Environmental Capacity in Industrial Clusters

Phase 4 Technical Annex 3 - Evidence Baseline and Analysis

Date: 10th February 2025

Version: 0.6

Prepared by:

Patrick Froggatt
Technical Air Quality Director
AECOM

On behalf of:

Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH

www.gov.uk/environment-agency

Contents

Glossary

Abbreviation	Definition
ANC	Acid Neutralising Capacity
APIS	UK Air Pollution Information System
AQAP	Air Quality Action Plan
AQMA	Air Quality Management Areas
AQS	UK National Air Quality Strategy
ASR	Air Quality Annual Status Report
ATR	Auto Thermal Reforming
AURN	Automatic Urban Rural Network
BAT	Best Available Techniques
BAU	Business as Usual,
CAZs	Clean Air Zones
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CO	Carbon Monoxide
CRA	Containment Risk Assessments
cSACs	Candidate Special Areas of Conservation
DA	Devolved Administration
DCO	Development Consent Order
Defra	Department for Environment, Food and Rural Affairs
EA	Environment Agency
EAL	Environmental Assessment Levels
EGR	Exhaust Gas Recirculation
ELVs	Emission Limit Values
EMS	Environment Management Systems
EPR	European Pressurized Reactor
ERC	Emission Reduction Commitment
EU	European Union
EUNIS	European Union Nature Information System
GET	Guidance on Emerging Techniques
GHG	Greenhouse Gas
GHR	Gas Heated Reforming
GMCA	Greater Manchester Combined Authority
HyNet	Hydrogen Network
IED	Industrial Emissions Directive
JNCC	Joint Nature Conservation Committee
kt	Kiloton
keq/ha/yr	Kilogram equivalent of pollutant per Hectare per Year
kgN/ha/yr	Kilogram of Nitrogen per Hectare per Year
LAs	Local Authorities
LAQM	Local Air Quality Management
LCP	Large Combustion Plant
LNR	Local Nature Reserve

Abbreviation	Definition
MEA	Monoethanolamine
NDMA	N-Nitrosodimethylamine
OEP	Office for Environmental Protection
N	Nitrogen
NAEI	UK National Atmospheric Emissions Inventory
NAPCP	National Air Pollution Control Programme
NECR	National Emission Ceilings Regulations
NH_3	Ammonia
NMVOCs	Non-Methane Volatile Organic Compounds
NO_2	Nitrogen Dioxide
NO_X	Oxides of Nitrogen
NSIPs	Nationally Significant Infrastructure Projects
P	Phosphate
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter with a diameter of 2.5 µm or less
PM_{10}	Particulate Matter with a diameter of 10 µm or less
pSPAs	Proposed Special Protection Areas
SAC	Special Areas of Conservation
SCR	Selective Catalytic Reduction
SNCR	Non-Selective Catalytic Reduction
SPAs	Special Protection Areas
SO_2	Sulphur Dioxide
SO_x	Oxides of Sulphur
SSSIs	Sites of Special Scientific Interest
UK	United Kingdom
VOCs	Volatile Organic Compounds
WHO	World Health Organisation
WM	With Measures
$\mu g/m^3$	Micrograms per Cubic Metre (unit of concentration)

Report Structure

The evidence baseline is divided into three sections: aims of the study, methodology, and discussion. This will strengthen the report's conclusion by incorporating evidence and academic analysis. Additionally, the appendices provide sources that support deeper exploration of the topic.

The following report is structured as follows:

- Air Quality and Ecological Considerations in the UK
- The HyNet Industrial Cluster
- Existing Air Quality in the HyNet Area
- Ecological Sites in the HyNet Area
- Low Carbon Technology in the HyNet Industrial Cluster
- Low Carbon Technology Emissions and Potential Human Health Impacts.

Air Quality and Ecological Considerations in the UK

National Air Quality Legislation

The principal air quality legislation within the United Kingdom is the Air Quality Standards Regulations (as amended 2016) [1], including amendments, such as 'The Environment (Miscellaneous Amendments) (EU Exit) Regulations 2020' [2].

In addition to the Air Quality Standards Regulations, several other key pieces of legislation govern air quality in the UK:

- Industrial Emissions Directive (EU) 2024/1785 [3]: The Industrial Emissions Directive (IED) provides an integrated approach to regulating pollution from industrial installations. It establishes a framework to prevent and control emissions to air, water, and land from major industrial sources.
- Clean Air Act 1993 [4]: This Act focuses on controlling emissions of smoke from industrial and domestic sources, establishing Smoke Control Areas where the use of certain fuels is restricted.
- Environment Act 1995 [5]: The Environment Act introduced the framework for Local Air Quality Management (LAQM), requiring local authorities to monitor air quality, identify problem areas (Air Quality Management Areas), and develop action plans to improve air quality.
- Environment Act 2021 [6]: Building on earlier frameworks, the revised Environment Act introduces new statutory targets for air quality, particularly addressing fine particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$). This Act emphasises a long-term strategy to achieve cleaner air and healthier ecosystems.

- Climate Change Act 2008 [7]: Although focused on greenhouse gas emissions, this Act indirectly supports air quality improvements by driving reductions in fossil fuel use, a major source of air pollutants.

Much of this information aligns with the legislative framework outlined in the Phase 3 report for the Teesside Industrial Cluster. The UK's exit from the EU continues to influence how certain types of EU legislation are applied domestically. Regulations and Decisions, which were directly applicable as law during the UK's EU membership, remain part of UK domestic law under section 2(1) of the European Communities Act 1972 (c.68). These types of legislation are now categorised as 'legislation originating from the EU' and are published on legislation.gov.uk. Directives, which require domestic implementing legislation, continue to be incorporated into UK law where relevant as of December 31, 2020.

Other types of EU legislation, such as Directives, are indirectly applicable, which means they require a Member State to make domestic implementing legislation before becoming law in that State. Legislation, as it applied to the UK on 31st December 2020, is now a part of UK domestic legislation under the control of the UK's Parliaments and Assemblies.

Industrial Emissions Directive

The IED was implemented in the UK through the Environmental Permitting (England and Wales) Regulations 2016 [8] and introduces significant updates, including an expanded scope to cover sectors such as battery gigafactories, metal extraction, and landfills. It mandates the use of Best Available Techniques (BAT) to minimise emissions, setting stricter limits for pollutants such as oxides of nitrogen (NO_x), sulphur dioxide (SO_2), and particulate matter (PM).

Additionally, the directive requires the implementation of Environmental Management Systems (EMS) to ensure continuous environmental performance improvements and enhance public participation and compensation mechanisms for pollution-related health damages. In the absence of established BAT standards for emerging technologies like hydrogen production and carbon capture, the Environment Agency (EA), in collaboration with environmental regulators from devolved administrations, has produced Guidance on Emerging Techniques (GET).

This guidance outlines best practices for post-combustion carbon dioxide (CO_2) capture and provides interim measures to manage emissions effectively while BAT standards are under development [9].

National Clean Air Strategy (2019)

In 2019, the UK government released its Clean Air Strategy 2019 [10], part of its 25 Year Environment Plan. The Strategy places greater emphasis on improving air quality in the UK than has been seen before and outlines how it aims to achieve this, including the development of new enabling legislation.

Air quality management focus in recent years has primarily related to one pollutant, nitrogen dioxide (NO_2), and its principal source in the UK, road traffic. But the 2019 Strategy broadened the focus to other areas, including domestic emissions from wood-burning stoves and agriculture.

A Green Future: 25 Year Plan to Improve the Environment

The 25 Year Environment Plan, originally published in January 2018, sets out the actions UK Government will take to help the natural world regain and retain good health [11]. The Environment Plan was updated in 2023 with the publication of the Environmental Improvement Plan 2023 [12]. This plan outlines several actions being taken to improve air quality, most notably the publication of the Clean Air Strategy [10] and the introduction of several Clean Air Zones (CAZs) across England. Emphasis is also placed on $PM_{2.5}$ concentrations, with several new targets for $PM_{2.5}$ concentrations stated within the plan including:

"A legal target to reduce population exposure to $PM_{2.5}$ by 35% in 2040 compared to 2018 levels, with a new interim target to reduce by 22% by the end of January 2028.

A legal target requiring a maximum annual mean concentration of 10 micrograms of $PM_{2.5}$ per cubic metre (µg/m^3) by 2040, with a new interim target of 12 µg/m^3 by the end of January 2028."

Environment Act (2021)

The Environment Act 2021 [6] was approved on 9th November 2021, after being first introduced to Parliament in January 2020 to address environmental protection and the delivery of the Government's 25-year Environment Plan following Brexit. It includes provisions to establish a post-Brexit set of statutory environmental principles and ensure environmental governance through an environmental watchdog, the Office for Environmental Protection (OEP). Part IV of the Environment Act (2021) requires the Government to update the UK National Air Quality Strategy (AQS) which contains standards, objectives and measures for improving ambient air quality. Details regarding the AQS and recent updates are provided below.

The Environment Act (2021) proposes that the Secretary of State publish a report reviewing the AQS every five years as a minimum with yearly updates to Parliament, in the form of the Environmental Improvement Plan [12].

Air Quality Strategy

The AQS was initially published in 2000 [13], as required by the Environment Act 1995 [5], and amended by the Environment Act 2021 [6]. The 2007 version of the AQS [14] set objectives for key pollutants as a tool to help local authorities manage local air quality improvements with the aim of avoiding, preventing or reducing harmful effects on human health and on the environment as a whole.

A new AQS was published in April 2023 [15]. It sets out the actions the government expects local authorities to take in support of achieving the new national $PM_{2.5}$ targets, by reducing emissions from sources within their control. The objectives set out in the AQS have been outlined in legislation solely for local air quality management, however, Defra has confirmed that they should also be considered when assessing impacts at applicable sensitive receptors, as set out in LAQM TG(22) [16].

Under the LAQM regime, the local authority has a duty to carry out regular assessments of air quality against the objectives and they must designate an Air Quality Management Area (AQMA) if it is unlikely that they will be met in the given timescale and prepare an Air Quality Action Plan (AQAP) to achieve AQS objectives. The boundary of an AQMA is set by the governing local authority to define the geographical area that is to be subject to the management measures to be set out in a subsequent action plan. It is not unusual for the boundary of an AQMA to include within it, relevant locations where air quality is not at risk of exceeding an AQS objective. The AQS objectives for the pollutants of relevance to this assessment are displayed in Table 1.

In addition, the EA has defined Environmental Assessment Level's (EAL's) for the protection of human health for pollutant species currently without AQS objectives and are presented as part of the "Air emissions risk assessment for your environmental permit" guidance website [17]. The only EAL applicable to this assessment is the 1-hour assessment criterion for carbon monoxide (CO), also presented in Table 1, with all other applicable EALs being the same as the AQS objectives already presented.

In the absence of an EAL for a specific pollutant, applicants must derive appropriate benchmarks using credible toxicological data. They should reference internationally recognised sources, such as World Health Organization (WHO) guidelines or scientific literature and provide a clear justification for the selected criteria to ensure they adequately protect human health [18]. For emerging or unregulated pollutants, such as amines (e.g., monoethanolamine (MEA) and N-nitrosodimethylamine (NDMA)), the Environment Agency's guidance on toxicological evidence offers methodologies for establishing temporary benchmarks until definitive standards are available [19]. Applicants are advised to consult these resources and address both direct and cumulative exposure risks in their assessments.

