmap is optimal. Collating accurate costings and data relating to technology options will form part of the Phase 2 activities, drawing and building on all Phase 1 projects, stakeholder engagement and current developments.

Installation Name	£/tCO2e
CCS with most mature technologies (with lowest cost opportunities in ammonia)	30 - 120
CCS with best available technologies	30 - 190
Hydrogen	65 - 240
Electrification (including heat pumps)	90 - 400

Table 3: High-level technology costs [20]

6 Analytical Approaches Appraisal

Sections 6.2**Error! Reference source not found.** to 0 consider the different analytical approaches available and appraise each of them in the context of the decarbonisation of the Humber. A recommendation of which modelling option is the most appropriate is made in Section 6.6.

Before discussing modelling options, it is useful to understand what a roadmap is and the key functional requirements of the Humber Decarbonisation Roadmap.

6.1 What is a roadmap?

A roadmap (Figure 8) is essentially a visualisation of getting from a starting point (A) to an end point (B).

However, Decarbonisation of the Humber Industrial Cluster is a complex problem where the start and end points are unknown. In fact, there could be multiple start and end points.

These multiple starting points derive from the uncertainty in the future baseline growth or decline of existing regional industries. This includes energy supply and demand and greenhouse gas emissions. It is also dependent on potential new industry entrants and their growth over time.

The possible multiple end points are associated with uncertainties in future technological advances to decarbonise industry; and the transition rate to develop and adopt these technologies. This in turn may also depend on central UK governing factors such as policy, regulation, subsidies, and funding mechanisms.

Figure 8: Visualisation of a roadmap

Industrial decarbonisation of the Humber is complicated further by uncertainties and interdependencies of the dense regional population of industries. These are present on a regional, national, and international scale, as the Humber is a critical international hub for industry and energy production. Many industrial companies are also directly integrated with key regional and national infrastructure, such as the electricity and gas transmission and distribution networks. Either supplying or taking demand from these energy networks.

6.1.1 Roadmap Development Strategy

It is important to have in mind the key reasons for the Humber Industrial Decarbonisation Roadmap Development Strategy before appraising modelling options. The development of a Decarbonisation Roadmap for the Humber Region should include the following:

- A vision of how the Humber region's industrial emissions will change over time. With milestone points of being Low Carbon by 2030 and Net Zero by 2040.
- A merit order of technologies and approaches to decarbonisation.
- An ability to assess sensitivities so that optimal and resilient solutions can be identified and assessed.
- An assessment of the impact decarbonization options on industries activity, wider economic activity and regional jobs.
- Legacy benefits beyond the current project. Including applicability to other industrial clusters and sectors.
- Understanding of what technologies are needed/need to be deployed/need to be developed, by when and where.

- Understanding of sensitivities and uncertainties associated with choices and pathways to understand, uncertainty, resilience and regrets / no regrets options associated with decision making, i.e. facilitate a conscious decision making model.

The Roadmap Methodology should also facilitate understanding around the following wider questions:

- Where energy is generated and used (demand) in the Humber industrial cluster currently by energy type and industry type.
- How energy demand is forecast to change over time and any uncertainties and sensitivities associated with this.
- Planned infrastructure deployment including:
  - Effects of actions arising from the ISCF HID Deployment project, the Humber Green Hydrogen project, and any other emerging deployment projects.
  - Proposed phasing and overall timeline of the infrastructure deployment.
  - Subsidies and funding mechanisms.
  - Any interdependencies with other sectors or regions.
  - Understanding and impact of any associated uncertainties and sensitivity analysis of these.
- Understanding of current CO_2 and GHG emissions, by large emitter point source, industry sector and possibly other cross-sectional analysis such as sub-sector and sub-regional.
- How CO_2 and GHG emissions will change over time, by large emitter point source, industry sector and possibly other cross-sectional analysis such as sub-sector and sub-regional. This will result from the scenario analysis of technology and infrastructure pathway analysis and indicate:
  - Optimal pathways with degrees of certainty.
  - Any blockers / enablers required, such as financial subsidies or latest start dates for critical pieces of infrastructure or technology.
  - Help identifying the optimal phasing of infrastructure and technology.
- Appreciation of the current employment and skills landscape across the Humber in association with the current industry landscape.
- Exploring how the employment landscape is likely to change under different pathway scenarios for both temporary and permanent workforce in the region and importantly the movements and any skills shifts that may be related with this. This will allow employment ingress, egress, re-training, and upskilling plans to be developed.
- Awareness of the current economic impact from industry across the Humber due to the current landscape.
- Exploring and understanding how the economic impact will likely change due to the effects of decarbonisation:
  - Temporary and transient workforces constructing decarbonisation and working to deliver decarbonisation programmes bringing direct and indirect economic benefit to the region.
  - Any enduring benefit associated with the above, for example ongoing maintenance of new infrastructure such as CCS pipelines and storage sites.
  - Change in economic value associated with any forecast change in industry energy demands, employment levels and associated power generation requirements.

This is not an exhaustive or prescriptive list of questions for Phase 2 but aims to illustrate what the methodology and the modelling should be capable of delivering. There should also be the flexibility to manage dynamic change during Phase 2.

6.1.2 Key Roadmap Functionality

Similarly, it is useful to have in mind the key functional requirements for the Decarbonisation Roadmap before beginning the modelling options appraisal. The Roadmap should:

- Provide **confidence to the approach** to decarbonise the Humberside cluster.
- Provide **industry groups** with knowledge around the **optimal approaches** to decarbonisation and associated technology pathways.
- Provide technology developers and universities knowledge around technology gaps and timescales for development, i.e. the **technology transition pathways**.
- Facilitate **leveraging and engaging policy and decision makers to** drive technology pathways where necessary. This may include working to remove potential blockers or leveraging pathway enablers.
- Enable the Humber LEP, CATCH to **communicate** key information and **engage** with major stakeholders.

6.2 Analytical Approaches

Now the context is framed, the main techniques of modelling can be explored in broad terms before moving into more detail in Section 0.

There are two main analytical approaches at the highest level: *qualitative* and *quantitative*. The key difference is that one is an objectively data-driven approach and the other is not. They both have their uses, but their nature and outputs naturally lend them to different purposes. The key features and application of these will be explored in section 6.2.1 and section 6.2.2.

6.2.1 Qualitative Analysis

Qualitative analysis is a holistic approach which involves active discovery and exploration. It is concerned with providing deeper levels of insight around opinions and perceptions. It often sets out to asks questions beginning with How? Or Why?

It is a descriptive and human-driven approach which collates and analyses information from a range of sources including interviews, surveys, stakeholder engagement and expert elicitation, *Table 4*. This requires the analyst to be actively immersed and engaged in the process and to make inferences from the information received. There is often no definable starting point or assumptions to work from; and this is an integral part of the discovery process.

<table>
<tr><th>Sources of evidence</th><th>Intermediate outputs</th><th>Pathways</th><th>Conclusions & example actions</th></tr>
<tr><td>Literature</td><td>Validated emission data</td><td rowspan="6">Analysis of evidence to construct decarbonisation & energy efficiency pathways</td><td rowspan="6">Analysis of evidence & pathways to develop strategic conclusions & possible next steps to:
• Overcome barriers & strengthen enablers
• Implement pathways</td></tr>
<tr><td>Publicly available emissions data</td><td>Decarbonisation options & associated data</td></tr>
<tr><td>Interviews, surveys, meetings & workshops with stakeholders</td><td>Energy efficiency options & associated data</td></tr>
<tr><td>Government policy and analytical teams, trade associations, academics as part of engagement with sector team</td><td>Barriers and enablers to decarbonisation and energy efficiency options & investment</td></tr>
<tr><td>Literature</td><td>Validated emission data</td></tr>
</table>

Table 4 Example traditional, qualitative approach

Typical outputs may include technical reports with indicative recommendations and limited numerical outputs. As it is not an objectively data-driven approach it is not testable, robust, or independent in the way that quantitative analysis is and may hold hidden biases. It can also be a time-consuming process to collate all the necessary information due to the required level of personal interaction with stakeholders and experts. This can also make for a difficult and lengthy process updating and adapting the analysis for any new information which comes to light.

Qualitative analysis is extremely useful for inferring trends in opinions or pain points and therefore initially determining a broad direction of travel. It can therefore be used to test a problem to see if there is something worth pursuing and if so, help with setting the strategic boundaries of the problem for further, more quantifiable, analysis. In this sense, it can and has been used by professional consultants to establish the framework for roadmaps in some sectors in respect of defining the initial high-level problem. But, as decarbonisation solutions are now progressing into the consideration of development pathways, which include complex systems models such as is present in the Humber, the indicative outputs from qualitative analysis are no longer adequate on their own. Section 6.4, Section 0 and Section 6.6 discuss the benefits of augmenting more advance quantitative analytics with qualitative analysis such as stakeholder engagement and elicitation. [26]

6.2.2 Quantitative Analysis

Quantitative analysis encompasses a wide range of approaches based on statistical and numerical analysis. They are used to assess causal relationships, predict trends, optimise solutions and carryout scenario, sensitivity, and stress analyses. This can arise in many forms, from diagnostic through to prescriptive analytics. It is a numerical, data-driven and objective approach where deduction rather than inference is used. This leads to more robust and objective outputs than those resulting from qualitative analysis. However, the levels of model output accuracy are dependent on the quality and completeness of the data inputs. Where possible, data inputs should be determined by analysis, such as statistical covariance analysis to ensure the most appropriate data inputs are being used and to understand sensitivity within the model. This may not be possible for all datasets or all types of data and some data inputs may initially be obtained via qualitative methods rather than by data-driven means. Where this happens and there are any areas of data uncertainty, scenario and sensitivity analysis can be used to support and provide an impact assessment. Data gap analysis including quality and completeness assessment can help prioritising collection of data within any future data projects.

The outputs from quantitative analysis can vary greatly in both detail and content, depending on which specific modelling method is used, see Section 0. They can include benchmarking, trend analysis, prediction, roadmaps and transition pathways, constrained optimisation and scenario and sensitivity analysis. These can be represented in a range of visual ways too: within dashboards, geographical visualizations, graphs, and reports.

Quantitative analysis is a good, robust, and objective technique to use to assess the numerical and quantifiable elements of a problem, including the development strategy for an industrial cluster decarbonisation roadmap. Section 0 looks in more detail at specific quantitative modelling methods and Section 6.6 discusses the recommended approach for the Humber Cluster Industrial Decarbonisation Roadmap. [26]

The nature of quantitative analysis makes it amenable to automation. This enables the core quantitative analysis activity to be hugely repeatable and scalable. This can be critical for dynamic problems where analysis must be repeated regularly to ensure results are updated to reflect the latest data available or where the analysis must be scaled such that multiple users can simultaneously access or carry out the analysis. For large complex problems, involving multiple stakeholders the ability for automation and scalability provides huge benefit.

6.3 Combined Approached

Sometimes semi-quantitative approaches can be taken, a mixture of qualitative and quantitative approaches. This section explores two examples of this.

6.3.1 Mixed Methods

Mixed methods, which combines the approaches of both qualitative and quantitative analysis began to emerge in the mid- to late-1900s. Previously, the two approaches were thought to be largely mutually exclusive of each other.

It can be seen from the descriptions of qualitative analysis in Section 6.2.1 and quantitative analysis in Section 6.2.2 that each approach has strengths and weaknesses. The aim of the Mixed Method approach is to maximise the strengths whilst minimising the weakness of each of the approaches by using them in support of each other.

Today qualitative and quantitative techniques can be supportive of each other in several ways. They can be run in series. As discussed in Section 6.2.1, analysis and solution framing may first start out using largely qualitative techniques in order to better understand and frame the problem in preparation for the next stage of quantitative analysis, or analytical trials. Alternatively, perhaps if there is more data and the initial problem is better understood to begin with, qualitative and quantitative techniques may be used in parallel to analyse the problem and develop solutions exploiting the strengths of both techniques. [26]

6.3.2 Morphological Analysis

Morphological analysis is a semi-quantitative approach used to identify and structure relationships and solution sets for multi-dimensional problems. It involves splitting up a complex multi-dimensional problem into several smaller and simpler constituent parts, which can be analysed more easily. This is done by manually identifying the key inputs, outputs, and drivers. This reduces the complexity of a problem by eliminating any infeasible or illogical solutions and any unnecessary interdependencies.

Key scenarios are developed, run, and analysed to support decision making. Usually this considers between 10 to 20 variables and analysis can take around 4 weeks to complete. Morphological analysis can therefore be considered a stepping-stone towards true systems modelling. [27]

6.4 Systems Modelling

Systems modelling is required to analyse and explore the behaviour of complex systems which have significant interdependencies and uncertainties. Systems modelling is made more widely accessible through advances in prescriptive analytics and cloud computing over the last decade. There are four main aspects to systems modelling:

- System Context.
- System Flow.
- System Evolution.
- System Optimisation.

6.5 Types of Quantitative Modelling

Quantitative modelling covers a range of modelling methods. This section will explore these in more detail.

There are principally four main types of quantitative modelling which use increasing levels of numerical analysis to gain insight to a problem:

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

Figure 9 shows the correlation between the complexity of the quantitative modelling method and the value, level of insight, it can provide. This does not always mean that the most complex model is always the best model. It means that each quantitative method is often best suited to a specific purpose. In Sections 6.5.1 to 6.5.5 each of these methods will be explored and assessed for the situations they are best suited for, as well as being assessed against the use case of the Humber Decarbonisation Roadmap.

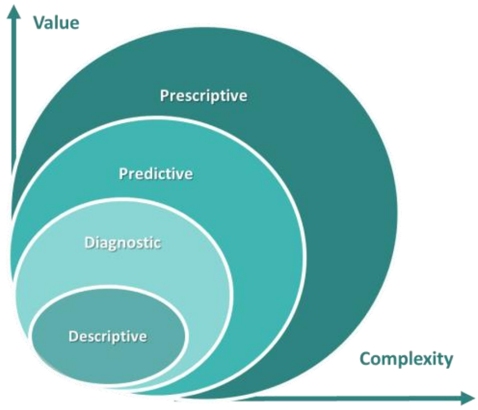


Figure 9: Quantitative methods: complexity & value correlation

6.5.1 Descriptive Analytics: What happened?

Descriptive analytics (Figure 10) is the most basic form of quantitative analysis. It uses statistics and numerical analysis to summarise, interrogate and describe historical data. This helps to gain understanding about what has happened in the past and enables learning from previous occurrences or behaviours.

Descriptive analytics, is often associated with:

- Mining of data.
- Summarising and reporting of data.
- Key performance indicators (KPIs). These are metrics used to measure business performance.
- Benchmarking: comparing business metrics to industry competitors or best practice.
- Visualisations and dashboards. These can be produced to aid business processes and performance and may be associated with some of the areas above, e.g. KPI tracking.