Table 1 - UK AQS Objectives

Pollutant	Concentration ($\mu g/m^3$)	Measured as
Nitrogen dioxide (NO_2)	40	Annual mean for the protection of human health
	200	1-hour mean, not to be exceeded more than 18 times a year (i.e. 99.79th percentile) for the protection of human health

Carbon monoxide (CO)	30,000	1-hour Environment Agency Permit Guidance for the protection of human health
	10,000	8-hour (running mean) for the protection of human health
Sulphur Dioxide (SO_2)	266	15-minute mean, not to be exceeded more than 35 times a year
	350	1-hour mean, not to be exceeded more than 24 times a year
	125	24-hour mean, not to be exceeded more than 3 times a year
Particulate Matter with a diameter of 10 µm or less (PM_{10})	40	Annual mean for the protection of human health
	50	24-hour mean, not to be exceeded more than 35 times a year (i.e. 90.41 percentile) for the protection of human health
Particulate Matter with a diameter of 2.5 µm or less ($PM_{2.5}$)	20	Annual mean for the protection of human health
	12	Future (2028) objective for the protection of human health
	10	Future (2040) objective for the protection of human health

Assessment Criteria for Sensitive Ecological Receptors

The UK is bound by the terms of the European Birds and Habitats Directives [20] and the Ramsar Convention [21]. The Conservation of Habitats and Species Regulations 2010 [22] provides for the protection of European sites created under these policies, i.e. Special Areas of Conservation (SACs) designated via the Habitats Directive, Special Protection Areas (SPAs) classified under the Birds Directive, and Ramsar Sites designated as wetlands of international importance. The 2010 Regulations apply specific provisions of the European Directives to SACs, SPAs, candidate SACs (cSACs) and proposed SPAs (pSPAs), which require them to be given special consideration and further assessment by any development likely to lead to a significant effect upon them.

The legislation concerning the protection and management of designated sites and protected species within England is set out within the provisions of the 2010 Regulations [22], the Wildlife and Countryside Act 1981 (as amended) [23] and the Countryside and Rights of Way Act 2000 (as amended) [24].

The impact of emissions from industrial sources on ecological receptors is quantified within in two ways:

- as direct impacts due to increases in atmospheric pollutant concentrations; assessed against Critical Levels; and
- indirect impacts from deposition of acids and nutrient nitrogen to the ground surface, assessed against Critical Loads.

The Critical Levels for the protection of vegetation and ecosystems are presented in Table 2 and apply regardless of habitat type.

Table 2 - Relevant Ambient AQS Objectives (for the Protection of Ecological Receptors)

Pollutant	Source	Concentration ($\mu g/m^3$)	Measured as
Oxides of Nitrogen (NO_x)	AQS objective & Environment Agency Permit Guidance	30	Annual Mean
	Environment Agency Permit Guidance	75	Daily Mean
Sulphur dioxide (SO_2)	AQS objective & Environment Agency Permit Guidance	20	Annual Mean
		10 (if lichens or bryophytes present)	Annual Mean
Ammonia (NH_3)	Environment Agency Permit Guidance	3	Annual Mean
	Environment Agency Permit Guidance	1 (if lichens or bryophytes present)	Annual Mean

Table 3 and Table 4 present the Critical Load criteria for the deposition of nutrient nitrogen for each habitat type in the UK as detailed on the UK Air Pollution Information System (APIS).

Table 3. APIS Indicative Nitrogen Deposition Critical Load Values for Habitats Mapped Nationally in the UK [25]

Habitat Type	Habitat Description	Critical Load Range (kgN/ha/yr)	UK Mapping Value (kgN/ha/yr)	Indication of Exceedance
Marine habitats	Mid-upper saltmarshes	20-30	25	Increase in dominance of graminoids
	Pioneer & low-mid saltmarshes	20-30	25	Increase in late-successional species, increase in productivity
Coastal habitats	Coastal stable dune grasslands (grey dunes)	8-15	Acid dunes: 9 Non-acid dunes: 12	Increase tall graminoids, decrease in prostrate plants, increased N leaching, soil acidification, loss of typical lichen species.
Mire, bog, and fen habitats	Raised and blanket bogs	5-10	8,9 or 10 depending on rainfall	Increase in vascular plants, altered growth & species composition of bryophytes, increased N in peat and peat water.
Grassland and tall forb habitats	Semi-dry calcareous grassland	15-25	15	Increase in tall grasses, decline in diversity, increased mineralization, N leaching; surface acidification.

Habitat Type	Habitat Description	Critical Load Range (kgN/ha/yr)	UK Mapping Value (kgN/ha/yr)	Indication of Exceedance
	Dry acid and neutral closed grassland	10-15	10	Increase in graminoids, decline in typical species, decrease in total species richness.
	Juncus meadows & *Nardus stricta* swards	10-20	15	Increase in tall graminoids, decreased diversity, decrease in bryophytes.
	Moss & lichen dominated mountain summits	5-10	7	Effects upon bryophytes and/or lichens.
Heathland habitats	Northern wet heaths: • *Calluna* dominated (upland) • Erica tetralix dominated (lowland)	10-20	10	Decreased heather dominance, decline in lichens and mosses, increase N leaching. Transition from heather to grass dominance.
	Dry heaths	10-20	10	Transition from heather to grass dominance, decline in lichens, changes in plant biochemistry, increased sensitivity to abiotic stress.
Forest habitats	Beach woodland	10-20	15	Changes in ground vegetation & mycorrhiza, nutrient imbalance, changes in soil fauna.
	Acidophilous oak-dominated woodland	10-15	10	Decrease in mycorrhiza, loss of epiphytic lichens and bryophytes, changes in ground vegetation.
	Scots Pine woodland	5-15	12	Changes in ground vegetation & mycorrhiza, nutrient imbalances.
Forest habitats overall	All forests: ground flora	10-20 or 5-15 depending on woodland type	-	Changed species composition, increase of nitrophilous species, increased susceptibility to parasites.
	Broadleaved woodland	10-20	12	Changes in soil processes, nutrient imbalance, altered composition of mycorrhiza & ground vegetation
	Coniferous woodland	5-15	12	Changes in soil processes, nutrient imbalance, altered composition of mycorrhiza & ground vegetation.

Habitat Type	Habitat Description	Critical Load Range (kgN/ha/yr)	UK Mapping Value (kgN/ha/yr)	Indication of Exceedance
	Mixed woodland	-	12	This is the mapping value used in 2003 for all unmanaged woodland and is applied to all unmanaged woodland in the UK

Source: Hall, J et al. Methods for the calculation of critical loads and their exceedances in the UK (2015)

Table 4. APIS Indicative Nitrogen Deposition Critical Load Values for Habitats not Mapped Nationally in the UK, but of High Conservation Value

Habitat Type	Habitat Description	Critical Load Range (kgN/ha/yr)	Indication of Exceedance
Coastal habitats	Shifting coastal dunes	10-20	Biomass increase, increased N leaching
	Coastal dune heaths	10-20	Increase in plant production, increased N leaching, accelerated succession
	Moist to wet dune slacks	10-20	Increased biomass of tall graminoids
Inland surface waters	Soft water lakes (permanent oligotrophic waters)	3-10	Changes in species composition of macrophyte communities, increased algal productivity and a shift in nutrient limitation of phytoplankton from N to P
	Permanent dystrophic lakes, ponds, and pools	3-10	Increased algal productivity and a shift in nutrient limitation of phytoplankton from N to P
Mire, bog, and fen habitats	Valley mires, poor fens and transition mires	10-15	Increase in sedges & vascular plants, negative effects on bryophytes
	Rich fens	15-30	Increase in tall graminoids, decrease in bryophytes
	Montane rich fens	15-25	Increase in vascular plants, decrease in bryophytes
Grasslands and tall forb habitats	Inland dune pioneer grassland	8-15	Decrease in lichens, increase in biomass
	Inland dune and siliceous grassland	8-15	Decrease in lichens, increase in biomass, increased succession
	Low and medium altitude hay meadows	20-30	Increase in tall grasses, decrease in diversity
	Mountain hay meadows	10-20	Increase in nitrophilous graminoids, changes in diversity
	Molinia caerulea meadows	15-25	Increase in tall graminoids, decreased diversity, decreased bryophytes

Habitat Type	Habitat Description	Critical Load Range (kgN/ha/yr)	Indication of Exceedance
	Alpine and subalpine acid grassland	5-10	Changes in species composition, increase in plant production
	Alpine and subalpine calcareous grassland	5-10	Changes in species composition, increase in plant production

Source: Source: Hall, J et al. Methods for the calculation of critical loads and their exceedances in the UK (2015)

The Critical Load criteria for acid deposition for each habitat type in the UK is highly dependent on the interest feature and underlying soil type and its buffering capacity. As such, there is generally no overarching Critical Load that applies to all habitat types with impacts of acidification determined based on the individual ecological sites minimum and maximum critical load function. Table 5 presents the general inflation on each key habitat type derived for the APIS system.