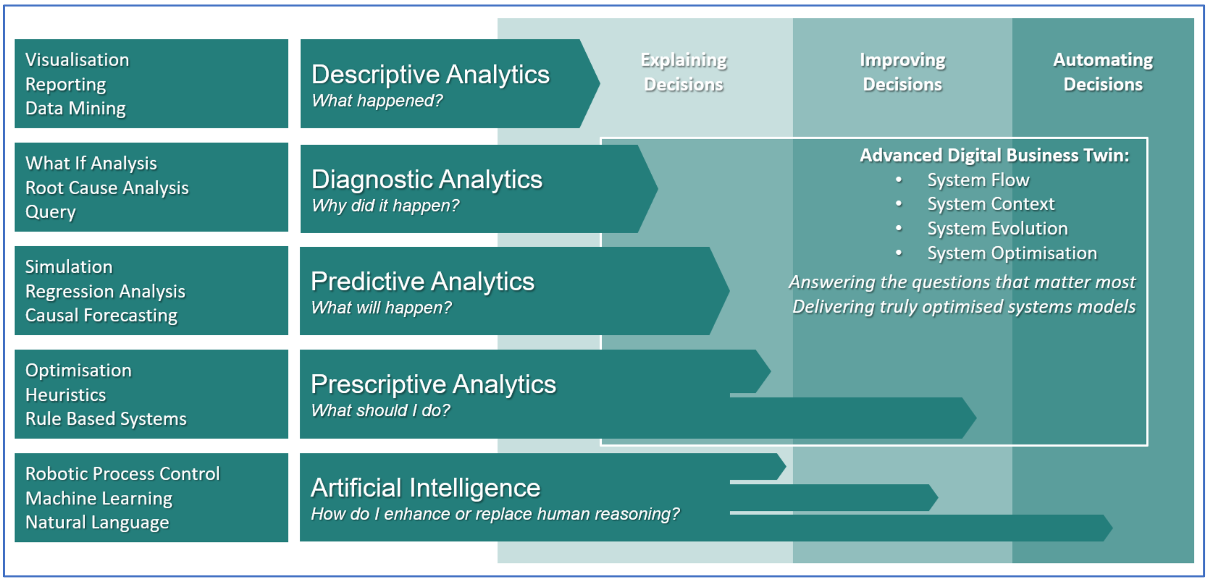


Figure 10*: Quantitative Analysis Methods*

Within the context of the Humber, descriptive analysis might enable visualisation and KPIs to be established so that performance could be monitored and tracked. Relevant KPIs might include annual carbon dioxide and other GHG emissions, energy supply and demand profiles, Gross Value Add (GVA) and regional employment (no. of jobs).

6.5.2 Diagnostic Analytics: Why did it happen?

Diagnostic analytics *Figure* 10 takes a step forwards from descriptive analytics. It drills down into the analysis of historic data: those KPIs and trend analyses, to ask why things have happened.

This includes the investigation of causal relationships. Using probability theory, regression analysis, root cause analysis, and time-series data analytics, hidden stories within data can be unearthed. This might include the identification and investigation of anomalies or determining trends that are dependent on multiple covariates which may not be identifiable by simple manual methods. [28]

Within the context of the Humber, analysis of KPIs can be actively monitored and tracked. For example, in diagnostic analytics, the progress towards Net Zero would be measured as 'net emissions' being released to atmosphere. This might be tracked and monitored over time. It would be expected that there would be a negative (downward sloping) gradient, which if extrapolated should approach zero by 2040. As low carbon is desired in 2030, it might also be expected that this gradient will be linear in nature.

6.5.3 Predictive Analytics: What is likely to happen?

Often businesses will have a defined plan they are working to. Descriptive and Diagnostic analytics are excellent ways of measuring performance against this plan and any deviations from it. They also will provide valuable insight into reasons why this has occurred. But, what about the future?

Predictive analytics (*Figure* 10) is the first step in predicting what may occur in the future. It uses historic data and trends to inform what may happen in the future. There can be no certainty, so there is a probability associated with a future event or occurrence. Increasing levels of sophistication of predictive analytics aim to reduce the uncertainty associated with forward prediction. Predictive analytics is however, fundamentally rooted in the analysis of historic data and does not take account of future step changes, or deviations from the historical trend.

Different types of techniques lend themselves to different problems depending on the type and amount of data available. These include:

- **Statistical analysis:** Statistical analysis is population or process analysis using techniques such as correlation analysis, regression analysis, analysis of variance (ANOVA), hypothesis tests, probability distribution analysis, covariate analysis, Monte Carlo simulation, Markov time-step and time series analysis. Statistical analysis allows relationships between data variables to be discovered and quantified, and then used to make forecasts with a formal degree of confidence.
- **Neural networks:** Neural networks were originally designed to mimic the function of the human brain. They are networks of nodes connected with each other in a computer system, which are analogous to the way the neurons in the brain are connected. Algorithms enable them to process raw data to perform pattern recognition or identify data correlation. With the ability to learn and self-develop their ability over time, neural networks are now helping to solve large, complex real-world problems. This type of 'Deep Learning' is an evolving area, but there is promise in being able to reveal hidden variances, relationships and make inferences from large amounts of raw data. Examples of use include credit card fraud detection, facial recognition, and robotic control systems. [29]
- **Machine Learning:** Machine learning is a form of artificial intelligence, whereby computer systems can learn from data and make decisions with minimal human intervention and without the need to follow explicitly programmed instructions. As with neural networks, it is good for processing large amounts of raw data, enabling pattern recognition and inferences to be made. Examples of use include Google's self-driving car and online recommendation of offers and advertisements. [30]
- **Data Mining:** Data mining includes the discovery of hidden patterns in historic data, which are used to predict future trends. Advances aligned with 'Big Data' (extremely large sets of raw data) have allowed powerful data mining of large data sets coupled with machine learning. This is being used in areas as diverse as price optimisation, social media, and providing better understanding around customer relationships. [31]

However, it is not just choosing a suitable modelling technique that is critical when using predictive analytics. The following should also be considered:

- **Data**: Is the data appropriate to the model? Also, is there sufficient quality and quantity to the dataset(s) to provide reliable results?
- **Validation:** Predictive analytics models should not be treated as 'black boxes'. Analysis outputs should be validated and calibrated against the real-world situations they are modelling to ensure they are representative.

Within the context of the Humber, analysis of KPIs can be actively managed. Scenarios of future projects might be modelled to forecast future positions of 'net emissions' at 2040 and compare them to the desired outcome of Net Zero.

In reality, it is also likely that many other outcomes or outputs are also required to be managed or understood simultaneously, such as employment levels, cost of investment, future technology, GVA etc. This results in a complex multi-constraint base problem, which requires the use of prescriptive analytics.

6.5.4 Prescriptive Analytics: What should I do?

Prescriptive analytics (*Figure* 10) often takes the results from predictive analytics as inputs. Combined with constraint-based optimisation, this allows decisions about the future to be informed.

> *"Prescriptive analytics is the application of logic and mathematics to data to specify a preferred course of action. The most common examples are optimization methods, such as linear programming; decision analysis methods, such as influence diagrams; and predictive analytics working in combination with rules. Prescriptive analytics differs from descriptive, diagnostic and predictive analytics as its output is a decision."* Forecast Snapshot: Prescriptive Analytics Software, Worldwide, 2019, January 23, 2019, Gartner

Like predictive analytics prescriptive analytics considers historic information but it is not restricted by it, rather using it as a flexible constraint. Prescriptive analytics can use the information gained in the past to define physical, operational and financial constraints which are combined with user defined or business defined constraints. Constraint can be made be made more-or-less flexible to test a wide range of scenarios. This makes prescriptive analytics well suited to mixed method approaches and enables scenario and sensitivity testing of future cost and revenue streams and workload plans.

Prescriptive analytics is therefore well suited to the development of business plans and critical infrastructure deployment plans where there are defined constraints, such as the Humber Decarbonisation Roadmap.

The key principle of prescriptive analytics is to maximise value given any constraints set. Value is defined by the user. Constraint based modelling is not deterministic (hypothesis-driven). That is, there is no analyst, engineer or expert informing the modelling in a deterministic way, more they are shaping the questions to ask of the model: a scenario. In the context of the Humber Decarbonisation Roadmap, one scenario may require Net Zero at 2040 (constraint) and a minimum cost solution (objective function); another scenario may require Net Zero at 2040 (constraint) and a maximum regional employment, jobs, impact (objective function).

Constraint-based optimisation uses a range of linear and non-linear mathematic optimisation techniques to determine the overall optimal solution from within the decision-space described by the constraints. If this is coupled with Systems Modelling (Section 6.4) this results in the optimal solution for the System taking into account interdependencies and associated opportunity values. [32]

As with predictive analytics, data quality and quantity and model validation are also key aspects to the modelling process (see Section 6.5.3).

In the context of the Humber, the constraint of Net Zero at 2040 can be set and a scenario can be run for various objective functions and scenarios. First, the baseline scenario is typically run with no interventions for carbon reduction. This would be to understand current drivers, economic impacts, and uncertainties around potential growth, i.e. what are the possible starting points (without investment to decarbonise).

Secondly, scenario and sensitivity analysis of decarbonisation options can be carried out. Each of the major technological interventions may be run individually in turn to test the extent to which is can support decarbonisation in the Humber before evaluating all technology interventions simultaneously to determine the optimal blend of technologies.

> *"Currently, 11% of large and midsize organizations have some form of prescriptive analytics; this will grow to 37% by 2022."*
>
> Forecast Snapshot: Prescriptive Analytics Software, Worldwide, January 23, 2019, Gartner

This would provide insights into the drivers, enablers and blockers associated with these investments in the specific context of the Humber region, as well as additional constraints and technological advancements to explore.

It is unlikely that any single technology pathway is viable in isolation. It is more likely, due to cost, emissions and other trade-offs (such as GVA or security of supply), that only a combined technology approach will be feasible – but the scenario analysis will allow this to be tested and explored. Additional objective functions can also be explored, such as minimising cost, or maximising employment. Leading edge prescriptive analytics solutions allow complex blended objective functions which would evaluate possible roadmaps against a weighted base of monetised values.

6.5.5 Quantitative Modelling Comparison Summary

This section compares each of the quantitative modelling techniques in *Table 5*.

Modelling Option	Descriptive	Diagnostic	Predictive	Prescriptive
Modelling Description	***What happened? Why?***		***What is likely to happen?***	***What should I do?***
Examples	Using historic data to benchmark or analyse trends	Summarising historical data or spotting patterns or meaning	Uncover insights in historic data which can be used to predict future events or occurrences	Constraint based optimisation, which uses historic data, user defined constraints & mathematical optimisation to inform what should be done in future
Advantages	Effective for solving less complex problems		More advanced modelling technique: allows for **future prediction of what will happen**, based on analysis of historic data.	**Advanced non-deterministic modelling technique**: Future end states & pathways can be considered by **scenario analysis, constraint-based optimization & sensitivity analysis.**
Disadvantages	**Simpler modelling technique:** does not account for the complexity of models in terms of systems interdependencies, uncertainties. Neither does it allow future projection of the state of the system.		**Does not fully account for the complexity of models** in terms of systems interdependencies, uncertainties. Neither does it consider the possible future pathway states, purely using historic experience to predict future expectations.	The advanced modelling can **increase the complexity of analysis**. However, this is typically designed for during solution build & user interface /dashboard development.
Summary	**Good at providing simple historic assessment** of systems where there is little complexity & interdependency.		**More advanced modelling technique than Descriptive / Diagnostic** but models the future state on historic experience and does not fully account for the complexity of systems interdependencies and uncertainties.	**An advanced non-deterministic modelling technique:** Scenario and sensitivity analysis can be used to explore what should be done in the future. This requires a more complex model, but user interface and dashboards can be developed for the user.

Table 5: Quantitative methods, summary

6.6 Recommended Analytical Approach

Sections 6.2 to 0 have discussed the various analytical and modelling methods across qualitative and quantitative techniques.

This Section details the recommended approach to use in Phase 2, Humber Decarbonisation Roadmap.

> The Humber Decarbonisation Roadmap requires analysis of a complex industrial system including significant interdependencies and uncertainties. Therefore, it is recommended that a quantitative**, prescriptive analytics** approach is taken. This should include **constraint-based mathematical optimisation**, **scenario**, **sensitivity analysis** and **systems modelling**.

This will be a robust, objective and data-driven approach. As with all quantitative modelling processes, it is anticipated that there may be some areas where data elicitation and stakeholder engagement is key to the process. Therefore, the above approach will be augmented with elements of the qualitative approach where appropriate.

6.6.1 Outcomes of recommended approach

Adopting this recommended modelling approach will:

- Inform the optimal direction of the decarbonisation pathway, with no regrets / least regrets visibility.
  - Including system interdependencies and uncertainties.
  - Enabling engagement with key decision and policy makers to drive technology pathways.
  - Facilitate engagement with technology developers, industry groups and academic / research institutions.
- Enable the management of future risks and uncertainties.
  - Decrease uncertainties through scenario and sensitivity analysis. This will increase conscious awareness of where uncertainty lies and the sensitivities relating to it.
  - Provide the ability to dynamically engage with the roadmap model. That is, the legacy ability to actively re-engage with the model and re-run scenarios as and when new data or information comes to light.
- Enable the modelling of different objective functions and scenarios, for example:
  - Time frame: the impact of time delay or bringing forward of the target date.
  - Cost: minimisation of cost.
  - Carbon level: Net Zero at 2040; Net Zero at 2045; Net Zero at 2050.
  - Maximise economic impact: regional employment levels (jobs) or GVA.
  - Lowest deliverability risk.
  - Possibility of other government or policy perspectives. Some policy elements and subsidies are likely to be constraints to the model scenarios rather than objective functions in and of themselves.

    Often BEIS, Innovate UK or Local Authorities, are simply interested in the bottom line, i.e. minimisation of cost. However, when the story of complex outcomes, such as critical infrastructure construction and ongoing asset management, as well as impacts on the environment, economy and employment levels are assessed in the round, it is often seen that cost minimisation is part of a suite of outcome deliverables where value trade-offs exist.

7 Phase 2 System Model Scope, Procurement & Delivery

This section outlines the recommended structure and core functionality of the required systems modelling solution to deliver the modelling approach recommended in section 6.

7.1 Solution Modules, Structures and Capabilities

In order to support the objectives of the Humber Decarbonisation Roadmap Phase 2 project the systems solution will require several core functional modules (Table 6) which are also outlined in more detail in the following sections.

Module	Functionality	Functionality use / output
Data ingestion and pipeline	Ease of data input & bulk import	Assemble & analyse detailed evidence base
	Data quality assurance including automated error trapping & descriptive analytics on imported data	Ensure HIDR impartiality, trust & full engagement
Data storage	Relational data base	Identify & model dependencies between technology & industries
	Support multiuser access & scenario analysis	Ability to run a range of 'what-if' scenarios & assess based on impact, cost & deliverability
	Auditability	HIDR is evidence based & robust
	Maintain single version of the truth	Coordinate large emitters, low carbon infrastructure providers, deployment projects & other stakeholders to develop a shared HIDR to achieve net zero by 2040 or before.
	Maintain single version of the truth	Ensure HIDR impartiality, trust & full engagement
Forecast	Forecast energy demand of industrial emitters represented in model	Assemble & analyse detailed evidence base
Systems Model	System flow (energy, inputs/output materials)	Ability to run multiple 'what-if' scenarios & assess based on impact, cost & deliverability
	Flexible scenario creation & analysis	Coordinate large emitters, low carbon infrastructure providers, deployment projects & other stakeholders to develop a shared HIDR to achieve net zero by 2040 or before.
	Optimisation - flexible objective function	Coordinate large emitters, low carbon infrastructure providers, deployment projects & other stakeholders to develop a shared HIDR to achieve net zero by 2040 or before.
	Optimisation - flexible objective function	Maximise local business & community benefits from decarbonisation
	Model financial impacts & opportunity values	Enhance Humber inward investment proposition
	Include wider impacts (including monetisable & qualitative impacts)	Align HIDR with local clean growth plans
	Include wider impacts (including monetizable & qualitative impacts)	Maximise local business and community benefits from decarbonisation
	Include wider impacts (including monetisable & qualitative impacts)	Include jobs created and safeguarded & improved air quality

	Multi-layer object orientated reasoning & metadata support	Break down decarbonisation of HIC into management parts
	Sensitivity and Stress Test Analysis	Ensure HIDR is robust and trusted
User interface	Allow controlled multiuser access to data, scenarios & results	Coordinate large emitters, low carbon infrastructure providers, deployment projects & other stakeholders to develop a shared HIDR to achieve net zero by 2040.
	Allow controlled multiuser access to data, scenarios & results	Build wider consensus around HIDR & actions required
Data Visualisation	Clear and compelling data & results visualisation	Build wider consensus around HIDR & actions required
	Clear and compelling data & results visualisation	Engage effectively with Government on business & regulatory models
	Clear and compelling data & results visualisation	Coordinate large emitters, low carbon infrastructure providers, deployment projects & other stakeholders to develop a shared HIDR to achieve net zero by 2040.

Table 6: Model functionality and output

7.1.1 Data ingestion and pipeline

Data import: The model must be able to effectively import and transform the necessary data to develop, optimise and test a robust decarbonisation roadmap. Given the wide variety and volume of data required the data import function must be user friendly and flexible: at least able to support common file types including flat files, spreadsheets, and open database connectivity databases (such as MS SQL). To support effective data governance where multiple scenarios and users are supported the model must store data in a model relational database.

Data quality: To provide assurance over data quality it will be important that the model supports an effective data pipeline (processes by which raw input data are transformed into model data). This should include automatic error trapping and data integrity testing to ensure that data quality is maintained. This is particularly important where multiple data sources will be integrated to run scenarios. A data integrity test is required to ensure that data is being integrated in a logical and consistent way for each scenario. The integrity of all further modelling and scenario development will be contingent on the quality of the underlying data.

7.1.2 Data Storage

Supporting scenario analysis and governance: For the model to support effective governance of multiple scenarios it must have a data storage module capable of maintaining a single version of the truth that is kept distinct from individual 'what-if scenarios. For example, when a user creates a scenario a clone of the core data should be taken and then manipulated as per the requirements of that scenario. While this can be achieved manually in a very basic system, such an approach would not offer any governance or auditability of scenarios. A more advanced system (as we would recommend for the HIDR phase 2) would maintain a record of what had been changed in a scenario (versus the base data) and who made those changes. This would remove the need for laborious version control and ensure the data underpinning all scenarios is robust, controlled and auditable.

Accessibility and security: Where multiple users are expected to be accessing data (whether to run scenarios or view results) it is important that data is stored on a platform that can support multiple user access. This can be achieved by using an enterprise grade modern open database connectivity database such as Microsoft SQL Server.

7.1.3 Systems model

The system modelling module is at the heart of the overall model required to deliver an optimised, deliverable decarbonisation roadmap for the Humber. To deliver the best possible outcomes for the HIDR phase 2 project the core systems modelling module must be capable of representing:

- System Context.
- System Flow.
- System Evolution.

Optimisation: With an overarching ability to represent system context, flow and evolution, the HIDR systems model must be able to optimise for the end to end system as a whole (**system optimisation**). A system cannot be optimised through siloed optimisation of subsystems. Any optimisation at a whole system will mean that some subsystems are run sub-optimally (from the subsystem perspective). Given the complex interdependencies, trade-offs and multiple impact variables (cost, jobs, clean air etc.) that will be encompassed in the HIDR it is highly likely that the overall optimal roadmap developed will be 'sub-optimal' for some individual sub-systems, industries or stakeholders.

Simple example of a constraint-based optimisation problem: an auto manufacturer has two assembly lines, Line #1 for cars and Line #2 for trucks. However, the manufacturer has a single paint shop, which acts as a constraint for the entire plant. The company, in this case, wants to know how many cars and trucks it should make to maximize profitability. When an optimal solution is obtained, neither assembly line's production can exceed the paint shop's capacity.

The recommended modelling approach to achieve system optimisation is constraint-based modelling. Constraint-based modelling is a mathematical approach, in which the outcome of each decision is constrained by a minimum and maximum range of limits (+/- infinity is allowed). For example, constraints can include financial constraints such as an available budget, the physical constraints of assets such as maximum capacity, or regulatory constraints such as achieving net zero carbon emissions by 2050. A constraint-based modelling approach is most commonly — and effectively — used with optimisation techniques, such as the use of linear and mixed-integer programming to maximize an objective function. When the model determines the optimal solution, it must find a solution where all the decision variables sharing a common constraint must have their solution values fall within that constraint's bounds. The most advanced constraint-based optimisation solutions are also able to:

Represent Soft constraints: These are constraints that can be broken but at a penalty. These are useful for more subtly constraining a problem and tuning model behaviour.

Quantify opportunity value: Opportunity value is the monetised benefit of relaxing a binding constraint. For example, if the rate at which hydrogen can be produced at plant A is constraining the ability of achieving low cost decarbonisation across the Humber as a whole, this will be highlighted and the Humber wide financial benefit of increasing hydrogen production at plant A quantified. Opportunity value is fundamental to effective systems planning because of its ability to clearly signpost the decisions and actions that would enable greater value to be achieved with a given system.

Optimise for Multiple Objective Functions: The ability to switch objective function quickly and easily is a useful capability, particularly for complex, multi-dimensional problems. Beyond simply being able to switch from a cost minimisation to a profit maximisation objective function, the HIDR model would benefit from being able to solve for other objective functions such as maximise job creation/retention or maximise speed of decarbonisation. A complete solution would also be able to solve for blended objective functions, for example to determine the optimal roadmap that best balances cost, job creation and improvement in local air quality.

Decision Support: Leading edge systems modelling solutions offer a wide decision support capability beyond simple optimisation. By combining hard and soft constraints with flexible objective functions they offer more nuanced support for a range of questions. In order to coordinate the perspectives of multiple stakeholders with potentially competing interests and consider a wider range of impacts including carbon emissions, cost, deliverability, local jobs and clean growth plans – developing an optimal and deliverable decarbonisation roadmap for the Humber will require a solution that can support a wide range of decision support functionalities. Put another way, it is important that the model used in Phase 2 has the flexibility to accommodate the full range of questions and scenarios required by stakeholders within and associated with the HIC. These may include Politicians, BEIS, the Humber LEP, matched funders, industrial stakeholders, deployment projects, technology developers and researchers, and local authorities.

Each decision support functionality allows the user to ask different questions of the solution for example, "what would be the optimal scenario to benefit local jobs?" or "what is the trade-off between cost and deliverability?". A complete list of decision support functionalities recommended, and corresponding scenarios enabled is provided in Table 7.

Decision Support Functionality	Scenario, Questions and Insights Enabled
Test the applicability of individual decarbonisation technology options to the Humber Industrial Cluster.	• Is the technology option championed; and is it a good fit for the Humber Industrial Cluster? • Which technology options are most relevant to the Humber Industrial Cluster?
Optimise transition pathway for lowest cost, considering multiple constraints, for example: • Timeline to Net-Zero. • Phasing of technology and infrastructure options. • Range of technology and infrastructure options. • Economic impact.	• What is optimal blend of technologies and infrastructure investments (to minimise cost) to achieve our decarbonisation objectives in a deliverable way. • Exploration of the evolution of hydrogen, including the balance of blue and green hydrogen, as well as the balance of hydrogen with other energy and technology solutions.
Exploring the impact of different Objective functions on the pathway.	• For example: ○ Minimum cost. ○ Minimum uncertainty. ○ Maximum employment.
Performing sensitivity analysis.	• This will help identify the areas of the HIC system that are most sensitive to change and where uncertainty is therefore higher as projections are made further into the future. This can help with uncertainty analysis, as well as no regrets /least regrets investment planning.
Performing stress tests.	• Stress tests are often used to assess the impact of a shock to a system, typically a low probability high impact event. This provides confidence to stakeholders that the HIDR is robust and resilient.
Trade-off analysis and optioneering.	• Analysis of impact of trade-offs and different options for decarbonisation technology, projects or phasing optioneering.
What-if' scenario analysis.	• For example, 'what if' new decarbonisation technology becomes available? This can inform real-options analysis and ensure opportunity value is fully accounted for.

Table 7: Illustrative Scenarios

7.1.4 User interface and data visualisation

It is very important that the model enables the visualisation of the roadmap such that it can be used to effectivity engage with the widest range of stakeholders including those at senior level, including:

- The UKRI ISCF commissioning committee, particularly with regards to the appropriateness and robustness of the proposed roadmap methodology and the strategy to secure the Roadmap project Phase 2.

- Potential partners and stakeholders such as Drax Group, National Grid Ventures, SSE and Equinor. They will require confidence in the strength and robustness of the roadmap, as well as the business case for the provision of match funding.
- Approval and engagement from national and local policy makers, e.g. BEIS and local authorities.

To successfully engage with stakeholders such as these, the roadmap needs to be accessible through clear, engaging, and dynamic visuals supported by more detailed views. For a modelling solution, this entails a result dashboard that can be used interactively with stakeholders.

It is expected that the Users of the model will include:

- Humber Decarbonisation Roadmap Team.
- Matched funders.
- Industrial stakeholders.
- Deployment Project teams.
- Technology developers and researchers.
- Local authorities.
- UKRI ISCF commissioning committee.
- National and local policy makers, e.g. BEIS, local authorities

It is important that the model platform supports different levels of users to enable (in a controlled and appropriate way) a full range of active stakeholder engagement both within HIC, as well as with technology developers, policy and decision makers and researchers. This is likely to include, for example:

- Super-user: active user who defines and updates core data and systems model.
- Analyst: active user who inputs data to define and run scenarios.
- Read-only: visibility of relevant results in dashboards.

7.1.5 Solution architecture: Modules and structure

The proposed high-level solution architecture of the model is shown in *Figure 11*. The solution architecture shows the core elements of the proposed solution from data to system model to user interface. It also illustrates how the different user types will interact with the solution. To allow for scalability and ease of user access this architecture would be web based ideally hosted on a cloud-based computing platform.

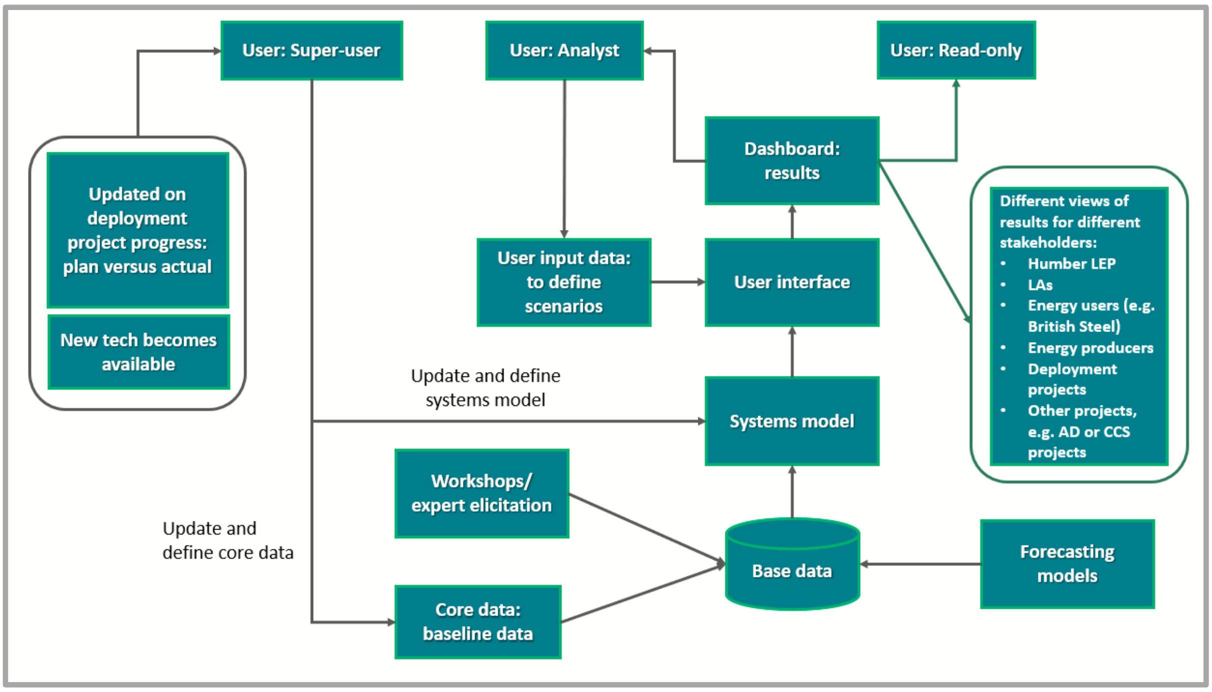


Figure 11 Solution Architecture

7.2 Summary of overall functional requirements

A summary of the overall systems modelling solution requirements aligned to key HIDR phase 2 outcomes is outlined in Table 8.

Core Systems Model Functionality	Link to Key HIDR Phase 2 Outcomes
Prescriptive analytics approach, including constraint-based optimisation, scenario, sensitivity analysis and systems modelling. This will inform the optimal direction of the decarbonisation pathway, including system interdependencies and uncertainties.	Provide **confidence to the approach** to decarbonise the Humberside cluster.
Enable the modelling of different objective functions and scenarios. Providing visualisation of scenarios & sensitivity analysis through a range of user-defined dashboards, including a range of levels of data presentation & formats. For example, geo-spatial & graphical. Easy to use & flexible user interface, allowing interaction with dashboards to show development & dynamics of pathways over time. Provide the ability to dynamically engage with the roadmap model. That is, the ability to actively re-engage with the model & re-run scenarios as & when new data or information comes to light.	Provide **industry groups** knowledge around the **optimal approaches** to decarbonisation & associated technology pathways.
Enabling engagement with technology developers, industry groups & academic / research institutions. Provide the ability to dynamically engage with the roadmap model. That is, the ability to actively re-engage with the model and re-run scenarios as & when new data or information comes to light.	Provide technology developers and universities knowledge around technology gaps and timescales for development, i.e. the **technology transition pathways**.
Enabling engagement with decision maker & policy makers to drive technology pathways.	Facilitate **leveraging & engaging policy & decision makers to** drive technology pathways when necessary. This may include working to remove potential blockers or leveraging pathway enablers.
Enabling engagement with technology developers, industry groups & academic / research institutions	Enable the Humber LEP, CATCH to **communicate** key information & **engage** with key stakeholders.

Table 8: Functional Requirements

7.3 Deployment Plan, costs, Delivery Partners and procurement recommendations

7.3.1 Deployment Plan

The high-level deployment plan for Phase 2 is shown in *Table 9*. Each of the activities: Gathering Data & Meta Data, Data QA / QC and Model Configuration estimated durations are long (9-12 months) and involve large periods of overlap. This is due to the anticipated need for extensive stakeholder engagement, data assurance and likely requirement for research and elicitation in areas where there is poor quality data or data is lacking.