Table 5. APIS indicative acid critical load values

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Acid Grasslands	No estimate available	Associated with lowland heath, parklands or coastal cliffs. Soils are nutrient-poor, free-draining, pH 4 to 5.5 and overlie acid rocks (sandstone and granites) or deposits such as sands, gravels and acid clays. Lowland acid grassland occurs below 300 metres and is normally managed for pasture.	Root damage, increased risk of nutrient imbalance leading to stunted growth, increased nutrient leaching.
Raised bog and blanket bog	0.1 to 1.0	Plant community composition is partly determined by the acidity of peat bogs and can change in response to increasing levels of mineral acidity. Bogs are naturally acidic, being rich in organic acids. Sphagnum mosses synthesise polygalacturonic acid and decomposition leads to the release of complex humic acid substances. These organic acids contrast the strong mineral acids that form acid deposition.	Changes in vegetation composition, i.e. bryophytes, lichens and species diversity of higher plant communities. The disappearance of Sphagnum species and the absence of acid-sensitive epiphytic species.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Broadleaved, Mixed and Yew Woodland	No estimate available	For broadleaved woodlands, adverse effects are likely to include low levels of phosphate (P) and base cation availability, particularly on acid mineral soils. Current acidification from deposited N compounds may also lead to reduced base cation availability, via leaching. Acid deposition effects are most likely to be mediated through indirect effects on soil chemistry.	Lichens and mosses, especially on tree branches, are directly impacted by deposition. Ground flora is likely to be less species-rich, although the level of effect will depend on the tree species. Branch dieback, abnormal branching patterns, reduced crown density and leaf discolouration may occur along with generally poor tree health and increased sensitivity to other factors such as pests, pathogens and climatic changes. Many of these effects reflect below-ground damage, particularly to fine roots resulting in increased sensitivity to drought and windthrow. Increased risk of nutrient imbalance which will lead to stunted growth.
Calcareous grassland	No estimate available	Low-productivity grasslands occur on shallow, well-drained, well-buffered soils, above pH 6, (with a calcium carbonate content of ~10%, formed by weathering of base-rich rock). Acid deposition effects on calcareous grassland are limited, except with large acid inputs, as they are well buffered.	Acidifying deposition probably represents a small threat to these grasslands, due to their inherent neutralising capacity. The critical loads for calcareous grasslands are therefore large and generally not exceeded, given the success in reducing S emissions in the UK.
Coastal and Floodplain Grazing Marsh	No estimate available	Coastal and floodplain grazing marsh form some of the last remaining unimproved grasslands. They lie inland of saltmarshes (which are inundated by tides on a regular basis). Grazing marshes are only periodically inundated by the sea and often have a network of dykes and shallow lagoons, and ditches to maintain the water levels.	Effects are likely to be small as these habitats are generally brackish and alkaline. They are more at risk from eutrophication via agricultural run-off, resulting in a loss of aquatic vegetation.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Coastal saltmarsh	No estimate available	Salt marshes are coastal and tidal (repeatedly flushed with saline, brackish water), occurring in the upper coastal intertidal zone between land and open salt water. They are dominated by dense stands of salt-tolerant plants (halophytes) such as herbs, grasses, or low shrubs. These plants stabilise the salt marsh by trapping and binding sediments, providing coastal protection. They play an important role in the aquatic food web and the delivery of nutrients to coastal waters.	Effects are likely to be small as these habitats are inter-tidal and experience large influxes of nutrients. The risks from acid deposition compared with eutrophication via agricultural run-off, are small. However, any actions that reduce or stop tidal flooding or cause a drop in the water table may result in environmental problems.
Coniferous woodland	No estimate available	Conifers e.g. Abies, Picea and Pinus tend to be more tolerant of acid soils than broadleaf trees but the acid soils where they grow may have low base cation buffering making them more sensitive to acid deposition and low levels of available phosphate (bound by aluminium). Conifers compared to broadleaves intercept the most precipitation and, therefore, can concentrate pollutants at sites where they grow. Coniferous forests are aerodynamically rough all year round and thus experience the largest pollutant deposition loading of all vegetation.	Acid deposition is mainly associated with nitrogen. Lichens and mosses, especially on tree branches, directly impacted by deposition, though lichens of conifers are better adapted to lower pH's than lichens on broadleaved tree species. Ground flora is likely to be less species-rich, depending on tree species. Poor general tree health increases secondary stress damage, both biotic (pests and pathogens) and abiotic (climatic). Rarely, visible decline symptoms may be observed e.g. branch dieback, abnormal branching patterns, reddening of needles, reduced crown density and leaf discolouration. Below-ground damage, particularly to fine roots, predisposes trees to drought stress and windthrow. Reduced mycorrhizal infection in roots increasing susceptibility to heavy metals and reduce nutrient foraging/ uptake. Increased risk of nutrient imbalance. The effects vary with prevailing climatic patterns (exposure effects), as well as distribution of acid soils (ecosystem sensitivity). In many cases, individual trees or groups of trees, rather than whole forests or stands are affected.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Dunes, Shingle & Machair	No estimate available	Sand dune habitats are one of the most natural remaining vegetation types in the UK, supporting over 70 nationally rare or red-data book species. Machair systems represent former beaches and sand plains standing above the current adjacent beach. Machair sands owe their fertility largely to their high seashell content, up to 90%, and to fertilisation with seaweed. The main areas of machair are found on the western Isles of Scotland.	In sand dunes, decalcification (in response to rainfall) reduces pH has the strongest influence on diversity. The majority of dune systems in the UK are calcareous, well-buffered and low in heavy metals so are more tolerant of acid deposition. However, they are generally infertile and thus sensitive to N deposition. Acid deposition has relatively little impact on dunes in the UK as they are generally well-buffered, except for the few acidic dune systems. Lichens and mosses are sensitive to direct effects.
Dwarf Shrub Heath	No estimate available	Dwarf Shrub Heaths are characterised by vegetation dominated (>25%) by members of the heath family (Ericaceae: e.g. heathers, blaeberry, cowberry) with some grasses (e.g. purple moor-grass and deer grass). The exact mix depends on the soil type and amount of rainfall in the area, whether they are in upland or lowland areas, as well as the history of burning and browsing. Generally, species inhabiting this ecosystem are acid tolerant, however, their roots may still be sensitive to mineral acids and the increase in ammonium ions. Species that are only moderately acid-tolerant may be sensitive.	Reduction of acid-sensitive bryophyte species, change in species composition and frequency of ground floor bryophytes. Mosses can be sensitive to acid deposition. Below-ground damage, particularly to fine roots and loss of ericoid mycorrhiza, however significant acidification (pH towards 3) is required before such effects would be expected. Root damage may increase the sensitivity of Calluna to winter desiccation.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Fen, Marsh and Swamp	No estimate available	Fens and marshes are characterised by a variety of vegetation types that represent their underlying geology and soil type. Fens represent more organic, peaty areas whereas marsh is found on mineral soils with a water table close to the surface, while in swamps the water table remains at or above the surface. Many are coastal or found in low-lying areas, e.g. flood plains and lakesides. Some occur on calcareous soils while others are found on acid, base-poor soils, typically peats (fens) or organo-mineral soils and also impoverished poorly draining mineral soils (purple moor grass and rush pastures). This latter pasture type consists of a mosaic of plant communities, reflecting differences in water table. Acid and basic flushes (up wellings of groundwater moving over or through the soil) can occur within these communities.	Due to the wide-range of vegetation types, responses to acid deposition have to be considered separately for the different ecosystem types and even within types. There are no specific studies of effects of acid deposition on these rather variable ecosystems. The process of acidification is largely dependent on the hydrology of fen ecosystems and the balance between rainfall and groundwater and/or surface water. Nutrient enrichment and polluted ground water represent the biggest threat, along with drainage / land use change and inappropriate or lack of management.
Improved Grassland	No estimate available	Grassland is improved to increase quantity and quality, i.e. nutritional status for grazers. The seed mixture may be chosen to reflect this. Less productive species and forbs would be excluded from the seed mix. The productive species may well be acid-sensitive, though less likely to be affected by the nutrient inputs associated with acid deposition. To increase productivity the soil is often limed, which provides buffering against acid deposition.	Increased removal of base cations with grassland fodder and fertiliser application leads to lower soil pH requiring the addition of lime to counteract it. Increased risk of nutrient imbalance which will lead to stunted growth.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Inland Rock & Scree	No estimate available	Mosses and lichens are expected to be the most sensitive components of these systems. This habitat covers a wide range of rock types, varying from acidic to highly calcareous. Non-vascular plants might be affected by acid deposition although species subject to and tolerant of sea salt spray may be relatively insensitive to acid deposition. Inland rock outcrop and scree habitats are widespread in upland areas of the UK, with more limited occurrence in the lowlands.	Acidic rock and scree are especially widespread, whereas calcareous communities are restricted by the underlying geology. Communities growing on acid rock are likely to be sensitive whereas calcareous communities should be relatively insensitive. Non-vascular plants (e.g. lichens and mosses) remain the most sensitive to acid inputs. Plant communities growing on acid rock are likely to be sensitive whereas calcareous communities should be relatively insensitive due to the acid neutralising capacity of the calcareous rock.
Montane habitats	No estimate available	Montane vegetation, heaths and scrubs of dwarf shrubs have adapted to low levels of nutrient availability since the generally acid, cold, wet, conditions restrict mineralisation and N assimilation. The main threats from acid deposition come from nitrogen emissions, although there can be a legacy effect associated with the decades of sulphur emissions at many sites. Montane environments, where weathering is combined with high rainfall, tend to be naturally acidic unless they occur on basic outcrops. High levels of precipitation may cause any nitrate to be easily leached.	Detrimental effects on lichens and mosses. Species sensitivity to other stresses (e.g. grazing pressure, climatic stress winter and summer desiccation, freezing stress) and pathogens may be enhanced. Nutrient limitation will be exacerbated, although this can mitigate against competition from grass species that favour nitrogen enrichment. Montane habitats are particularly at risk from long-range transport of acid pollutants and from acid flushes, e.g. when snow melts and deposition is concentrated into one event which can happen several times a winter.
Neutral Grassland	No estimate available	Neutral grasslands are semi-natural swards dominated by grasses with associated dicotyledonous herbs without the calcifuge / calcicole element on lowland clays / loams. They are mesotrophic, with a pH of around 5.5-7. These ecosystems are generally poor in nutrients because of long agricultural use with low levels of manure addition and removal of plant parts by grazing or haymaking.	Acidifying deposition represents a moderate threat to these grasslands as it exhausts their acid-neutralising capacity, so favouring acid-tolerant/resistant species, reducing diversity. Disappearance of endangered acid-sensitive species when pH falls outside the pH range 4.5 to 6.5. Effects of acidification associated with nitrogen (N) will be associated with the amount of ammonium that is nitrified.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Rivers and Streams	Value varies depending on species of interest and mineralogy, size & other characteristics of the waterbody and its catchment.	Acid deposition on acid-sensitive catchments (mostly overlying rock types with low weathering rates, such as granites, sandstones and schists) can result in chronic acidification of runoff into drainage waters, and particularly headwater streams. The ability of surface waters to withstand acid deposition is determined by the calculation of Acid Neutralising Capacity (ANC). Salmonids are most sensitive to acid waters during hatching, fry and smelting stages. Low pH has been shown to impair the regulation of ions (and particularly sodium) across cell membranes, while elevated levels of inorganic aluminium impair gill function.	The acidification of rivers and streams by acid deposition has been shown to influence aquatic biota and overall reduction in species biodiversity at all levels of the food chain, from primary producers, such as aquatic algae and macrophytes, to macroinvertebrates, fish and even water birds. Growth of some plants may be affected by the reduced availability of dissolved inorganic carbon The acidity of acidified streams tends to increase at times of high rainfall as a result of a proportionally smaller contribution to runoff from relatively well buffered groundwater (i.e. water that has interacted with mineral bearing rock) and increased export of organic matter from soil horizons near the surface in the form of organic acids. Acidity is also accentuated at sites within a few tens of kilometres of the coast following the deposition of sea salt during winter storms.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Standing Open Water and Canals	Value varies depending on species of interest and mineralogy, size & other characteristics of the waterbody and its catchment.	Acid deposition on acid-sensitive catchments (mostly overlying rock types with low weathering rates, such as granites, sandstones and schists) can result in chronic acidification of runoff into drainage waters, particularly headwater streams. The ability of surface waters to withstand acid deposition is determined by the calculation of Acid Neutralising Capacity (ANC).	Effects of acid deposition on standing waters are predominantly in oligotrophic lakes in catchments underlain by granites, sandstones and schists which have low weathering rates, leading to base cation releases which are insufficient to balance deposited acidity. Oligotrophic lake acidification influences aquatic biota reducing biodiversity at all levels of the food chain, from primary producers, (aquatic algae and macrophytes) to macroinvertebrates, fish and water birds. Acidification rarely affects mesotrophic to eutrophic lakes or canals as the base cation supply is higher so sufficient to buffer the acidification. Acid episodes, driven either by high rainfall events or sea salt episodes, tend to have a less deleterious effect on water acidity in standing waters compared to streams due to the buffering effect of the larger volume of standing water.

Source: APIS [26]

Summary of Primary Air Pollutants in the UK

As of August 2024, a total of 236 (69.5%) of the 363 Local Authorities (LAs) across the UK had declared one or more AQMAs [27] which represents a slight decrease in the percentage of Local Authorities with AQMAs compared to August 2023, when 251 (69.5%) of the 361 LAs across the UK had declared one or more AQMAs [28]. Additionally, the total number of AQMAs has decreased, with 545 declared for NO_2, 75 for PM_{10} and 6 for SO_2 in August 2024 compared to 628 for NO_2, 83 for PM_{10} and 6 for SO_2 in August 2023. These changes indicate progress in air quality improvements, possibly leading to the revocation of some AQMAs as air quality objectives are met. The 'Air pollution in the UK 2023' report [27] states that " most *AQMAs in the UK are in urban areas and have been established to address the contribution to air pollution from roadside emissions of nitrogen dioxide or PM_{10}, or in some cases both*". The majority of the AQMAs declared for PM_{10} are in London (39%) and 31% in Scotland due to the more stringent AQS objective for PM_{10} adopted by Scotland.