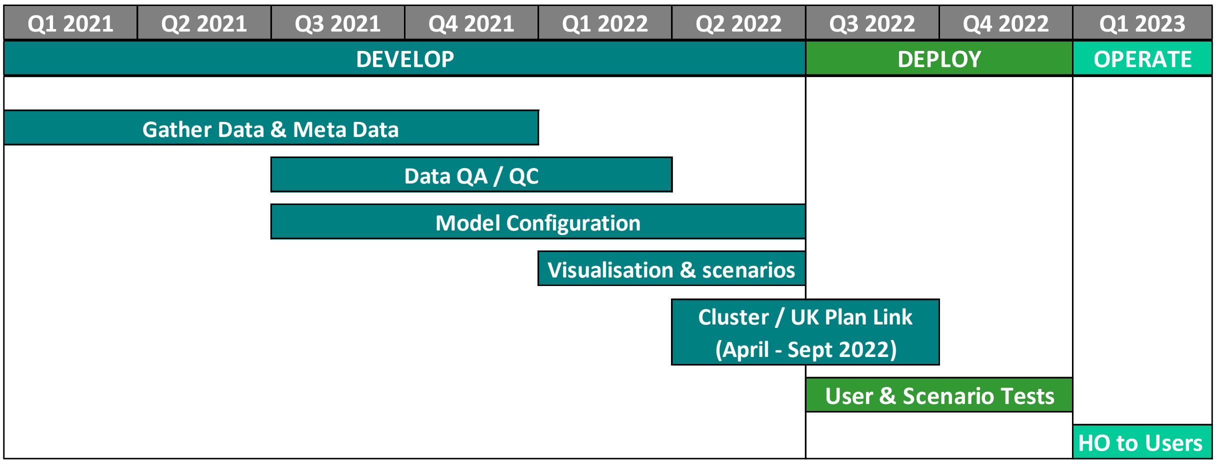


Table 9: Phase 2 Development Plan

7.3.2 Delivery Partners

In selecting a Delivery Partner for the Energy Systems Model it is essential that this is undertaken in the context of:

a) maximising the effectiveness of the investment made in the Model;

b) ensuring the delivery is done in line with the overall Phase 2 Project requirements (both time and quality);

c) minimizing the potential risks of the delivery of a sub-standard model with the knock-on impacts this could have on the overall Phase 2 project goals.

Sections 7.1 and 7.2 have highlighted the functional requirements of the proposed model. It is also important to explicitly highlight the Critical Success Factors required to best achieve the core objectives of Phase 2. By identifying these factors this can assist in creating a framework to assess the relative advantages and disadvantages of selecting the various types of Delivery Partner.

7.4.2.1 Critical Success Factors

The following represent the Critical Success Factors for model development, deployment, usage and maintenance:

a) **Timely Delivery** – the essence of Phase 2 is to use a model-led approach to determine, through a broad based stakeholder engagement process, the ‘optimal’ Roadmap for the Humber as a whole to achieve net Zero (as opposed to a particular Roadmap favoured by an individual stakeholder or select set of stakeholders). The model is the key enabler of this stakeholder process. If the model is therefore only available towards the end of Phase 2 this will have negated the value of a model-led approach (and associated investment) and will result in an ‘opinion based’ outcome;

b) **Working System (fit for purpose) –** in line with point (a) above the model delivery cannot be approached as a Research project or an exploratory software development. Unless the model can be utilized quickly and effectively (i.e. in line with the Functional requirements) it will not build the advocacy required to drive the Roadmap development process across the stakeholder base;

c) **Usability –** the model delivered must be easy to use (particularly the ability for the non-expert user across the stakeholder community to rapidly develop scenarios) easy to access, and easy to audit (in terms of stakeholder usage). This 'usability' is another key factor in building the 'buy-in' from stakeholders such that model adherence can be maximized;

d) **Cost & Cost Management –** funds available for this project will be limited by the guidelines of the Phase 2 criteria. For varying commercial reasons different Delivery Partners will approach project costing in different ways. This is even more applicable for the management of project budget over-runs, which often occur on large scale IT projects. The pragmatic reality of Phase 2 is that there will be no scope for Budget over-runs, and no Finance department to approach to divert funds from other projects into this one. So, the Delivery Partner selected must have a track record of delivering against a fixed budget;

e) **Support & Maintenance –** as the Phase 2 bid partners, the Humber LEP and CATCH do not have extensively resourced IT departments to call upon. Phase 2 therefore requires a model that is light on both support and maintenance to ensure that unbudgeted costs do not arise during Phase 2, particularly at critical times in the stakeholder engagement process;

f) **Objectivity / Conflict of Interest –** as with any project it is essential that all partners and contractors declare any relevant conflicts of interest. This is particularly important for the Humber region where significant commercial interests will be affected by the chosen decarbonization roadmap.

7.4.2.2 Types of Delivery Partner

This section details the different types of Delivery Partners and approaches that could be used for Phase 2 (Table 10), with relative pros and cons, as compared against the previously highlighted Critical Success Factors.

Advantages	Cons
Academic / Not-for-profit organisations, including Universities	
• Possibly a lower cost option; • Academic endorsement may be useful with Innovate UK / BEIS etc.	• Typically, not experienced with delivering project on time and on budget • Universities rely on inexperienced resource (PhD students and post-graduate researchers to deliver applied projects as experienced academics are busy with teaching and research) • Universities are typically more interested in leading edge research than pragmatic applied science
Inhouse Team This would entail the building a Software development team within the Phase 2 Bid Leaders organization(s).	
• Possibly lower cost option, (although this can grow out of control and budgetary limits) • Familiarity and dedicated resource • Opportunity to build in-house capability	• CATCH/Humber LEP core organizational capability is not software development and management • High risk of non-delivery within the required time frames without bringing in additional software development resources
Consultancy firms Includes larger National / Multi-National Engineering Consultants, niche Engineering / Energy consultants, large Audit / Regulatory Advisory firms.	
• Experienced in delivering projects on time and on budget • Can offer domain expertise and knowledge of industry best practice	• Not specialized or experienced in software development, typically using Excel or building simple analytical models in R or Python.
Niche Tech development firms (specialising in Whole Systems Modelling)	
• Experience and track record of delivering similar niche software solutions • Focused and relevant experience and expertise	• May have resource availability issues due to small size and other commitments • May not have sufficient resource to deliver outputs outside of core model delivery (such as training or stakeholder engagement)
Systems Integrators Systems Integrators are companies specializing in the development and implementation of large scale 'Industrial strength', Enterprise IT solutions, typically to large user Communities.	
• Experienced in managing and delivering large-scale IT projects (100 plus users) • Often able to reduce cost with outsourced data input and development resource	• Typically, only experienced in delivering well established solutions (limited ability to deliver highly customized or bespoke solutions) • No specialised domain expertise beyond generic IT development • Overkill for solutions with smaller user-bases

Table 10: Delivery partner approaches

7.4.2.3 Recommendations

1. Ideal Team structure

The ideal team structure would include a consortium of partners that together could provide:

- energy system domain expertise;
- knowledge and ability to manage Humber Industrial Cluster stakeholders; and
- specialised systems modelling experience and expertise.

We would therefore recommend a team comprising:

- a Delivery Partner selected through an RFP process;
- an internal Subject Matter Expert;
- possible support from an external consulting firm to provide external data sets (should this be required);
- possible inhouse training and support advisor to assist with stakeholder model usage and data.

2. Recommendation - approach to RFP

On the assumption that standard procurement processes need to be followed, we would recommend that a maximum of three potential Delivery Partners are approached to tender, one Systems Integrator, one Niche tech firm and one Audit / Regulatory Advisory firm. This will limit the time and effort expended in the procurement process while providing options for all types of Delivery Partner.

7.3.3 Costs

The following indicative costs (Table 11 a) to e)) for delivering a systems modelling as recommended in section 6 and specified in sections 7.1 and 7.2 are based on our recommendation that a customise software acquisition approach is taken (see section 7.4.4). In additional to these system model delivery costs we would estimate that data gathering activities would require an additional £100,000 of cost. These costs are based on our industry experience.

	a) Core Model: Humber Industrial Decarbonisation (major industry)
Description	The Core Model is the recommended minimum viable product (MVP) for Phase 2 delivery. Additionally, several extensions are set-out, which can be carried out additionally to this MVP, either separately or together - to create a more comprehensive programme of works for Phase 2.
Value	Delivers MVP of developing the Humber Industrial Cluster 2040 net zero decarbonisation roadmap and optimal delivery transition pathway for the six principal industry sectors detailed below.
Areas	Hull, East Riding, North Lincolnshire and North East Lincolnshire.
Industrial Sectors	Steel and iron, refining, chemicals, cement, glass, and paper.
Power Generators	CHPs linked to industry: VPI Immingham & Triton Power.
	Power Stations: Keadby, South Humber Bank; and include Drax.
Renewables Generators	Core region: Operational, under construction and planned (plus Dogger Bank offshore wind farm, which is not included in the Data Project 'core region').
Objective functions examples	o Time frame: the impact of time delay or bringing forward of the target date.
	o Cost: minimisation of cost.
	o Carbon level: Net Zero at 2040; Net Zero at 2045; Net Zero at 2050.
	o Maximise economic impact: regional employment levels or GVA.
Budget Cost	**Core Model = £400,000 - £500,000**

	b) Extension: Plus…additional sectors and onsite CHPS in core region
Description	Extends the Core Model to consider whether any other industry sectors, in addition to the core six industries, should be included in the pathway to decarbonisation in the Humber. This should include assessment of the carbon emissions of sectors, single point emissions, whether sector emissions are clustered or disparate and locations of significant large single point emitters. CHPs onsite at industrial sites will also be included, where valuable and where data can be obtained
Added Value	Assessment to determine whether there are any other industries which can contribute significantly to Net Zero 2040, or a possible second decarbonisation phase. Adding in data from these identified industries to the model will provide an augmented view of the decarbonisation roadmap and transition pathways.
Areas	Hull, East Riding, North Lincolnshire and North East Lincolnshire.
Industrial Sectors	Core Model, plus additional industries will be incorporated into the modelling.
Power Generators	Core Model, plus CHPs onsite at industrial, where valuable and where data can be obtained
Renewables Generators	Core Model
Budget Cost	**Core Model + £150,000 - £250,000**

	c) Extension: Plus…Supporting South Yorkshire Regional Hydrogen Economy
Description	Supporting South Yorkshire Regional Hydrogen Economy through significant hydrogen export through the 2030s (ref: 'Establishing a regional hydrogen economy Accelerating the carbon transition in South Yorkshire, UK', (Arup, 2019; p.7)). This will include the interdependencies between the two regions, the required timeline and key milestones and necessary interconnecting infrastructure.
Added Value	Support of the hydrogen economy in South Yorkshire also has the potential to drive and augment the hydrogen economy in the Humber region. This may have multiple potential effects including advantages for the economy of CCS and hydrogen infrastructure, increasing hydrogen production and the jobs and revenue associated with this; and altering the forecast pathway for blue and green hydrogen. All these aspects, and more, can be questioned and tested within the model once the appropriate data from both regions has been collated.
Areas	Humber LEP and Sheffield City Region LEP (Barnsley, Doncaster, Rotherham & Sheffield)
Industrial Sectors	Core Model
Power Generators	Core Model
Renewables Generators	Core Model
Budget Cost	**Core Model + £100,000 - £150,000**

	d) Extension: Plus…neighbouring Power Generators
Description	Include neighbouring Power Generators to the South of the Humber LEP.
Added Value	Modelling will assess whether including these additional Power Generators will make the CCS infrastructure in the Humber industrial cluster more economical.
Areas	Core Model, plus area to South of Humber LEP.
Industrial Sectors	Core Model
Power Generators	West Burton A CCGT, Westburton B CCGT
Renewables Generators	Core Model
Budget Cost	**Core Model + £100,000 - £150,000**

	e) Extension: Plus…supporting domestic decarbonisation of heat, in line with H21 North of England
Description	This will look at the synergies and interdependencies with the domestic decarbonisation of heat and the hydrogen transition pathways of the gas distribution and transmission networks which interconnect with the Humber region.
Added Value	By considering the synergies and interdependencies of these stakeholders who are also looking to decarbonise regional and national gas networks, significant benefits may be realised by working in an interconnected and collaborative way. The Humber industrial cluster is not an independent, segregated region, but has many potential sources and sinks of energy sources, gas / hydrogen production and emissions removal or storage. Opening collaboration across these source / sink boundaries is a significant area of potential gain which can be explored through the model and collaborative working.
Areas	Core Model, plus Tyneside (Newcastle, Gateshead), Teesside, York, Hull, West Yorkshire (Leeds, Bradford, Halifax, Huddersfield, Wakefield), Manchester and Liverpool
Industrial Sectors	Core Model
Stakeholders	Industrial and commercial sites - including any industrial sites and power stations in the core model; Gas distribution network, Gas transition network, BEIS, Ofgem, Local Authorities.
Power Generators	Core Model
Renewables Generators	Core Model
Budget Cost	**Core Model + £250,000 - £350,000**

Table 11: Core Model and Extension Costs

7.3.4 Software procurement approach and considerations

Following Gartner (leading international IT analysis) best practice there are three basic approaches to acquiring the Humber decarbonisation roadmap solution. These are:

1) Buy – buy an off-the-shelf software solution and use
2) Customise– buy an off-the shelf but configure or customise it
3) Build it – develop a new, bespoke software solution

In common with any software procurement exercise the Humber Decarbonisation Roadmap team must consider the following variables to understand whether buy, customise or build it. These are:

- Unique functional requirements: The degree to which the solution must meet unique requirements and whether there is a need for customisation in support of our business goals.

The solution requirements of the Humber Industrial Cluster do pose some unique aspects not typically catered for in an off-the-shelf investment planning solution, for example the need to facilitate stakeholder engagement.

- Time to value: The timeframe within which results, or benefits must be realised.

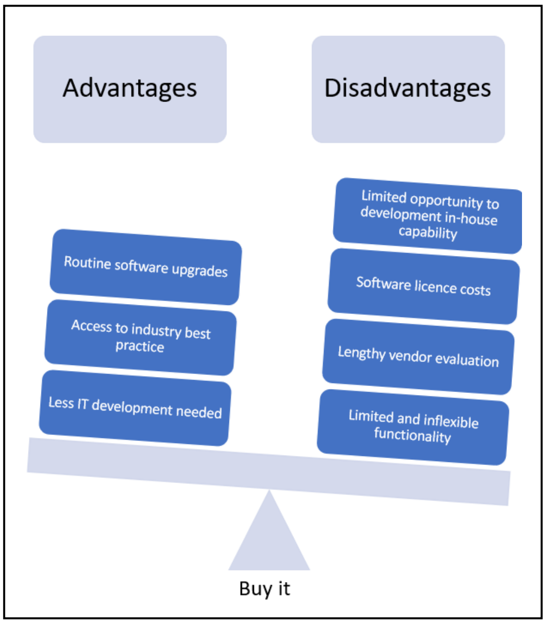
There is a desire to develop a roadmap solution as rapidly as possible in phase 2. This could be achieved through a buy or customise scenario, however developing a bespoke model (build it) is likely to require significantly more time.

- Financial considerations: It is important to consider the whole cost of ownership including software licence costs, implementation costs (including development, integration and training costs), maintenance costs, ongoing development costs and staffing costs.

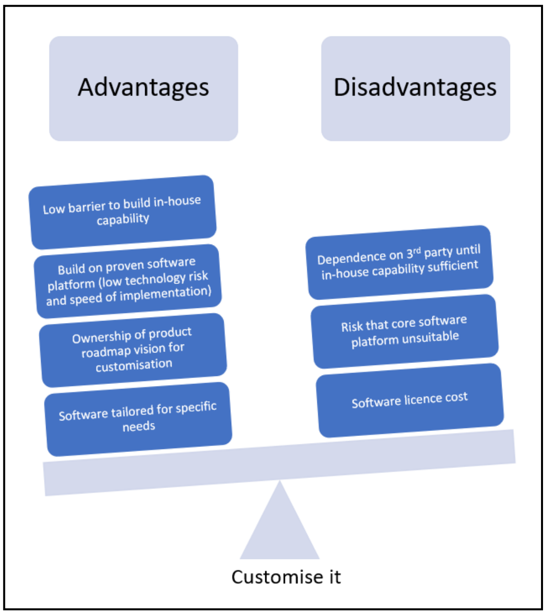
Typically, a build it option has the highest upfront costs and ongoing staffing costs, while 'buy it' and 'customise it' have lower upfront costs but incur an ongoing software licence cost.

Summary

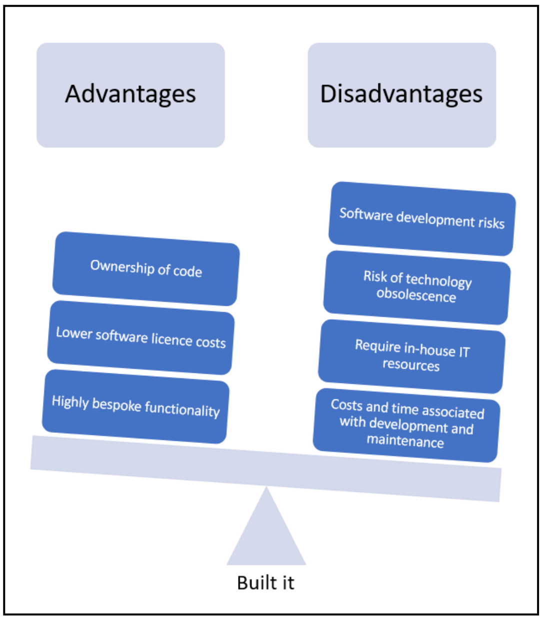
Buy it: Likely to have the lowest cost of ownership, however it is unlikely that an off-the-shelf solution will meet all the requirements of Humber Decarbonisations Roadmap Model. In addition, given the need for flexibility to respond to changing requirements of stakeholders, political and regulatory requirements choosing an off-the-shelf solution would come with a risk that may not have the functionality to respond to emerging requirements.



Customise it: A middle ground between buy and build it, a highly configurable off-the-shelf solution would offer the best of both worlds in terms of bespoke functionality, flexibility and low cost of ownership. The risk would be that the solution cannot be sufficiently customised, therefore it would be important to gain assurance (for example, through case studies) that a prospective software can be readily customised. A solution that can be configured and customised 'code free' would offer the lowest barriers to building an in-house capability and independence in using the chosen software.



Build it: The highest potential risk and reward option. While this route offers the most bespoke and tailored functionality it comes with considerable risk and requirements for upfront investment. Software model development is a complex undertaking and cost and time over-runs are common. Software development requires dedicated and specialised resource that are typically not available in-house. In addition, this approach requires a long-term internal resource commitment as software must be maintained to ensure data and information security. Typically, this additional risk and cost is only justifiable if the functionality is simple not available elsewhere.



8 Data Requirements

8.1 Data Framework

The data framework defines the data and datasets required for Phase 2. It is important to understand that the data framework is just that, a framework for capturing data during stakeholder engagement, research or elicitation in Phase 2. This will provide the inputs to the model and model scenarios.

The Structure of the Data Framework is shown in Figure 12. Whilst this framework may look linear and two-dimensional in nature, it is capturing data for a multi-dimensional system with complex interdependencies and uncertainties. The data framework should remain flexible and dynamic to enable the capture of evolving or emerging datasets as work progresses into Phase 2.

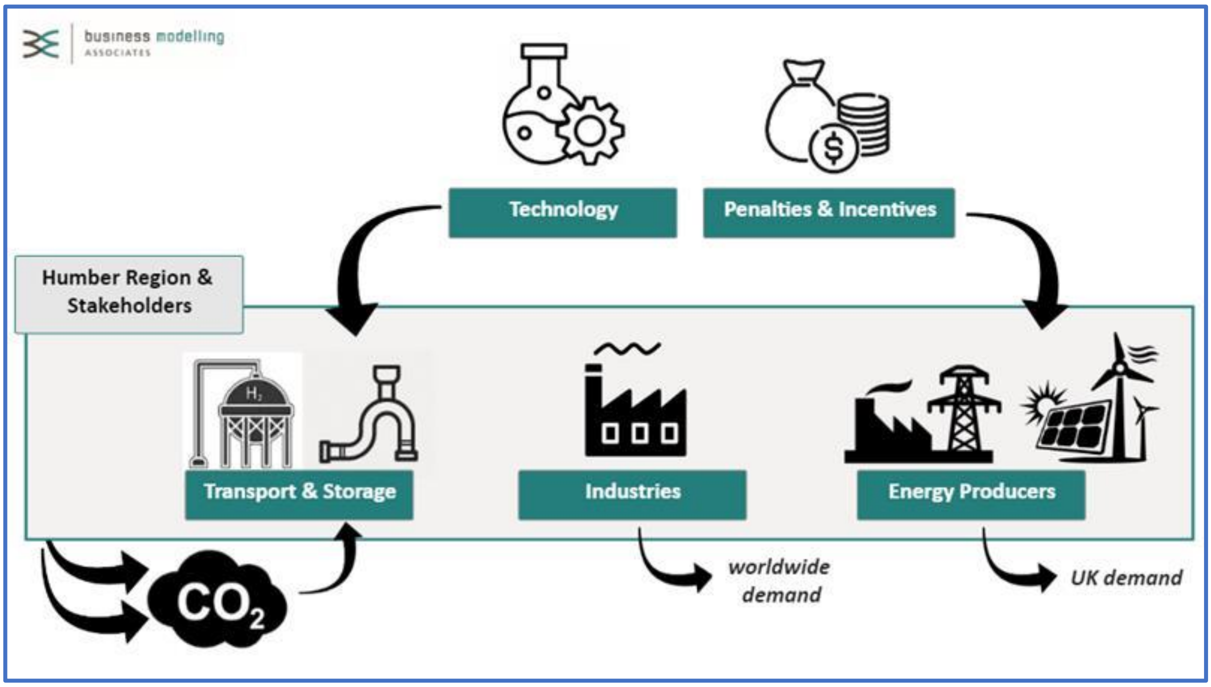


Figure 12: Data Framework Structure

The landscape of the emitters and emissions being assessed is a key input. This will require a definitive list of all emitters under consideration along with agreed baseline emissions (Phase 1, Data Project).

A list of energy producers and decarbonisation technology options with appraisal view of maturity levels, deployment timelines and forecast CAPEX and OPEX costs will be needed.

Details of any ISCF projects, AD projects or CCS projects, e.g. British Steel, which are in progress in terms of the deployment of infrastructure or technology, or under consideration for Phase 2.

Data relating to economic impact, e.g. the effect on regional jobs and GVA, of decarbonisation technology options / pathways, at least at a sectoral level. Again, this is likely to require stakeholder engagement and research during Phase 2. This will also require a consistent definition of GVA across all Industrial Clusters to be agreed.

As the model is assumed to be a mass balance, the data inputs will be the end of value-chain industrial product demands forecast over time, plus unit rate relations along the value chain. For example:

- the energy demand per unit of product.
- MtCO2e per TWh energy demand.

- £/TWh.

Any constraints concerning any of the aforementioned areas, which should be considered will also be inputs. As will any penalties, incentives and the details of funding mechanisms.

A full copy of the Data Framework is provided in a separate Excel spreadsheet and associated PowerBI dashboard for stakeholder engagement.

8.2 Data Gap Analysis

A data gap analysis has been completed by comparing the data collected by the HIDR Data project against the Data Framework.

Table 12 summarises each area of the data framework at a *data line* level. It is important to make the distinction between *data lines* and *data points*. For example, the *Industries* area of the Data Framework has 42 data lines (as shown in Table 12), but each data lines will require the capture of multiple data points e.g. a data series of forecast emissions over time. Furthermore, each of the *data line* will be applicable to multiple industries. If we assume 50 industries, we would have 2,100 data points (50 x 42) if we apply the industry area of the Data Framework to 50 industries.

Data Framework Area	Data Framework Data Lines	Collated by Data Project	Covered by Data Project with queries	Data Gaps (Phase 2 collection)
Energy Producers	32	**16%**	**3%**	**81%**
Industries	42	**14%**	**0%**	**86%**
Technology	23	**0%**	**0%**	**100%**
Transport and Storage	37	**0%**	**0%**	**100%**
Penalties and Incentives	13	**0%**	**0%**	**100%**

Table 12: Data Gap Analysis at 'data line' level

Table 12 provides a high-level view of how many data lines are within each section of the Data Framework and the percentage of these where:

- Data has been collated as part of the HIDR Data project (highlighted in green).
- Data has been collated as part of the HIDR Data project, but with outstanding queries, for example around data source or level of granularity in the Data project, against that which would be required (highlighted in orange).
- Data has not been collated in Phase 1 and will need to be collated in Phase 2 (highlighted in red).

8.3 Data Governance & Assurance

For a project of this complexity and diversity of data sources, and if the final models are to be credible and generate trusted outputs and recommendations, it is essential that appropriate data governance roles and processes are established and adhered to throughout the model development process.

The best way to ensure appropriate data governance is to incorporate the data deliverables within the project methodology and to allocate clear roles and accountabilities for data management throughout the project lifecycle. It is unlikely that these project roles will be full-time, but they are essential if ‘data relationships’ are to be established with data providers within stakeholder organisations. The cooperation of Data Stewards, Data Owners, IT functions and any other data providers will be critical to the success of the project as a whole, not just the data stream.

Whilst establishing and communicating clear expectations, protocols and standards from the outset is essential, given the disparate nature of the stakeholder organisations, a degree of flexibility is inevitable when coordinating the collection and collation of data.

The project manager should consider the development of a data dashboard to track the collection of data from candidate organisations and they should report against data characteristics, specifically accuracy, completeness, consistency, timeliness, validity, and uniqueness. Given the importance of data to the project, this dashboard should be reviewed on a regular basis by the Project Steering Committee. The project manager may also wish to develop a range of data tools and artefacts to orchestrate a wide range of data management process, such as:

- data collection and storage;
- data transformation, normalisation, enrichment, consolidation, error detection and correction; and
- data classification, taxonomy services and rule administration.

Whilst personal data is unlikely to be required by the project, the project manager should be mindful of and ensure compliance with the General Data Protection Regulations (GDPR) 2018, as well as ensuring appropriate data security protocols and arrangements for any commercially sensitive data.

Whilst the project manager should always seek their own assurance, we strongly recommend that the selected Delivery Partner is certificated to a recognised international standard for IT security such as ISO27001.

ISO27001 provides a specification for an information security management system (ISMS). An ISMS is a framework of policies and procedures that includes all legal, physical and technical controls involved in an organisations information risk management processes.

9 Project Delivery Risks

As part of the standard project governance arrangements, a project risk and issues register should be established, maintained and regularly reviewed by the project team. As an introduction to this process, the following draft project risk register has been developed to provide insight into the types of risks that can lead to delays, impact the quality of the output or cause an increase in cost. This risk register is illustrative and would be finalised as part of project initiation in phase 2.

Risk Category	Risk Description	Pre-Mitigation			Risk Mitigation
		Risk Probability	Risk Impact	Risk Score	
Data	• Poor quality data undermines model integrity • Delays in collecting data • Data loss or data breach	VH	VH	15	• Robust data management • Clearly defined roles and accountabilities within project team • Clear expectations, standards set with data providers • ISO27001 accreditation
Procurement	• Compliance with procurement legislation creates additional cost and delays project start	M	H	12	• Robust procurement process • Experienced procurement specialists
Supplier Capability	• Supplier unable to deliver to Client specifications	L	VH	10	• Robust procurement and supplier selection process • Relevant case studies & references, including reference site visits, where applicable • Named or ring-fenced resources committed to project from outset
Project Governance	• Ineffective project governance leads to delays, additional cost or poor-quality outcomes	L	VH	10	• Dedicated project management team • External assurance
Project Scope	• Scope of project drifts or grows during delivery	M	M	9	• High quality design specification • Robust change authorisation process
Solution Design	• Solution design selected is unable to deliver complex system optimisation • Solution design does not meet Client requirements • Technology selected is unfit for purpose	M	M	9	• Robust procurement process • High quality design specification • Independent assurance (e.g. Gartner)
Critical Skills	• Critical skills or personnel are lost through the project lifecycle	L	M	6	• Pre-identification of critical personnel / skills • Knowledge share / transfer • Retention bonus

Table 13: Example Project Risk Register

10 Recommendations

This section sets out recommendations for the Phase 2 modelling approach, as well as some general recommendations.

10.1 Analytical Modelling Approach

The Humber Decarbonisation Roadmap requires analysis of a complex industrial system including significant interdependencies and uncertainties. Therefore, it is recommended that a quantitative, prescriptive analytics approach is taken. This should include constraint-based optimisation, scenario, sensitivity analysis and systems modelling.

It is recommended that a mass balance model is used. Within a mass balance model, the flow of material, and associated resource, energy demand, economic impact and emissions produced is driven by forecast demand for products or services, which create a pull-effect through the value-chain.

It is recommended that the modelling approach be tiered:

Core model: This should model the decarbonisation roadmap within the Humber LEP region (North Lincolnshire, North East Lincolnshire, East Riding and Hull) and cover the six BEIS industries sectors (steel / iron, refining, chemicals, cement, glass, and paper).

It is also recommended that the core model include Drax, which lies close to the boundary of the Humber LEP due to the contribution it can provide towards Net Zero and the economics of CCS infrastructure through future plans for BECCS and hydrogen.

It is recommended that emissions from power stations be included where they are related to energy demand for industrial processes. This should apply whether the power stations are directly linked to industry (e.g. VPI Immingham) or not and they input power into the electricity grid (e.g. Drax).

It is recommended that academic peer review by IDRIC or other academic partner(s) is considered.

Adopting this recommended core modelling approach will:

- Inform the optimal direction of the decarbonisation pathway.
    - Including system interdependencies and uncertainties.
    - Enabling engagement with decision maker and policy makers to drive technology pathways.
    - Enabling engagement with technology developers, industry groups and academic / research institutions.
- Enable the management of future risks and uncertainties.
    - Decrease uncertainties through scenario and sensitivity analysis. This will increase conscious awareness of where uncertainty lies and the sensitivities relating to it.
    - Provide the ability to dynamically engage with the roadmap model. That is, the ability to actively re-engage with the model and re-run scenarios as and when new data or information comes to light.
- Enable the modelling of different objective functions and scenarios, for example:
    - Time frame: the impact of time delay or bringing forward of the target date.
    - Cost: minimisation of cost.
    - Carbon level: Net Zero at 2040; Net Zero at 2045; Net Zero at 2050.
    - Maximise economic impact: regional employment levels (jobs) or GVA

Model Extension: Whilst the core model considers the modelling of the core complex system, in reality the Humber region is connected to other regions, clusters and national networks. Significant additional value could be obtained through extending the model in several ways.

1. **Application to other industry sectors**

Analysis of other industry sectors should be carried out to determine baseline emission scenarios for the sector and include identification of significant point-source emitters. Analysis should also determine whether the emissions sources within each of these sectors are close to each other, other sources of emissions and potential means of decarbonisation; or whether they are disparate. This will enable prioritisation (phasing) of the decarbonisation of additional industry sectors, or individual point source emitters.

2. **Power generators outside the Humber**

Inclusion of power generators outside of the Humber LEP region, e.g. to the south. If the core model were to indicate that CCS is required to achieve net zero. The model extension could be used to determine whether additional value could be gained by using the CCS infrastructure to additionally capture emissions from power stations outside the Humber region, thereby making the infrastructure more economic.