The development of hydrogen as an energy source and the application of carbon capture technologies introduce specific air quality considerations. NO_x emissions, for instance, are a critical issue in hydrogen combustion due to the high flame temperature, which can lead to increased NO_x levels, particularly in industrial settings or for heating applications. NO_x is a precursor to ozone formation and contributes to respiratory health issues. Techniques such as staged combustion or exhaust gas recirculation (EGR) are being explored to mitigate NO_x formation during hydrogen combustion. PM_{10} and $PM_{2.5}$ emissions, while not directly produced by hydrogen, can result from associated infrastructure during production and transport. Secondary particulate emissions may arise due to wear and tear on equipment, construction activities, or leakage. Additionally, carbon capture systems themselves can emit particulates during operational phases if flue gas scrubbing systems are not optimised. These particulates contribute to ambient air quality concerns, impacting both human health and environmental conditions (Environment Agency, 2024 [9]).

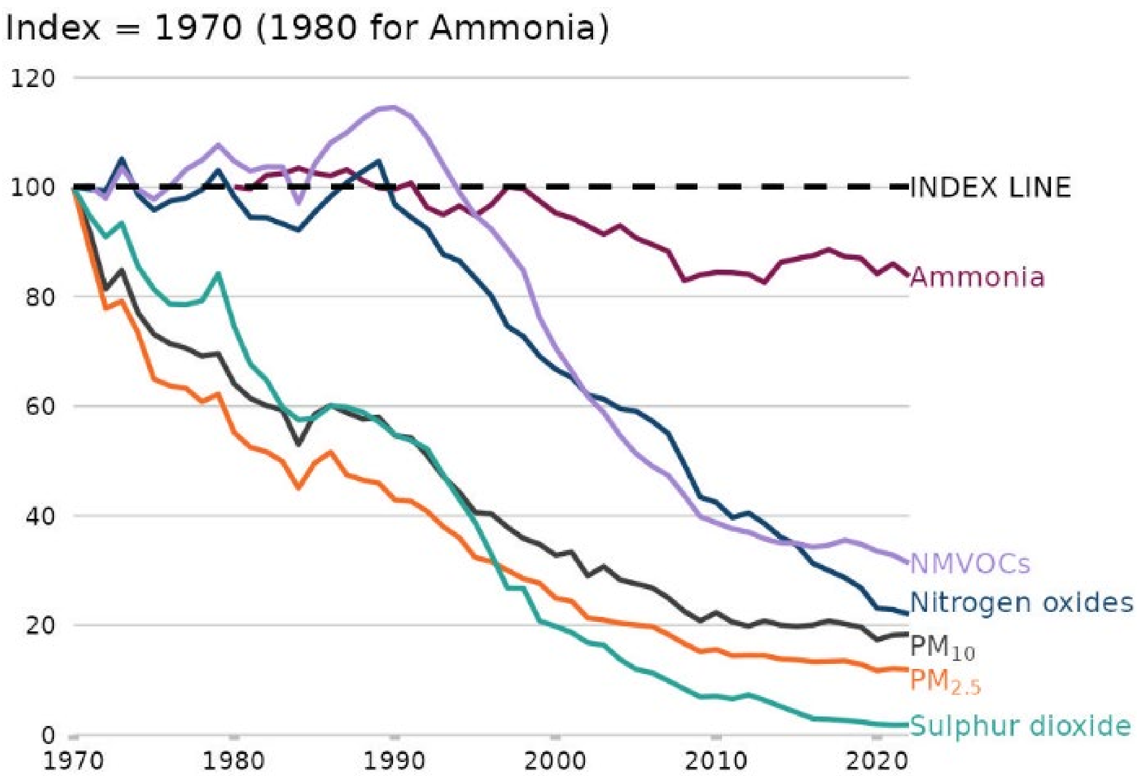
SO_2 emissions are typically minimal in hydrogen systems but can arise from upstream processes such as the production of blue hydrogen using natural gas with carbon capture, particularly if the feedstock or processes involve sulphur containing compounds. This highlights the need for stringent controls in the production processes to prevent secondary emissions.

Ammonia is another pollutant of concern, particularly in carbon capture systems. Amine-based solvents used in carbon capture can degrade into ammonia and other nitrogen-containing compounds, which can contribute to secondary particulate formation and nitrogen deposition. These emissions have implications for sensitive ecosystems, requiring robust mitigation strategies to minimise their impact. Natural England has issued guidance on nutrient neutrality, emphasising the need to consider nutrient impacts from new developments on protected habitats (Natural England, 2023 [29]). This guidance is particularly relevant to the HyNet industrial cluster, as the project encompasses regions with sensitive ecosystems, including freshwater habitats and estuaries. Increased nutrient levels, such as nitrogen and phosphorus, can lead to eutrophication, adversely affecting these environments. It's therefore crucial to implement robust mitigation strategies to minimise nutrient emissions, ensuring compliance with environmental regulations and the protection of local ecosystems.

Volatile organic compounds (VOCs), while generally low in hydrogen production, can still emerge from grey or blue hydrogen processes during storage and handling. Electrolytic hydrogen production offers a pathway to minimise VOC emissions, further supporting its role as a cleaner alternative. Hydrogen leakage, though not a pollutant in the traditional sense, can indirectly affect air quality by interacting with atmospheric radicals, influencing the formation of ozone and methane. This highlights the need for advanced containment and monitoring systems across the hydrogen lifecycle to mitigate unintended environmental impacts (Environment Agency, 2024 [9]).

The UK National Atmospheric Emissions Inventory (NAEI) estimates emissions in the UK using internationally standardised methods and administrative data from internal and external governmental sources. Emissions of air pollutants in the UK Summary [30] was initially released in 2012 and is updated each year with the latest annual statistics for six primary air pollutants: ammonia (NH_3), Non-methane volatile organic compounds (NMVOC's), NO_x, PM_{10}, $PM_{2.5}$ and SO_2. Figure 1 presents the data from the February 2024 publication and illustrates the long-term trends in UK emissions to air.

Figure 1 - Emissions of Air Pollutants in the UK



Source: Emissions of Air Pollutants in the UK Summary [30]

The index line illustrates annual emissions if they had remained constant at 1970 levels while the y-axis represents the percentage of emissions against the 1970 levels. There has been a clear reduction in atmospheric emissions for all six air pollutants since 1970. These long-term reductions relate to a number of factors, some specific to only one or two pollutants, however, the key drivers are:

- The phase-out of coal use in the UK for power generation and domestic heating;
- Implementation of emission mitigation technology, e.g. flue gas desulphurisation and NO_x reduction systems on industrial fossil fuel combustion plants; and
- Stricter legislation and regulations reducing emissions from road transport and agriculture, e.g. use of low and ultra-low sulphur diesel, Euro 1 to 6 emission limits for vehicles etc.

The same publication outlines the UK's emission reduction commitment (ERC) that are set out in the National Emission Ceilings Regulations (NECR) (2018) (HM Government, 2018 [31]). These are shorter-term air quality goals that aim to reduce annual emissions of air pollutants by a certain percentage of 2005 levels and are presented in Table 6. The UK achieved both the national and international ERC for the pollutants outlined in NECR

(2018), though the NH_3 ERC was only met after the inclusion of an agreed reduction commitment. The UK does not have an ERC for PM_{10} emissions.

Table 6. UK's compliance against ERC in 2022

Pollutant	2005 Emissions (k tonnes)	2022 Emissions (k tonnes)	2020-2029 ERC (%)	Percentage Reduction Achieved (%)	Compliance Status
Ammonia (NH_3)	280	246	8	12	Compliant
Non-Methane volatile organic compounds (NMVOC)	1123	624	32	44	Compliant
Oxides of nitrogen (NO_x) (as nitrogen dioxide (NO_2))	1696	619	55	63	Compliant
Particulate matter ($PM_{2.5}$)	109	65	30	41	Compliant
Sulphur dioxide (SO_2)	782	120	59	85	Compliant

Source: Emissions of Air Pollutants in the UK Summary [30]

The following section provides a more detailed insight into the long-term emissions of the six pollutants measured by NAEI in its most recent publication.

Emissions Data and Trends in the UK

The UK Informative Inventory Report (1990 to 2022) (HM Government, 2023 [32]) provides an overview of emissions of NH_3, NMVOC's, NO_x, PM_{10}, $PM_{2.5}$ and SO_2 in the UK from 1990 to 2022. Table 7 shows that there have been reductions in emissions of all six pollutants between 1990 and 2022.

Table 7 – UK Emissions Reductions between 1990 to 2022, and 2005 to 2022

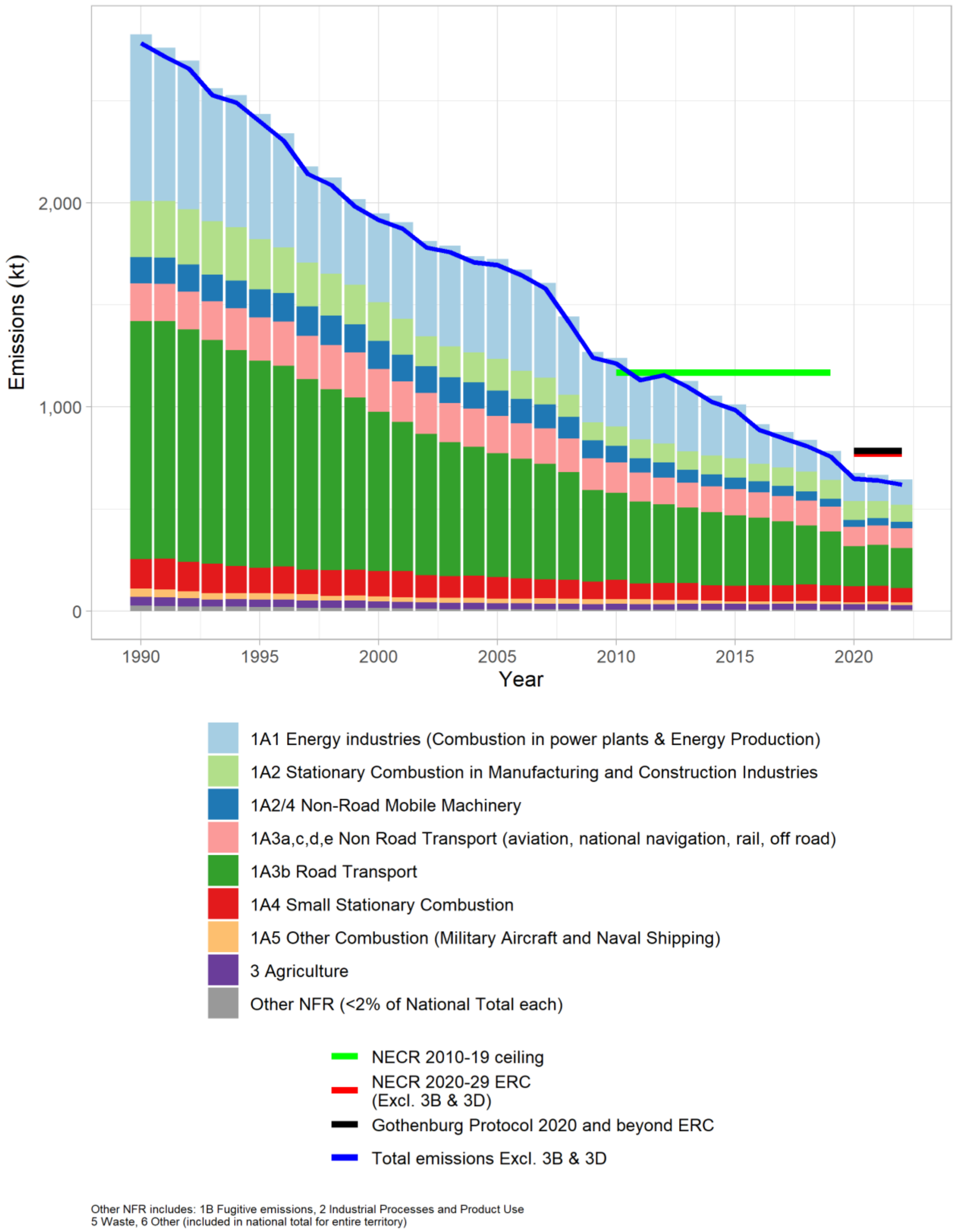
Pollutant	% Change from 1990 to 2022	% Change from 2005 to 2022
Oxides of nitrogen (NO_x) (as nitrogen dioxide (NO_2))	-69	-54
Oxides of sulphur (SO_x) (as Sulphur dioxide (SO_2))	-96	-84
Ammonia (NH_3)	-15	-7
Non-Methane volatile organic compounds (NMVOC)	-70	-36
Carbon Monoxide (CO)	-83	-57
Particulate matter (PM_{10})	-64	-34
Particulate matter ($PM_{2.5}$)	-72	-44

Source: UK Informative Inventory Report (1990 to 2022) [32]

Nitrogen Oxides

UK emissions of NO_x have shown a substantial decline since 1990. The sectors which contribute most to the NO_x emissions in the UK are energy industries (predominantly power stations) and road transport, with the latter accounting for approximately 25% of UK NO_x emissions in recent years (see Figure 2). The observed reductions in NO_x emissions are predominantly driven by legislation associated with these key sources (i.e. electricity generation and large-scale industrial combustion (e.g. the provisions of EPR (European Pressurized Reactor)) and road transport (e.g. the Euro Standards in vehicle regulation). Technological advances have also had a role in the large decreases reported from the 1990s onwards. These include the fitting of NO_x reduction technologies (such as low NO_x burners) to power stations, as well as a phasing out of coal-fired power stations in the UK and a general move towards natural gas in other sectors.

Figure 2 - Total UK NO_x emissions for 1990-2022



Source: UK Informative Inventory Report (1990 to 2022) [32]

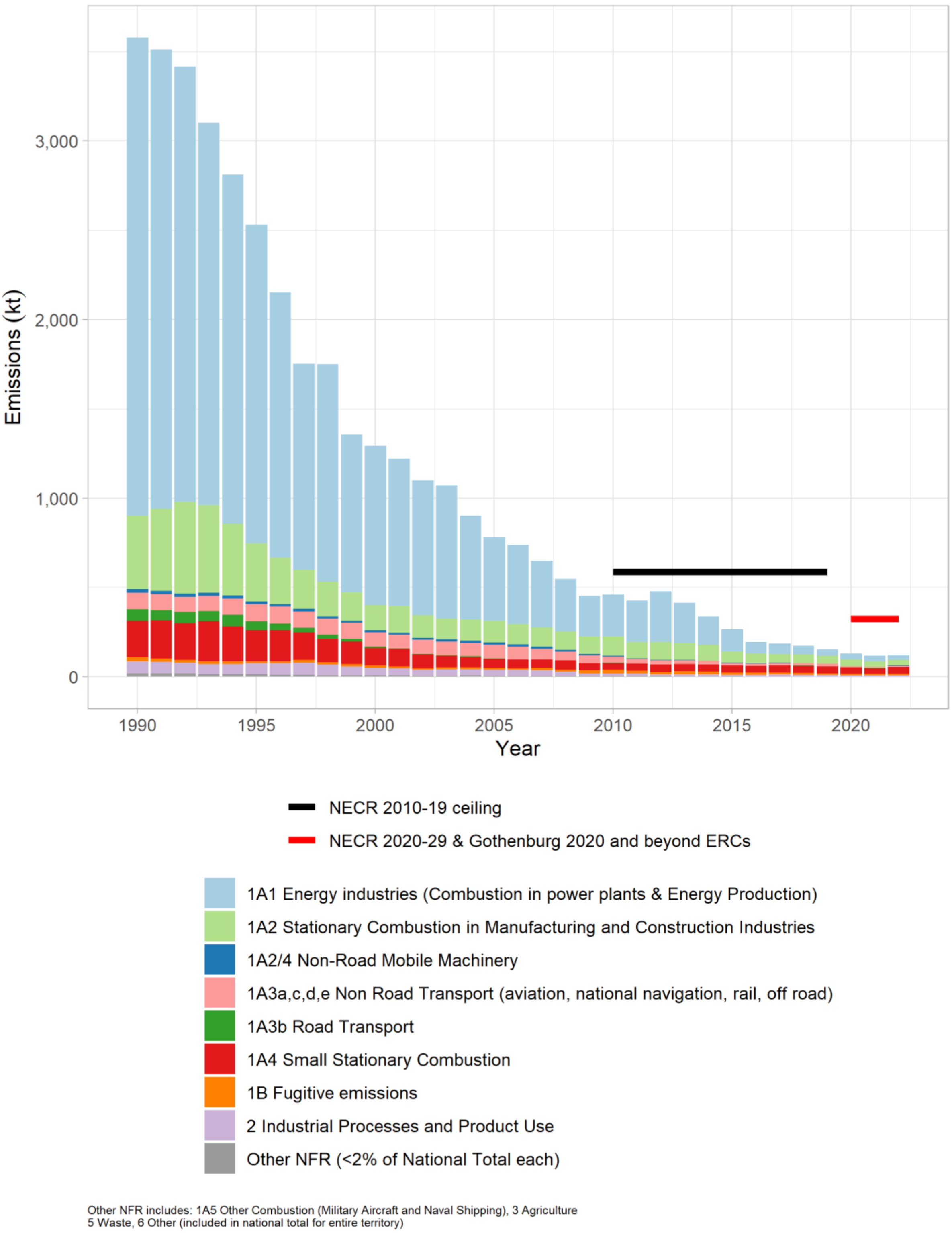
Sulphur Dioxide

Emissions of SO_2 in the UK have fallen 96% between 1990 and 2022. This is the biggest decline of all the air quality pollutants controlled by the NECR and Gothenberg Protocols.

Emissions of SO_2 in the UK measured approximately 3580kt in 1990, with the largest source being from the energy industries which accounted for 75% of total emissions. Three decades later, total SO_2 emissions measure around 120kt, with approximately 30% sourced by the manufacturing and construction industries.

The substantial reduction in SO_2 emissions over the last three decades directly links to an economic and nationwide shift away from sulphur-containing fuels such as coal. In the same period, total coal mass used nationwide fell over 93%, and in the industries where coal remained prevalent, modern emission abatements further reduced emissions. The shift away from sulphur-containing fuels was driven by the introduction of the Environmental Protection Act (1990) [33] and the Industrial Emissions Directive (2010) [34], which implemented stricter regulations and mitigations on SO_2 emissions from energy and industrial sources.

Figure 3 - Total UK SO_X emissions for 1990-2022



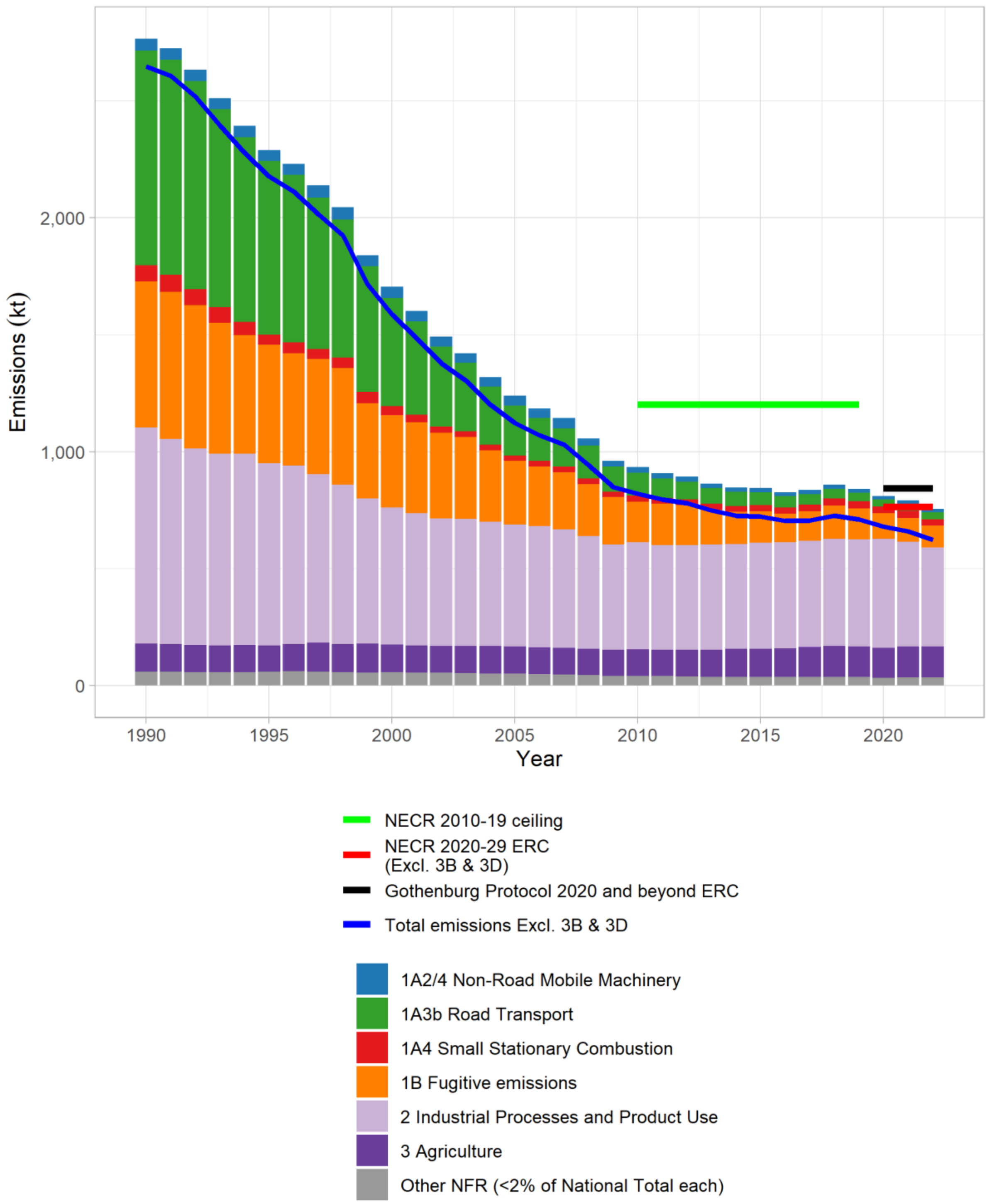
Source: UK Informative Inventory Report (1990 to 2022) [32]

Non-Methane Volatile Organic Compounds (NMVOC's)

In 1990 NMVOC's emissions measured approximately 2,754 kt, with the largest source being industrial processes, accounting for 34% of total emissions. Emissions of NMVOC's in the UK have fallen 70% between 1990 and 2022 to approximately 756 kt with industrial processes accounting for approximately 58% and so remaining the largest contributor. The industrial processes category is very broad and includes emissions from the use of domestic products that contain solvents, as well as the use of solvents by industry.