3. **Other projects and stakeholders**

Consideration of other projects and other stakeholders which may have significant impact on the HIC decarbonisation roadmap, including timeline, phasing and value. For example:

- Arup's' report: *Establishing a Regional Hydrogen Economy* considers the potential opportunities within the hydrogen industry in South Yorkshire. Its vision shows forecasts of significant hydrogen import into South Yorkshire from the Humber region. This may have synergy benefits to each region and bring added value to the Humber by supporting a hydrogen economy. [33]
- Integration with regional and national gas hydrogen transition pathways, to support the decarbonisation of heat.
- Integration with Teesside in terms of CCS pipeline and storage – creating links with neighbouring industrial cluster, including shared use of Endurance carbon storage facility in the North Sea.

Bringing in additional stakeholder interdependencies such as these to scenario modelling and sensitivity analysis will likely change value (cost benefit), timeline and phasing of technology and infrastructure as well as no regrets and least regrets decisions.

10.2 General recommendations

It is recommended that the following are carried out when Phase 1 projects are coalesced, and at the very latest at the start of Phase 2:

- Determine which emitters are in scope for evaluation within the Phase 2 project.
- Determine baseline emissions – agree on source data, e.g. EU-ETS, Local Authority data.
- Define carbon emissions evaluation and Net Zero in more detail, specifically.
    - what emissions are in scope, e.g. scope 1, scope 2, scope 3.
    - define an evaluation methodology which is consistent across UK clusters and accepted by BEIS.
- A consistent definition of GVA should be agreed across all Industrial Clusters.

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12 Appendix A – Project Scope and Context

12.1 Project Scope

Phase 1 was split into two sub-projects, one led by CATCH (supported by Business Modelling Associates (BMA) on work package 4) which concentrated on the HIDR Strategy Definition and Methodology (HIDR Roadmap Project), and a second led by the Humber Local Enterprise Partnership (LEP) in conjunction with Element Energy which concentrated on data gathering and baseline scenarios (HIDR Data Project).

Phase 1 was split into five work packages. The scope of each of these work packages are summarised in *Table 14*.

Work Package	Lead Party	Scope Description
WP1: Baseline data acquisition	LEP	Emissions data, infrastructure mapping requirements, supply chain linkages and interdependencies, project pipeline (commercially confidential), 2050 sector roadmap implications and relevant data from the Deployment project (sub-cluster and Humber cluster level). Aligned with Deployment project data requests to avoid duplication.
WP2: Technology overview	CATCH	High level overview of technical options, costs and potential phasing – based on literature review, technical knowledge and industry engagement.
WP3: Scenario development	LEP & CATCH	*Taking the outputs of WP1 and WP2* – confirmation of current CO_2 baseline, development of baselines for 2025/2030/2040 based on project pipeline (including CO_2 impact and high level costs, development of technology rollout scenarios, combining of scenarios to develop high-level Roadmap Scenarios for Phase 2, and prioritisation based on impact, cost and deliverability.
WP4: Systems modelling	CATCH	Development of scope, outline approach and costs for Humber systems model in Phase 2. *Verified against WP3 output.*
WP5: Roadmap development strategy	LEP & CATCH	*Integrates outputs of WP1-4 to develop a strategy for producing the roadmap.* Identification of technical-economic and socio-economic work required for Phase 2, agreement of industrial partners, match funding and work packages, development of MOUs and Phase 2 bid.

Table 14: HIDR Phase 1 work packages, scope [8]

At the end of Phase 1 a report will be produced illustrating the range of scenarios, associated timelines and carbon savings linked to data provided. Data assumptions which have been made where data is not available will also be detailed.

Phase 2 is expected to include detailed analysis of the prioritised scenarios, including project-level feasibility and commissioning. This will be achieved by applying the systems model approach selected from Phase 1 to understand system interdependencies, uncertainties and their associated impacts. This will ensure the evidence that supports the roadmap is data-driven, robust and objective, enabling conscious decision making. The final approach for Phase 2 will be confirmed at the end of Phase 1.

12.2 Deployment Projects

There are two Humber Industrial Cluster Deployment Phase 1 projects running concurrently with HIDR Phase 1. These are:

- The **Humber Industrial Decarbonisation (HID) deployment Project:** this project will identify and develop potential anchor projects with the aim of maximising emissions reduction in the most appropriate way, whilst establishing a world leading industrial CO_2 transport and storage system. [34]
- The **Green Hydrogen for Humberside Deployment Project Study**: this project will assess the feasibility and scope of deploying green hydrogen with major industrial partners in Humberside. This will lead to the production of renewable hydrogen, at the Gigawatt scale, from polymer electrolyte membrane (PEM) electrolysis. [34] [35]

12.3 HIDR Data Project

The key objectives of the HIDR Data Project are:

- Define the landscape of emitters (point source or industrial sector), their baseline scenario emissions.
- Mapping and analysis of:
  - Data sources, existing relevant infrastructure and unutilised allocated employment land surrounding the cluster.
- Identification of key relationships between local emitters and linked emissions (e.g. product supply chain, power stations directly supplying industry).
- Collation and mapping of a near term project pipeline, comprising potential future projects by industrial emitters and infrastructure owners that would have a material impact on the Humber's CO_2 emissions along with the likelihood of occurrence.
- Linkages between projects and potential barriers (e.g. infrastructure constraints, policy certainty).
- Generate a range of reasonable assumptions for CO_2 emissions arising from future development of unutilised allocated employment land surrounding the Humber industrial cluster.
- Review implications of relevant 2050 sector roadmaps agreed with BEIS, Capture for Growth report, HyImpact series and any other relevant strategies for the Humber.
- Collate, organise and review relevant data arising from the Humber Industrial Decarbonisation Deployment project, including from the three sub-clusters
- Identify any gaps in data/understanding that would need to be addressed in Phase 2.

12.4 HIDR Roadmap Strategy and Definition Project

The work package 4 (WP4) part of the HIDR Roadmap Strategy and Definition project led by CATCH in conjunction with Business Modelling Associates (BMA) is focussed on Systems Modelling. More specifically, the development of scope, outline approach and costs for the Humber systems modelling in Phase 2.

CATCH is an industry led partnership supporting the process, energy, engineering and renewable industries in Yorkshire and the Humber.

BMA are a Yorkshire based company specialising in analytics and systems modelling methodologies, consultancy and supporting software. BMA's systems models are used by UK and international clients to support long term challenges such as energy decarbonisation and water resilience through their investment and strategic planning processes.

12.5 HIDR Roadmap Project WP 4 Report Objectives

The key question to be answered in Phase 2 is:

> What is the most effective way of delivering a net-zero industrial cluster in Humberside by 2040, taking into account the available resources, existing and future assets including those planned around the "ISCF Deployment" project[s], the geography of Humberside, industrial emissions, time, technology options and logistics networks? [1]

To enable this question to be answered in Phase 2, this report has the following objectives:

- Provide an understanding of the pros and cons of using a model led approach vs alternative approaches to achieving the Phase 2 project objectives. i.e. to objectively reflect on whether a model led approach is the best way forward (including legacy options), taking into consideration the level of funding that will be available.
- Definition on the organisation of data inputs to the level of detail needed to enable a potential accelerated start i.e. what data will be needed and in what form(s). This is likely to include definition of "industry sector" and how power plants located in Humberside are/are not included, sub sectors (e.g. pharmaceuticals, personal care, food, refining) and perhaps even sub sectors to sub sectors (e.g. fish processing, meat processing etc within food).
- Definition on how the Roadmap methodology/model would be constructed. To include (as appropriate):
    - Modules structures and optimisation/sensitivity capabilities.
    - Modelling environment and whether there are benefits to using open-source or other licensed languages.
    - Options for who might deliver a model in the Phase 2 Project.
    - Cost estimations and implications (what can be achieved in a Phase 2 project for what costs).
    - Assessment of risks and mitigations.
- Identifying how the outputs from the Phase 2 activities (e.g. modelling) will achieve the desired Phase 2 Project outputs including key sensitivities.
- Defining key technical requirements for model (e.g. modelling environment, data input structure to the level of detail needed to enable a potential accelerated start, technical on how it will be written and what is needed).

The scope of this report (WP4) can be seen in the context of the Data Project and Phase 2 in *Figure 13*.

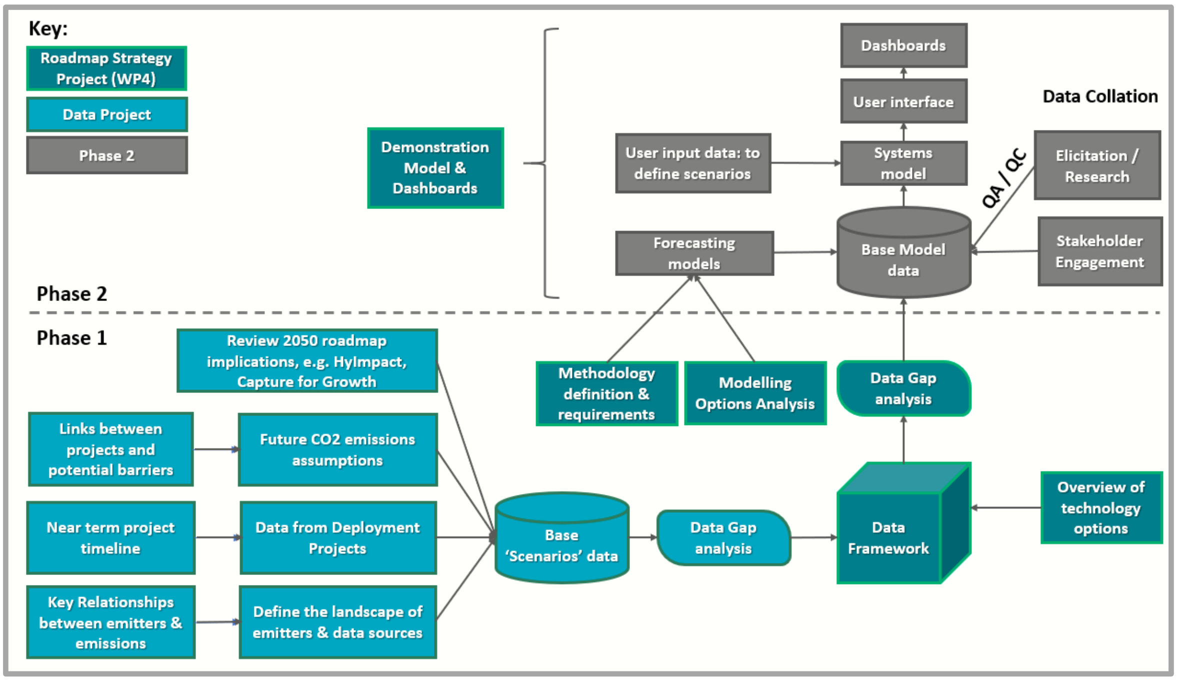

Figure 13: Scope of this Roadmap project, the Data project and Phase 2 as per RfQs

13 Appendix B – Humber Industrial Cluster

13.1 Types of Energy-Intensive Industry

This section explores each type of industry within the HIC. This includes a brief description of the key processes involved, how these impact energy consumption and emissions production and the opportunities available in each industry sector to approach Net Zero. The most recently available emissions data, the latest reportable emissions for regulated EU-ETS stationary installations as provided by DEFRA and published by the Environment Agency is also provided. [36]

13.1.1 Chemicals

The HIC is one of the top four chemical-producing regions in the UK. Contributing to this are Saltend Chemicals Park and South Humber Bank. [37]

Saltend Chemicals Park is a cluster of world-class chemicals and renewable energy businesses located near the port of Hull. It includes the following companies:

- **Px:** own, operate, and manage Saltend Chemical Park. [38]
- **Triton Power:** are the independent power generating company which provide electricity to the UK wholesale electricity market at Triton Power gas fired power station which has an output capacity of **1,200 MW** providing power to the UK electricity market, and power and steam to the adjacent Saltend Chemicals Park. It also supports National Grid's Electricity System Operator - in terms of supply /demand management on the grid. [39]
- **BP European Acetyls:** own and operate two acetyls plants, which are the largest producers of acetic acid in Europe. Acetic acid plays an important part in the manufacture of films, fibres, fabric, washing powder and food packaging. [37]
- **BP Petrochemicals Technology:** have a centre which is leading research and technology into petrochemicals on the site. [37]
- **Air Products:** provide atmospheric gases, process and speciality gases to industry, energy and healthcare markets. [37]
- **Ineos:** operate a world-scale chemical plant at the Saltend Chemical Park, producing ethyl acetate. This is a chemical used in the manufacture of a range of household products including perfumes, printing inks, paints, varnishes, and flavour enhancers. [37]
- **Nippon Gohsei:** operate a world-leading Ethylene-Vinyl Alcohol Copolymer (EVOH) plant. This is a packaging material used to preserve the freshness and flavour of food. [37]
- **Yara:** is the number one global supplier of mineral fertilizers. Yara help provide food and biomass which can be used for renewable energy. Yara help provide food and biomass which can be used for renewable energy for a growing world population. [37]
- **Tricoya Ventures UK:** produces panels and cladding materials. This plant is not yet operational. [37]

The reportable EU-ETS emissions in 2018 for companies at Saltend Chemicals Park were around 0.4 $MtCO_2e$/yr excluding Triton Power station and 3.1 $MtCO_2e$/yr including it. [36]

South Humber Bank cluster of chemical companies includes:

- **Tronox:** operate a plant in Stallingborough which has an annual production capacity of producing 165,000 tonnes of titanium dioxide, which is used as a whitening agent. Reportable EU-ETS emissions in 2018 were 0.2 $MtCO_2e$/yr. [36]
- **BOC Immingham:** handle a wide range of gaseous and liquefied speciality gases, supplying products to both domestic and foreign markets for use as raw materials, treatment chemicals, sterilisers of

medical equipment, propellants and calibration standards in a wide range of Industries. Customers include pharmaceutical, cosmetics, microelectronics, petrochemical, refrigeration and water supply companies.

- **Solenis:** manufacture chemicals to improve the quality of water. Solenis supply Products which help a wide range of industries reduce the environmental impact of their activities by allowing them to recover and re-use process water.

Other chemical companies outside of the above Chemical clusters (Saltend Chemical Park and South Humber Bank) are:

- **Croda:** situated in Goole, supplies high performance, special additives for applications across high technology industries. Reportable EU-ETS emissions in 2018 were 0.02 MtCO2e/yr. [36]
- **Novartis:** situated in Grimsby, plant closure is at risk of closure by the end of 2020 if a third party does not step in before closure. [40]

Decarbonisation of the Chemicals industry includes the potential for fuel-switching.