The decrease in NMVOC's can be attributed to the introduction of stricter legislative control on how NMVOC's are handled and incorporated into industry production, as well as how they are emitted into the atmosphere. Emissions from road transport have substantially decreased since 1990 due to the introduction of three-way catalytic converters and tighter controls on evaporative emissions from vehicles (EU Fuel Quality Directive 98/70/EC [35]). Coal mining was a relatively high emitter of NMVOC's in 1990 but was practically zero in 2022, largely due to coal being phased out for energy generation.

Figure 4 - Total UK NMVOC's emissions for 1990-2022 [32]



Other NFR includes: 1A1 Energy industries (Combustion in power plants & Energy Production), 1A2 Stationary Combustion in Manufacturing and Construction Industries
1A3a,c,d,e Non Road Transport (aviation, national navigation, rail, off road), 1A5 Other Combustion (Military Aircraft and Naval Shipping)
5 Waste, 6 Other (included in national total for entire territory)

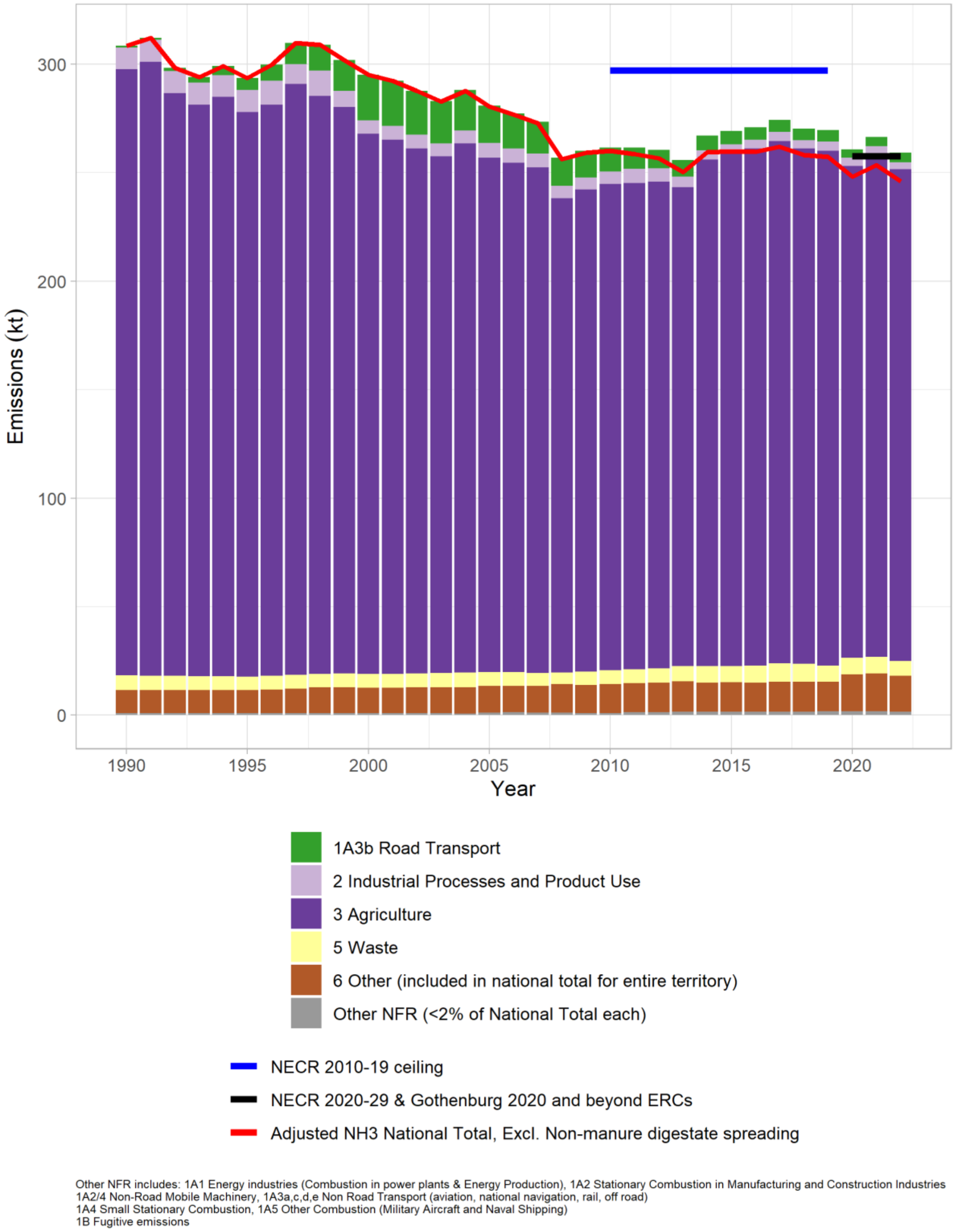
Source: UK Informative Inventory Report (1990 to 2022) [32]

Ammonia

Emissions of NH_3 reduced by 13% between 1990 (306 kt) and 2022 (259 kt) with the vast majority dominated by agricultural emissions. The breakdown of livestock waste and the use of urea-based fertilisers make up the bulk of these emissions, however this makes estimations of total NH_3 relatively uncertain compared to other pollutants since livestock is a diffuse source and not a point source.

The relatively small reduction in NH_3 emissions throughout the time period can be attributed to the increase of urea-based fertilisers marginally offsetting the decrease in some types of livestock, primarily beef cattle, turkeys and pigs and hence lower emissions from the excreta from these animals. Legislation such as the Nitrate Sensitive Areas Order (1990) [36] controlled the use of nitrogen-based fertilisers and resultant emissions, but small increases in the waste sector, from other miscellaneous sources (domestic pets, golf courses etc.), and the natural fluctuation of fertiliser price has resulted in the relatively slow reduction in NH_3 emissions in the UK.

Figure 5 - Total UK NH_3 emissions for 1990-2022 [32]



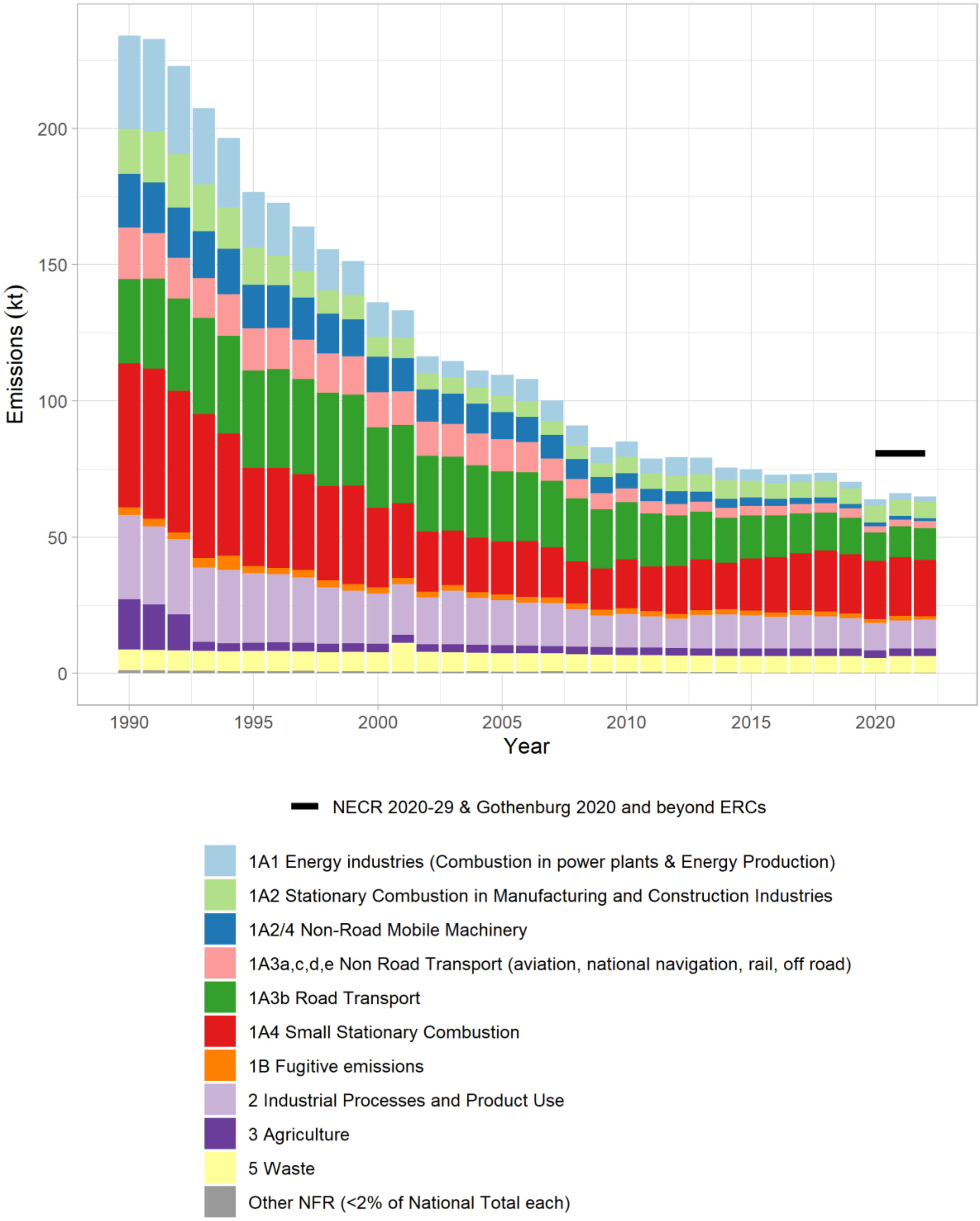
Source: UK Informative Inventory Report (1990 to 2022) [32]

Particulate Matter

Between 1990 (234.1kt) and 2022 (64.9kt), there has been a 73% reduction in total $PM_{2.5}$ emissions, however since 2002 the rate of the continued decrease has slowed. Industrial combustion contributed 10 per cent of $PM_{2.5}$ emissions while small stationary combustion represents the largest source of $PM_{2.5}$ emissions in the UK, 29% of total $PM_{2.5}$. This includes residential wood combustion primarily used for heating or cooking. Domestic wood combustion has seen an increase in popularity since the mid-2000's, probably as a solution to reduce personal heating costs amid rising gas prices, increasing by 56% between 2012 and 2022. Road transport continues to be a major source of PM emissions, as it contributed 18 per cent of total $PM_{2.5}$ emissions in 2022.

Stringent legislation has been put into place since the 1990's to control and regulate $PM_{2.5}$ emissions. The Euro Standards on diesel vehicles has helped bring the contribution of road transport to total emissions down to the point now where non-exhaust emissions of $PM_{2.5}$ are exceeding tailpipe emissions.

Figure 6 - Total UK $PM_{2.5}$ emissions for 1990-2022 [32]



Other NFR includes: 1A5 Other Combustion (Military Aircraft and Naval Shipping), 6 Other (included in national total for entire territory)

Source: UK Informative Inventory Report (1990 to 2022) [32]

Ecology in the UK

The Joint Nature Conservation Committee (JNCC) [37] reports that in 2020 more than a third (36%) of UK land area (91,000 km^2) is sensitive to acidification, 38% (94,000 km^2) is sensitive to eutrophication, with many areas (72,000 km^2) are sensitive to both. In 2020, acid deposition exceeded critical loads in 45% of sensitive terrestrial habitats, which is a 32% decrease since 2003 [37]. Eutrophication exceeded critical loads in 86% of sensitive habitats, an 8% decrease since 2003.