13.1.2 Glass

Guardian Industries, part of Saint-Gobain Glass Limited, operate a float glass plant. Reportable EU-ETS emissions in 2018 were 0.1 $MtCO_2e$/yr. Glass is made by putting silica sand, soda ash, limestone and other raw materials into a furnace and heating to c. 1,600 °C. The molten glass then floats on a tin bath at c.1,100 °C forming a flat ribbon. Gear controlled rolling mechanisms are used to produce the required thickness and controlled cooling removes internal stresses and toughens the glass. [41]

There are opportunities to reduce emissions going forwards by using alternative heating methods such as electric furnaces or biogas as a source of heating within the processes described above. Increasing strategies for the recycling of glass could also reduce emissions compared with the current majority use of virgin materials. [13], [42]

13.1.3 Oil refining

Phillips 66 and Total Linsey operate two of the UK's six oil refineries, processing around a third of the UK's fuel. Located in Immingham, they are both supplied with electricity and steam by VPI Immingham, a 1,240 MW combined cycle gas turbine (CCGT) power station. Reportable EU-ETS emissions for VPI Immingham in 2018 were 3.4 $MtCO_2e$/yr. [13], [36], [14]

The Phillips 66 refinery has a processing capacity of 221,000 barrels of crude oil per day. Crude oil processed at the refinery is supplied primarily from the North Sea and includes lower-cost, acidic crudes. It is the only coking refinery in the UK , the world's largest producer of specialty graphite cokes and the largest anode coke producer in Europe. Phillips 66 have also developed projects to enable the processing of waste oils, converting these to high demand products. They continue to invest in this capability. Reportable EU-ETS emissions in 2018 were 2.1 $MtCO_2e$/yr. [43], [36]

Total's Lindsey Oil Refinery is one of Europe's most advanced refineries, processing over 20 different types of crude oil with an annual production of over seven million tonnes. The refinery's products include petrol, diesel, bitumen, fuel oil and aviation fuels which are transported across the UK and abroad by sea, road, rail and pipeline. Reportable EU-ETS emissions in 2018 were 1.5 $MtCO_2e$/yr. [44], [36]

The refining process breaks down crude oil into various petroleum products. Each raw crude oil input can vary in composition and so the economics of production and the balance of output constituents can vary. However, the three basic steps in the conversion process are the same:

- **Separation:** the crude oil is passed through hot furnaces. Hot liquids and gases move into a distillation unit where they separated out into layers (factions) according to their boiling points and are syphoned off and therefore separated out.

- **Conversion:** Heavier components can be converted into lighter and more readily useable products such as petrol by using techniques such as 'cracking'. This involves using heat, pressure and catalysts to split long chain molecules into shorter chain molecules. Hydrogen is a key input to processes such as cracking (hydro-cracking). Other processes can be used to change the structure of molecules, such as alkylation and reformation.
- **Treatment:** Steam treatment is applied to refine the quality and specification of some products before shipping to specific high-quality markets. This includes products like petrol. [45]

Heat, steam and energy are key input requirements for energy-intensive oil refineries. Opportunities to reduce emissions going forwards include using low-carbon energy supply and low-carbon or green hydrogen for processes such as hydro-cracking. There are also options to explore the future of refining and potentially moving towards a bio-refinery - a combination of crude, synthetic and bio-fuels, Figure 14**Error! Reference source not found.**. [46]

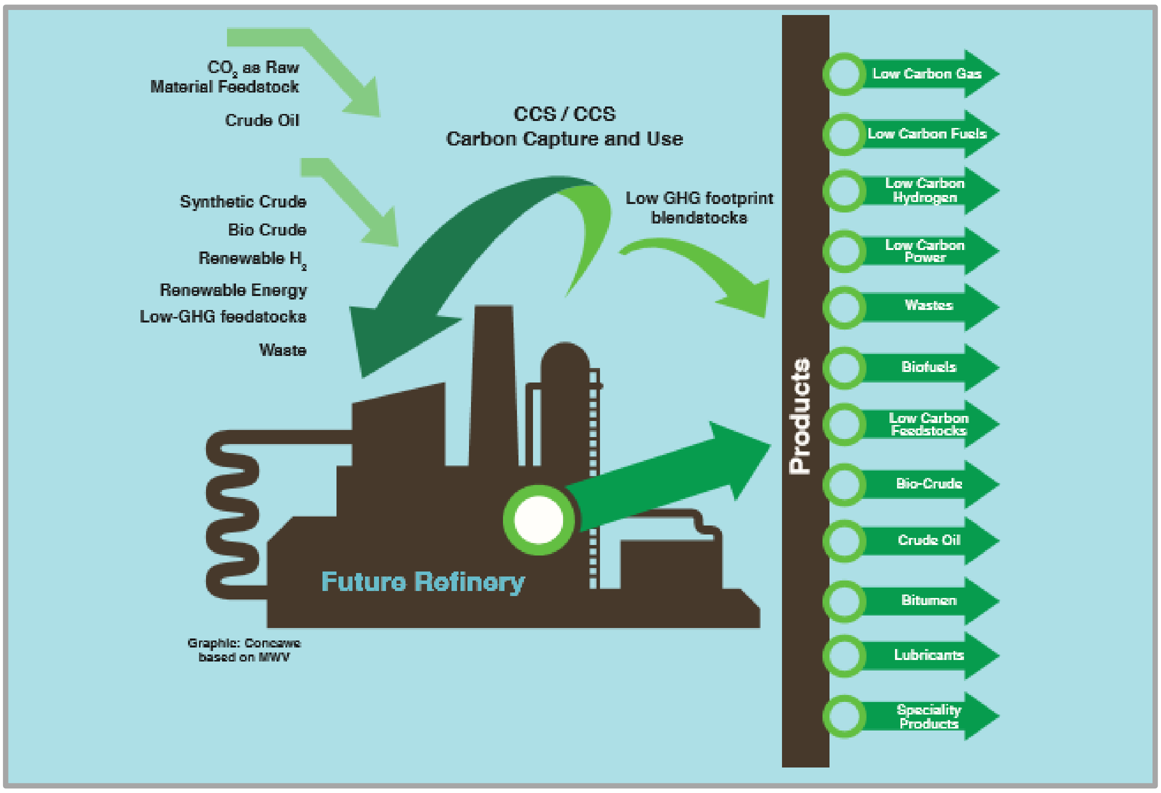

Figure 14: Future Refinery [32]

Biorefineries allow multiple products such as plastics, chemicals and fuels to be produced from biomass feedstocks, in a similar way to oil refineries. The global market for biorefineries is around £350bn, set to rise to almost £550bn by 2021. Greenergy currently operate a manufacturing plant in Immingham converting waste vegetable oils into biodiesel. Reportable EU-ETS emissions in 2018 were 0.03 MtCO2e/yr. In future, more advanced processing techniques and processes will become available that will widen the potential for biorefining, producing a wider range of materials, chemicals and fuels from non-food feedstocks and wastes. [15], [36]

13.1.4 Iron and Steel

British Steel's Scunthorpe site is one of two integrated steelworks in the UK. It employs 5,000 people from the Humber region and largely produces steel using the blast furnace - basic oxygen furnace (BF-BOF) process. This produces virgin steel from raw materials. Compared to an Electric Arc Furnace (EAF) which recycles waste steel, the BOF furnace produces more emissions.

However, with insufficient scrap steel to meet market demand, BOF furnaces are still required.

Coal is turned into high quality coke by heating at 1,000°C for 18 hours. This is combined with other raw materials: iron ore, limestone and sinter and put into blast furnaces. Temperatures increase from 1,000°C to 2000°C creating iron and slag as a bi-product. The iron is then made into steel in a process which involves blowing high-purity oxygen onto the surface of the molten iron at extremely high speed and pressure. Lime and an alloying element are added to the steel to give it its required specification.

Making steel requires several stages of significant heating: producing coke, making iron and making steel. British Steel is the Humber's largest industrial emitter with reportable EU-ETS emissions in 2018 of 5.1 $MtCO_2e$/yr. Future carbon reduction opportunities exist in optimising processes, increasing the proportion production by EAF methods and using CC(U)S - via amine capture, calcium looping or mineralisation. Hydrogen can also be used as a reducer in iron ore reduction leading to a reduction in carbon emissions. Plasma reduction would increase the utilisation of hydrogen; and reduce carbon emissions further. [47], [36]

13.1.5 Food and drink

The Humber has one of the largest concentrations of food manufacturing and cold storage in the UK. The region has more than 2,500 businesses in the food and drink sector, employing 35,000 people and contributing more than £2 billion GVA to the UK.

Humber companies in this sector include AAK UK, Aunt Bessie's, Country Style, Cranswick plc, Golden Wonder, Greencore, Hain Daniel Group, Icelandic Seachill, Lincoln & York, Pipers Crisps, William Jackson Food Group, Young's Seafood, Reckitt Benckiser FMCG and Grimsby Seafood Village. [13], [14]

The largest energy consumption in this sector is associated with baking, brewing and sugar manufacture. Future decarbonisation can be approached through process and cooling efficiencies coupled with low-carbon or negative emission energy supply. [48]

The Food industry is not currently within scope of industrial decarbonisation. However, it is recommended that data reconciliation across all Phase 1 projects is considered to define:

- the total baseline emissions of the food and cold storage sector as a whole;
- any large-emitters within the food and cold storage sector; and
- whether the food and cold storage sector should be included within the HIC Decarbonisation Roadmap Phase 2.

13.1.6 Cement & Lime

Singleton Birch operate Melton Ross lime works. They employ 120 people and supply lime products to industries including steel, chemicals, wastewater treatment, water treatment and construction. Reportable EU-ETS emissions in 2018 were 0.3 MtCO2e/yr. Cemex currently operates a plant in South Ferriby. However, there are plans to close this site. Reportable EU-ETS emissions in 2018 were 0.3 $MtCO_2e$/yr. [36], [49]

13.1.7 Port Complex

The HIC is a key port and logistics hub for the UK. It handles more than 77milion tonnes of cargo annually (worth approximately £75bn), supporting over 33,000 jobs in the region and contributing £2.5bn to the UK economy. It has four port towns:

- Grimsby, a hub for food processing and the operation and maintenance of offshore wind farms.
- Immingham, the UK's largest port by tonnage, including the transfer of biomass to Drax power.
- Goole, the UK's most inland port.
- Hull, home to Siemen Gamesa's site for offshore wind turbine blade manufacture. [14]

13.2 Power Generators

This section looks at the landscape of key power generators in the Humber: renewable, non-renewable and hybrid, e.g. Drax which *currently* burns a mixture of biomass and coal.

13.2.1 Power Stations

Five power stations operate within HIC with combined emissions more than 1MtCO_2e/yr, **Error! Reference source not found.**. They are Drax, Keadby, Immingham, Saltend and South Humber Bank, Figure 15. Total reportable EU-ETS emissions in 2018 were 12.6 MtCO_2e/yr. However, it should be noted that Drax lies outside the boundary of the Humber. Drax power stations reportable EU-ETS emissions in 2018 were 4.1 MtCO_2e/yr. [36]

Figure 15: Power Stations and Industrial Processes in the Humber [37]

VPI Immingham CHP power station provides a direct feed of electricity and steam to Phillips 66 and Total Lindsey oil refineries as well as feeding the national electricity grid. Similarly, Triton Power gas fired power station supplies electricity and steam to the adjacent Saltend Chemicals Park as well as electricity to the national electricity grid.

Briggs Biomass Power Plant is situated in North Lincolnshire, it has a generating capacity of 40 MW. [50]

It is known there are a number of CHPs which operate directly on industrial sites, some of which appear in the emissions data in Appendix C. It may be beneficial to collect additional data during Phase 2 and include them in the future pathway modelling. This may support Phase 2 Stakeholder Engagement.

Decarbonisation of carbon emitting power generation includes fuel-switching, CC(U)S, as well as combinations of these which may lead to overall negative emissions – for example bio-energy and CCS (BECCS).

13.2.2 Renewable Energy Generators

Based on the Data Project findings, there are 49 operational renewables generators in the *core Humber region* providing around 0.6 GW_e of capacity, around half of which relates to onshore wind and the rest is approximately distributed across other renewables generation: solar photovoltaics, biomass, energy from waste, landfill gas and advanced conversion technologies. If projects where planning permission has been granted and where construction is underway are also taken into account then the generation capacity increases to 1.1 GW_e ; being generated by 68 renewable generation sites – 28 of which are onshore wind and 12 are solar. For further details and definitions of the core and broader Humber regions, refer to Table 19, Table 20Table 23 and Table 23 in Appendix D. [16]

If the *broader area* of the Humber, as defined by the Data Project, is considered there are 140 renewables sites in operation with a capacity of 1.6 GW_e with around 50% renewables generation capacity from onshore wind, 23% from offshore wind, 17% from solar photovoltaics and the rest split across other renewables generation. If projects where planning permission has been granted and where construction is underway are also taken into account the generation capacity increases to 6.2 GW_e ; being generated by 190 sites, with around 62% of renewable capacity now coming from *offshore* wind, 19% from onshore wind and the rest from other renewables. For further details and definitions of the core and broader Humber regions, refer to Table 21, Table 22 and Table 23 in Appendix D. [16]

13.3 Industry and Power

This section looks at the mix of industry and power stations in the Humber region. Section 13.3.1 paints the current picture of industry and power emitters. Section 13.3.3**Error! Reference source not found.** explores the integration of the two sectors and opportunities for decarbonisation.

13.3.1 Industry and Power landscape

Reportable EU-ETS emissions data for 2018 is included in Appendix C for HIC emitters. This has been split into three tables which detail:

- Large emitters (emissions of more than 1MtCO_2e/yr), comprising 5 power and 3 industrial installations.
- Medium emitters (50,000 to 1M tCO_2e/yr), comprising 7 industrial installations.
- Small emitters (less than 50,000 tCO_2e/yr), comprising 9 industrial and 2 power installations.

The sum of the emissions of the 8 Large emitters is 21.3 MtCO_2e. This is much greater than the 12.4 MtCO2e challenge, currently the snapshot baseline of the ISCF challenge (*Figure 2*).

13.3.2 Data Validation

For each of the four Humber local authorities and Drax Power Station, emissions data has also been checked against the yearly average from the last 5 years-worth of data from the *2005-2017 UK Local and Regional CO_2 Emissions Data*. The comparison of this data against the EU-ETS Regulated emissions is shown in Appendix C for each installation. The totals are broadly comparable when looking at all emitters 23.0 $MtCO_2e$/yr from the Local and Regional data against 22.7 $MtCO_2e$/yr from EU-ETS data; and also when just looking the large emitters (as defined in Appendix C), with 19.9 $MtCO_2e$/yr from the Local and Regional data and 21.3 $MtCO_2e$ in EU-ETS data. There are also more installations in the Local and Regional data. This points to the need to define a clear starting baseline both in terms of emitters and sectors being included in the landscape and the source point for baseline emissions data.

There may be differences for several reasons including:

- different emitters being included within the emissions total, e.g. the inclusion of Drax in the 21.3 $MtCO_2e$/yr figure;
- further reductions in emissions that have occurred in the intervening 2 years; and
- changes to the definition of applicable carbon emissions for evaluation of baseline emissions and Net Zero.

There are also more installations in the Local and Regional data. This points to the need to define a clear starting baseline both in terms of emitters and sectors being included in the landscape and the source point for baseline emissions data. It is recommended that this is done either at the end of Phase 1 when the Roadmap Strategy Report (this report) and the Data Project Report are brought together to enable the writing of the Phase 2 bid; or at the latest at the outset of Phase 2. [51]

It is recommended that the following are carried out when Phase 1 projects are coalesced, and at the very latest at the start of Phase 2:

- Determine which emitters are in scope for evaluation within the Phase 2 project;
- Determine baseline emissions – agree on source data;
- Define carbon emissions evaluation and Net Zero in more detail, specifically:
  - What emissions are in scope, e.g. scope 1, scope 2, scope 3; and
  - Define an evaluation methodology which is consistent across UK clusters and accepted by BEIS.