Over the longer term (2003-2020), the terrestrial habitat areas at risk of acid and nitrogen deposition have declined, however, there is generally a time-lag between deposition reductions and flora/fauna recovery, which means total ecosystem recovery over the period doesn't always correlate.

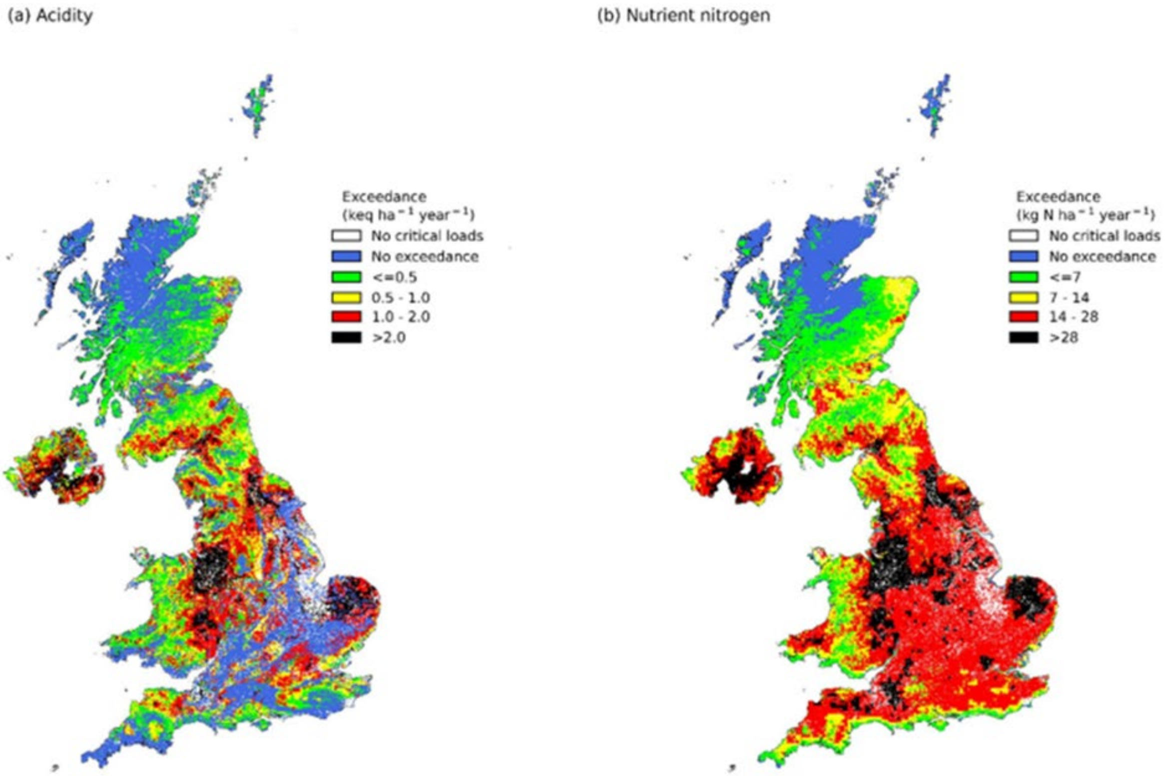
The development of low-carbon industrial projects, such as HyNet, introduces specific challenges and opportunities related to nitrogen deposition. While hydrogen production and carbon capture technologies aim to reduce greenhouse gas emissions, they can also contribute to localised nitrogen emissions, primarily through the release of NO_x during hydrogen combustion and energy-intensive industrial processes. NO_x emissions are precursors to nitrogen deposition, which can exacerbate eutrophication in sensitive ecosystems, potentially impacting habitats and species of high conservation value (Environment Agency, 2024 [9]).

Furthermore, NH_3 emissions from industrial activities and amine-based carbon capture technologies also contribute to nitrogen deposition. Amine-based solvents can degrade into ammonia and other nitrogen-containing compounds, requiring robust mitigation strategies to minimise impacts. Nitrogen deposition can have cascading effects on biodiversity and soil health, with sensitive habitats like Special Areas of Conservation (SACs) and Sites of Special Scientific Interest (SSSIs) particularly vulnerable (Natural England, 2023 [38]).

To address these challenges, critical mitigation strategies include the use of advanced NO_x reduction techniques (e.g., selective catalytic reduction), optimising carbon capture systems to limit ammonia slip, and ongoing monitoring to ensure emissions remain within acceptable thresholds. The JNCC's latest data highlights the need for careful management of nitrogen emissions to protect ecosystems while facilitating sustainable industrial growth (Environment Agency, 2024 [9]).

Figure 7 displays UK spatial coverage information for acidity and nutrient nitrogen critical load exceedances in the UK for 2022. As illustrated, the majority of terrestrial areas exceed the acid and nutrient nitrogen critical load in the UK.

Figure 7 - Acidity and Nutrient Nitrogen Critical Load Exceedances in the UK in 2022 [39]



Source: Join Nature Conservation Committee (JNCC) [22]

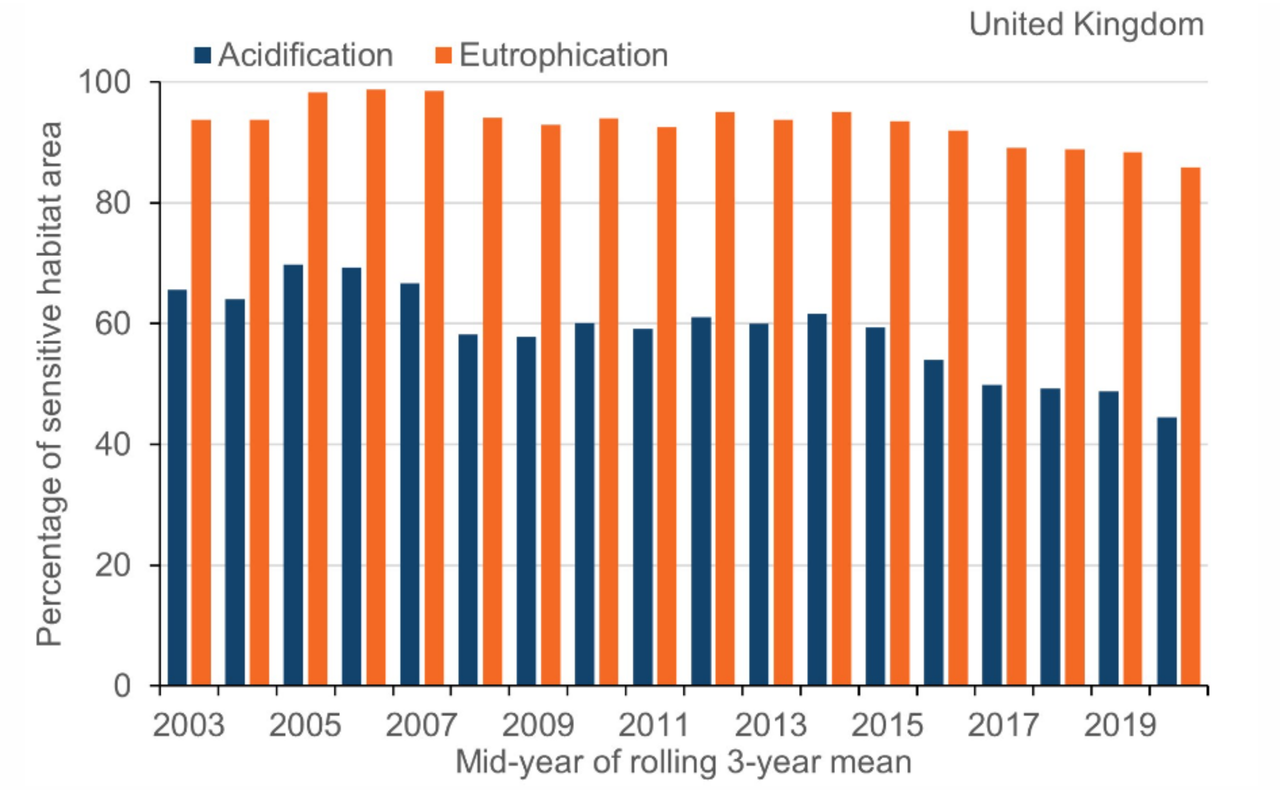
The latest update to the JNCC report [22] found that short-term and long-term sensitivity to acid and nitrogen deposition was improving, as outlined in Table 8 and illustrated in Figure 7.

Table 8. Change in Area of Sensitive Terrestrial UK Habitat Exceeding Critical Loads

Deposition	Long term	Short term	Latest available year (2020)
Area affected by acidity	Improving 2003-2020	Improving 2015-2020	Decreased
Area affected by nitrogen	Improving 2003-2020	Improving 2015-2020	Decreased

Source: Join Nature Conservation Committee (2023) [37]

Figure 8 - Percentage area of sensitive terrestrial UK habitats exceeding critical loads for acidification and eutrophication, 2003 to 2020



Source: Join Nature Conservation Committee (2023) [37]

Table 9 provides a summary of relevant critical load and critical level exceedances for the UK and also breaks down into constituent countries for a more detailed view.

Table 9. Exceedances of Nutrient Nitrogen Critical Loads and NH_3 Critical Levels for Sensitive Habitats (SAC's and SSSI's) in 2020.

Nitrogen Critical Load Exceedance	England	Wales	Scotland	NI	UK
N-sensitive area exceeded (%)	95.1	87.6	34.0	81.2	57.6
Excess N for habitats kgN/ha/yr	11.5	8.1	1.8	7.3	5.2
SAC sites exceeded (%)	94.4	94.9	76.1	98.0	87.9
SSSI sites exceeded (%)	85.9	97.1	71.5	88.3	84.8
NH_3 Critical Level Exceedance (%)	**England**	**Wales**	**Scotland**	**NI**	**UK**
Land area exceeding 1 μg/m^3	87.9	56.3	17.9	90.8	62.9
Land area exceeding 3 μg/m^3	6.3	1.0	0.1	27.3	5.1
N-sensitive habitat exceeding 1 μg/m^3	64.6	28.4	3.2	75.2	25.4
N-sensitive habitat exceeding 3 μg/m^3	1.9	0.1	0.0	9.2	1.0

SAC sites exceeding 1 μg/m^3	91.3	72.9	17.1	90.7	60.6
SAC sites exceeding 3 μg/m^3	11.3	4.7	0.0	18.5	7.7
SSSI sites exceeding 1 μg/m^3	87.3	61.8	24.5	88.6	70.4
SSSI sites exceeding 3 μg/m^3	5.8	2.7	0.4	16.3	4.7

Source: Join Nature Conservation Committee (2020) [40]

NH_3 is a key pollutant involved in nitrogen deposition, which causes a cascade of environmental effects. Over the last twenty years, emissions of NH_3 have remained fairly level in comparison to some other atmospheric pollutants, as discussed in the previous section. The table above provides clarity to the large proportion of sensitive habitats, SAC's and SSSI's that are exceeding the relevant NH_3 emission targets. Future forecasts of nitrogen deposition rates are very difficult to quantify because the process is contingent on a number of natural processes that are extremely difficult to predict. Table 10 shows a comparison of NH_3 emission totals for 2017 and 2030 baseline scenarios and can be loosely correlated to nitrogen deposition rates.