13.3.3 Industry and Power interdependency

There is an important integral link between the power and industrial plants within the HIC. There are 5 power stations in the Humber which are large emitters, emitting more than 1 $MtCO_2e$ each year. In total, all the power plants account for just over half of all emissions (*Figure 16*). The next largest contributor of annual emissions is steel manufacturing, accounting for nearly a quarter of emissions. This is in fact the largest point source of emissions, highlighting the need to have the perspective of point sources of emissions as well as sector/sub-sector and regional/sub-regional perspectives. This takes place at the British Steel steelworks site in Scunthorpe. The Phillips 66 and Total Lindsey oil refineries account for a further 16% of emissions; with the chemical industry, food and drink, glass and other industries accounting for the remainder. [36]

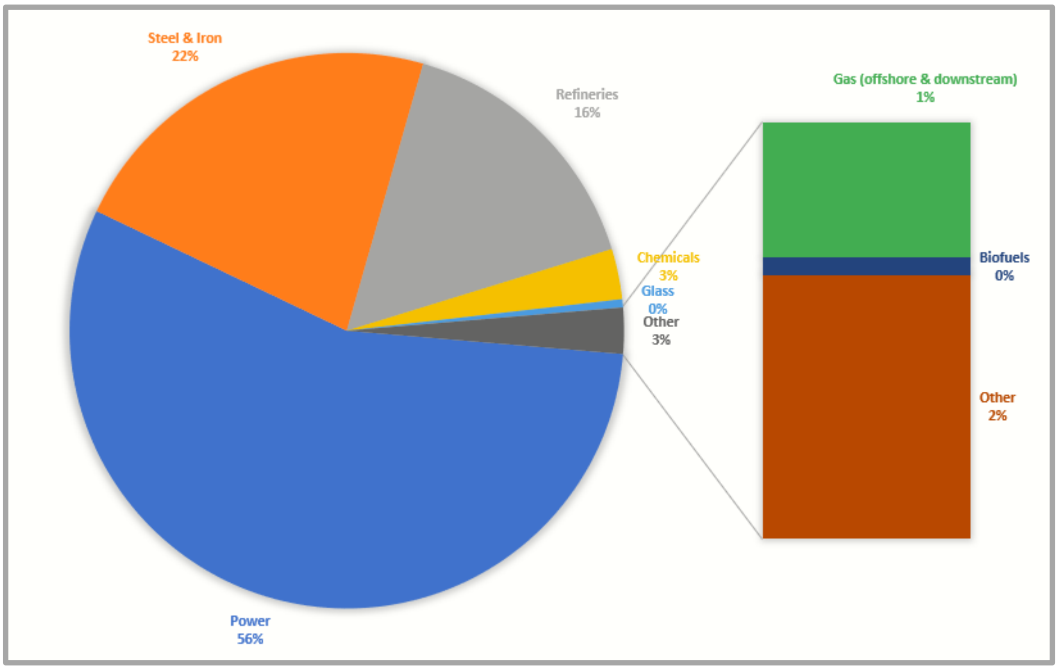

Figure 16: Percentage of emissions by Sector (Humber Cluster), based on 2018 emission data [21]

If the emissions from Humber industries are considered in isolation from those from power stations, it can be more clearly seen that the single steel manufacturing site accounts for around half of pure industrial emissions, oil refineries account for a further 36%; Chemical industries 7%; glass manufacture 1%, gas and biofuel production 2% each, with the remaining 6% due to other industries (*Figure 17*).

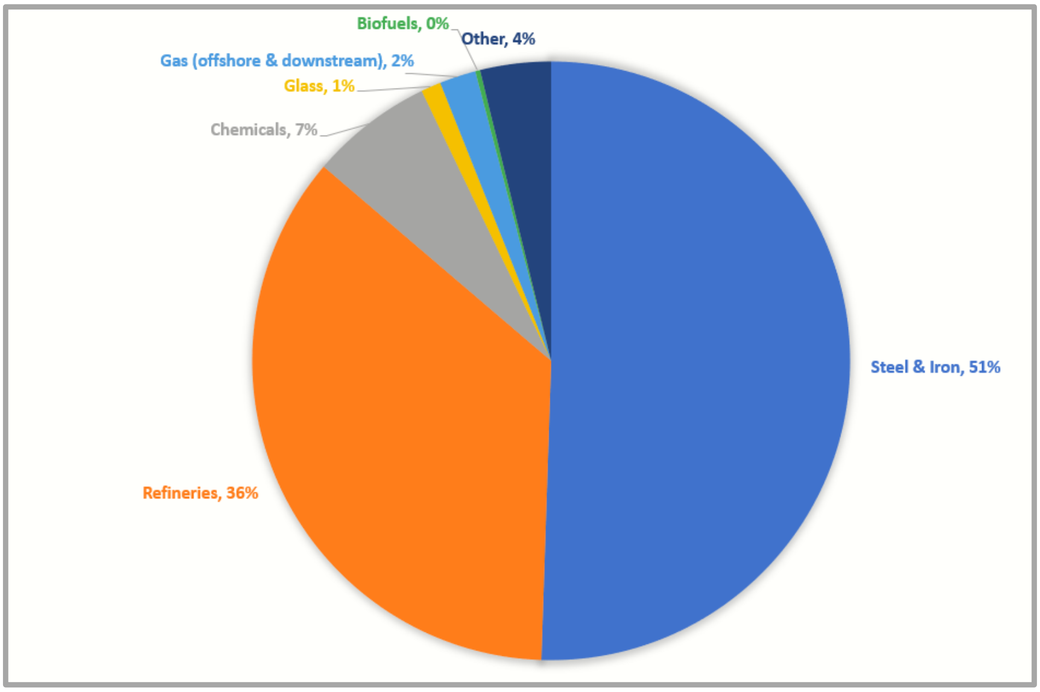

Figure 17: Percentage of emissions by Industrial Sector (Humber Cluster), based on 2018 emission data [21]

VPI Immingham CHP power station is one of the largest CHP plants in Europe. Most of the electricity it produces is exported at high voltage to the UK electricity grid and then on to households in the UK. The remainder is used by the local oil refineries. The steam it produces is also used by the refineries in their processes.

Triton power gas fired power station also provides electricity to the UK electricity grid, but also provides both electricity and steam to Saltend Chemicals Park and is therefore an integral part of their industrial processes.

Whilst emissions relating to direct electricity to the grid for the purposes of supply of energy to homes does not form part of the decarbonisation of industry, the emissions associated with the energy demand for industrial process should form part of the decarbonisation of industry. This should apply equally to energy that is supplied direct to industry from a power station, as is the case for VPI Immingham or Triton Power power stations, or where it is supplied indirectly through the electricity or gas networks. Where it is supplied indirectly, there are also opportunities to move to a mix of energy provision including renewables and low-carbon or negative emissions alternatives, for example through the use of a combination of CCGT, BECCS, hydrogen and CC(U)S.

In order to develop the optimal industrial decarbonisation transition pathway, it is important that the roadmap methodology represents the capacities, constraints, profiles and uncertainties of the energy demands, flows and sources for all key industries (current and future) within the Humber region. In doing this the methodology must take into account the target of decarbonising industrial emissions, interdependencies of the Humber industries (in terms of energy but also raw materials) and the balance of energy provision between Humber industries and the national energy network flows.

14 Appendix C – Humber Emitters

Installation Name	EU-ETS Sector	Sector	Reportable Emissions Annual tCO2e (2018)	UK LA Pollution Inventory (5yr average to 2017) tCO_2e/yr
British Steel: Steel & Iron Works	Steel & Iron	Industry	5,073,764	5,863,363
Drax Power Ltd: Drax Power Station	Large Electricity Producers	Power	4,138,591	4,138,591* assumed same as EU-ETS as UK LA data is only at start of biomass conversion
VPI: Immingham CHP Power Station	Large Electricity / Heat Producers	Power	3,371,537	2,855,916
Triton Power	Large Electricity / Heat Producers	Power	2,733,240	2,744,532
Phillips 66: Humber Refinery	Refineries	Industry	2,112,338	1,948,800
Total: Lindsey Oil Refinery	Refineries	Industry	1,474,041	926,800
EPUK: South Humber Bank Power Station	Large Electricity Producers	Power	1,344,908	1,072,584
SSE: Keadby Power Station	Large Electricity Producers	Power	1,026,050	336,094

Table 15: Humber Large Emitters

Installation Name	EU-ETS Sector	Sector	Reportable Emissions Annual tCO2e (2018)	UK LA Pollution Inventory (5yr average to 2017) tCO_2e/yr
BP Chemicals	Chemicals	Industry	341,202	356,347
Singleton Birch: Melton Ross Lime works	Lime	Industry	278,182	241,710
Tronox: Cristal Pigment - CHP Plant	Chemicals	Industry	206,028	128,940
Perenco: Dimlington-Easington Shore Terminal	Offshore (exploration)	Industry	141,145	173,522
Saint-Gobain Glass (United Kingdom) Limited: Guardian Glass	Glass	Industry	108,095	
Industrial Energy Services Limited, Cofely Humber Energy	Chemicals	Industry	82,608	49,466
Knauf (UK) GmbH, Immingham	Other (Building Materials)	Industry	53,035	47,685

Table 16: Humber Medium Emitters

Installation Name	Local Authority	Sector	Reportable Emissions Annual tCO2e (2018)	UK LA Pollution Inventory (5yr average to 2017) tCO_2e/yr
Gassco, Langeled Receiving Facilities - Water/Glycol Heater Plant (Easington)	Offshore	Industry	31,598	
ETEX Building Performance Limited – Ferrybridge	Other (Building materials)	Industry	28,527	
Greenergy Biodiesel Processing Plant	Other (biofuel)	Industry	25,847	
AAK (UK) Limited	Food and Drink	Industry	24,697	29,320
Creyke Beck Peaking Plant	Other Electricity Producers	Power	20,919	
Centrica Storage Ltd	Downstream gas	Industry	20,562	32,563
EPR Glanford Brigg Generating Station	Other Electricity Producers	Power	17,180	
Croda Europe – Hull	Chemicals	Industry	15,411	19,568
Saltend Chemicals Park	Chemicals	Industry	14,140	
INEOS, ETAC Plant (Ethyl Acetate)	Chemicals	Industry	6,835	7,240
Aldbrough Gas Storage	Downstream gas	Industry	4,010	

Table 17: Humber Small Emitters

Installation Name	Local Authority	UK LA Pollution Inventory (5yr average to 2017) tCO_2e/yr
Total Petrochemicals UK Ltd	North Lincs	663,017
Rugby Group Ltd	North Lincs	340,917
Vivergo Fuels Ltd	East Riding	229,755
BWSC Generation Services UK Ltd	North Lincs	127,730
Centrica KPS Ltd	North Lincs	111,635
Fibrogen Ltd	North Lincs	107,986
Px Ltd	North East Lincs	101,005
Biffa Waste Services Ltd	North Lincs	69,600
Newlincs Development Ltd	North East Lincs	59,807
E.ON UK Plc	North Lincs	49,339

ENGIE FM Ltd	North East Lincs	32,456
Coal Products Ltd	North East Lincs	21,865
Yorkshire Water Services Ltd	East Riding	17,580
Caparo Merchant Bar Plc	North Lincs	15,310
Integrated Waste Management Ltd	North Lincs	14,129
Centrica Brigg Ltd	North Lincs	11,189
Waste Recycling Group Ltd	East Riding	8,924
Uniper UK Ltd	North Lincs	5,288
Anglian Water	North East Lincs	5,000
Integrated Waste Management Ltd	East Riding	914

Table 18: Additional Emitters in Local authority data

15 Appendix D - Renewables Generators

Renewables Generation (Type)	Operational (MW)	Planning Permission Granted (MW)	Under Construction (MW)	Total (MW)
Advanced Conversion Technologies	25	35	Nil	60
Anaerobic Digestion	14	Nil	Nil	14
Battery	50	148	Nil	198
Biomass (dedicated)	49	50	18	116
EfW Incineration	3	139	Nil	143
Landfill Gas	18	Nil	Nil	18
Solar Photovoltaics	95	47	Nil	142
Wind Onshore	377	8	Nil	385
Total Capacity (MW)	**632**	**427**	**18**	**1,076**

Table 19: Renewables Generators in the core Humber areas - generating Capacity [16]

Renewables Generation (Type)	Operational (No. of sites)	Planning Permission Granted (No. of sites)	Under Construction (No. of sites)	Total (No. of sites)
Advanced Conversion Technologies	1	3	Nil	4
Anaerobic Digestion	5	Nil	Nil	5
Battery	1	4		5
Biomass (dedicated)	2	1	1	4
EfW Incineration	1	4		5
Landfill Gas	5	Nil	Nil	5
Solar Photovoltaics	8	4	Nil	12
Wind Onshore	26	2	Nil	28
Total (No. of sites)	**49**	**18**	**1**	**68**

Table 20: Renewables Generators in the core Humber areas - number of sites [16]

Renewables Generation (Type)	Operational (MW)	Planning Permission Granted (MW)	Under Construction (MW)	Total (MW)
Advanced Conversion Technologies	25	94	Nil	119
Anaerobic Digestion	23	Nil	Nil	23
Battery	99	208	Nil	307
Biomass (dedicated)	80	50	18	148
EfW Incineration	6	165	Nil	172
Landfill Gas	26	Nil	Nil	26
Solar Photovoltaics	280	107	Nil	388
Wind Offshore	377	1,408	2,060	3,845
Wind Onshore	743	427	18	1,187
Total Capacity (MW)	**1,660**	**2,459**	**2,095**	**6,214**

Table 21: Renewables Generators in the core and broader Humber areas - generating Capacity [16]

Renewables Generation (Type)	Operational (No. of sites)	Planning Permission Granted (No. of sites)	Under Construction (No. of sites)	Total (No. of sites)
Advanced Conversion Technologies	1	5	0	6
Anaerobic Digestion	9	0	0	9
Battery	2	7	0	9
Biomass (dedicated)	5	1	1	7
EfW Incineration	2	5	0	7
Landfill Gas	9	0	0	9
Solar Photovoltaics	31	7	0	38
Wind Offshore	26	3	2	31
Wind Onshore	55	18	1	74
Total (No. of sites)	**140**	**46**	**4**	**190**

Table 22: Renewables Generators in the core and broader Humber areas - number of sites [16]

Area	Description
Core Humber Area	Includes the local authorities within the Humber LEP (East Riding, North Lincolnshire, North East Lincolnshire and Hull).
Broader Humber Area	Includes: **West:** West of the Core Humber cluster including Selby, home of Drax power station, the largest power station in the region, industrial and power generation sites around Leeds and Bradford, and York (home of Nestle) in the North. **South West:** Includes several cement and lime sites around Sheffield and stretching South until reaching the boundary of but not including Nottingham and Derby. **South:** Area south of the Humber LEP boundary stretching to the North of Boston (not included) but including the British Sugar Site outside Newark on Trent.

Table 23: Humber core and broader regions definitions [16] [52]

16 Appendix E – Glossary

Abbreviation	Description
BECCS	Bioenergy with carbon capture and storage
BF-BOF	Blast furnace - basic oxygen furnace
CCC	Committee on Climate Change
CCUS	Carbon capture, utilisation and storage
DACCS	Direct air capture with carbon sequestration
EAF	Electric arc furnaces
ETS	Emissions Trading System
GHG	Greenhouse gas
GVA	Gross Value Add
HIC	Humber Industrial Cluster
HIDR	Humber Industrial Decarbonisation Roadmap
IEEA	Industrial Energy Efficiency Accelerator
IHRS	Industrial Heat Recovery Support
IPCC	Intergovernmental Panel on Climate Change
ISCF	Industrial Strategy Challenge Fund
KPIs	Key performance indicators
LEP	Local Enterprise Partnership
PEM	Polymer electrolyte membrane
UNFCCC	UN Framework Convention on Climate Change