Table 10. UK NH_3 emission totals by major sector

Scenario	2017	2030 BAU (WM)		2030 NAPCP+DA (NECR NO_x)	
	2017 Baseline (kt NH_3)	(kt NH_3)	(%) difference to 2017	(kt NH_3)	(%) difference to 2017
Cattle	115.8	112.3	-3	94.9	-18
Sheep	9.6	9.0	-6	9.0	-6
Pigs	18.6	19.1	3	17.1	-8
Poultry	37.7	38.8	3	34.6	-8
Mineral fertilizer	44.9	43.5	-3	28.7	-36
Horses, Goats and Deer	1.4	1.4	0	1.4	0
Non-Agric emissions	61.4	67.9	11	67.9	11
Total	289.3	292	1	253.6	-12

Source: Join Nature Conservation Committee (2020) [40]
Notes: Business as Usual (BAU), National Air Pollution Control Programme (NAPCP), Devolved Administration (DA), With Measures (WM), National Emissions Ceilings Regulations (NECR).

The HyNet Industrial Cluster

The primary aim of the HyNet project is to provide a low-carbon future for the northwest of the UK by removing carbon dioxide emissions from heavy industry, via infrastructure to capture, transport, and securely store carbon dioxide emissions and providing regionally produced hydrogen for industrial processes and transportation.

Operators plan to transition from natural gas to hydrogen, either by utilising the planned hydrogen supply pipeline or by producing hydrogen for their own use. The HyNet project will upgrade and develop both existing infrastructure and new infrastructure. This includes underground pipelines, hydrogen production plants, onshore hydrogen storage in salt caverns and offshore carbon dioxide storage in depleted oil and gas reservoirs, which have been identified as secure and reliable storage sites for captured CO_2.

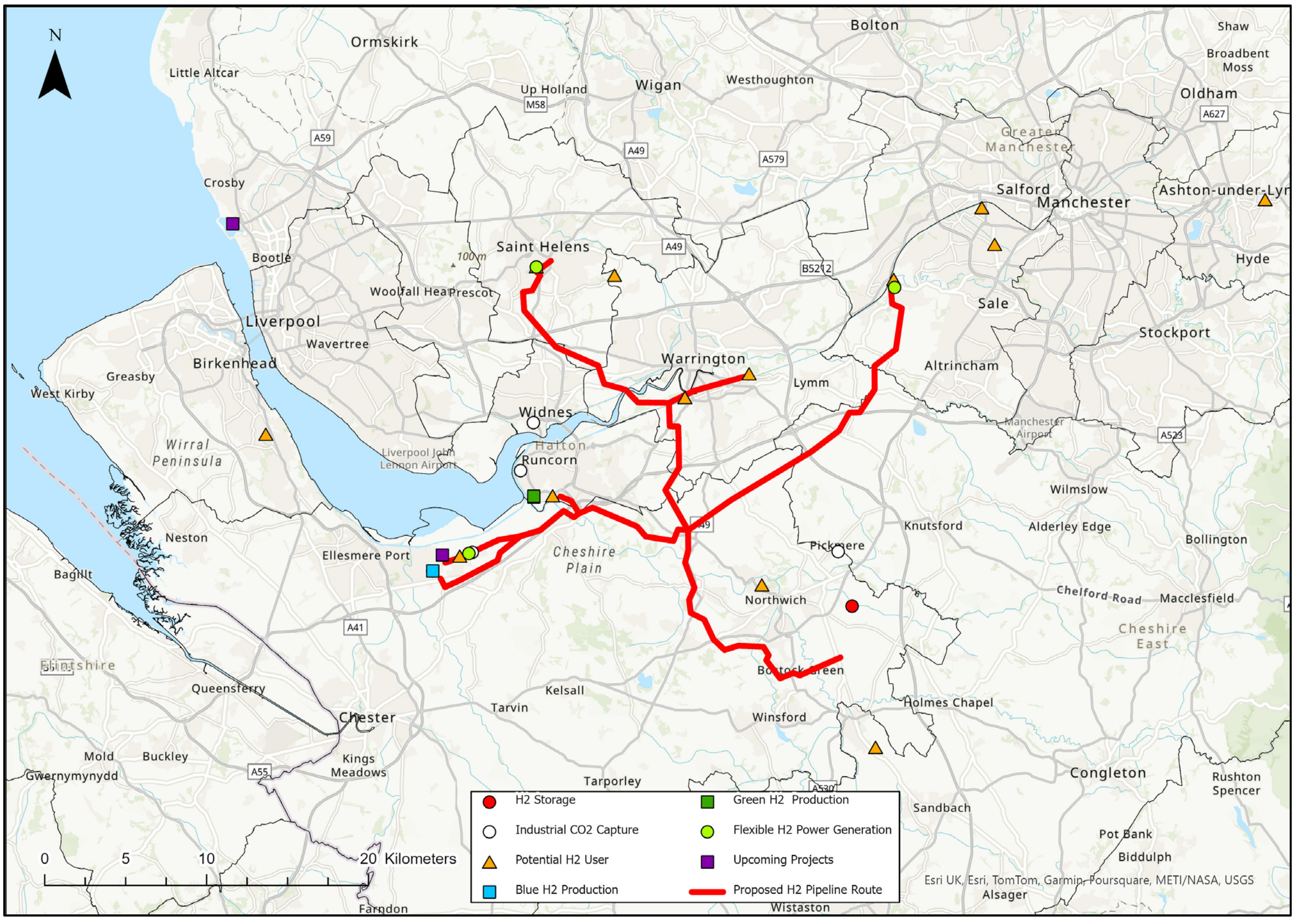
The different elements of the HyNet project

The hydrogen pipeline, being developed by Cadent, consists of over 62 miles of new underground pipeline to form a major part of the HyNet Project. The pipeline is currently going through the Development Consent Order (DCO) planning process which covers planning applications which are deemed to be Nationally Significant Infrastructure Projects (NSIPs) i.e. major infrastructure projects in the fields of energy, transport, water, wastewater, and waste. Figure 9 illustrates the extent of the current DCO application, the permanent elements included in the proposal that was subject to the third stage of public consultation, which concluded on 19th November 2024. This consultation, conducted over a period of approximately five weeks, sought public feedback, and is currently under review at the time of writing. A final application for development consent is anticipated to be submitted to the Planning Inspectorate and the Secretary of State for Energy Security and Net Zero in Spring 2025.

Hydrogen will be manufactured in the North West at the Stanlow Manufacturing Complex by EET Hydrogen. The low carbon hydrogen production plant will supply local industry with locally produced hydrogen via the proposed hydrogen pipeline. As production increases, the network of industries supplied will expand. HyNet partners INOVYN are repurposing salt caverns in the Northwich area of Cheshire which currently store natural gas, to store 35,000 tonnes hydrogen, providing a secure supply of home-grown energy and enable us to manage peaks and troughs in energy demand.

Over 40 organisations have indicated an interest in decarbonising their site using hydrogen from the HyNet pipeline, with HyNet already having completed successful demonstrations at Pilkington Glass and Unilever sites on how the switch over from natural gas to hydrogen could work.

Figure 9 - Current Extent of the HyNet Hydrogen Pipeline



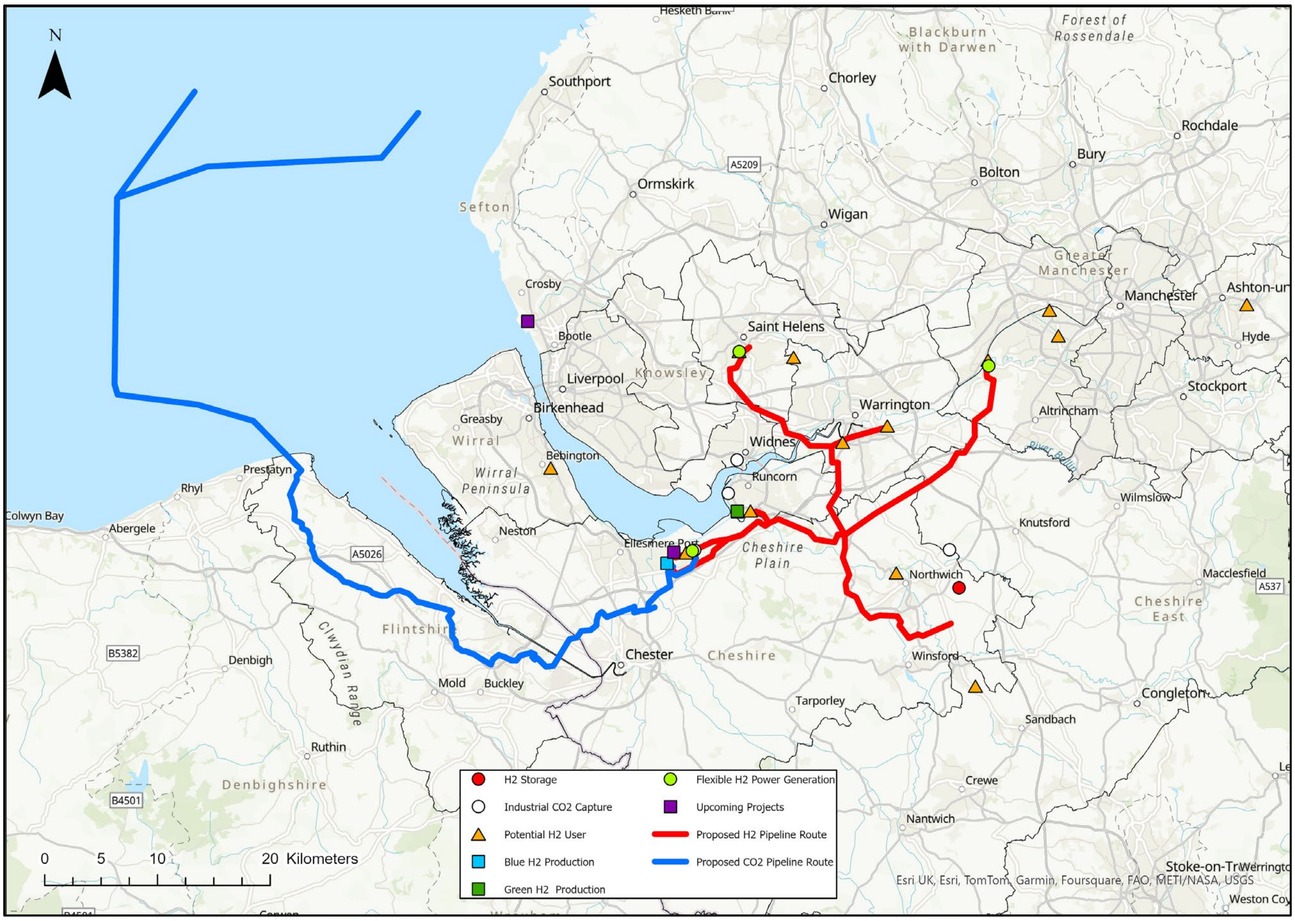
Cadent, HyNet North West Hydrogen Pipeline interactive map. Available from: [Cadent Hynet NWHP]

In addition to hydrogen infrastructure, HyNet is developing a dedicated network for carbon dioxide capture, transport, and storage. HyNet partner, Eni is supporting those sectors which are hard to decarbonise by repurposing and expanding the network of underground pipes. These pipelines will be used to transport carbon dioxide captured by Carbon Capture plants fitted to major industrial facilities which cannot convert to pure hydrogen use across the North West and North Wales and transport it for permanent storage in almost-empty gas fields under the sea in Liverpool Bay.

The onshore section of the proposed carbon capture pipeline, shown in Figure 10, is based on a DCO submitted in September 2022. Eni, as the CO_2 transportation and storage operator for the HyNet project, has indicated that both its Marine Licence application and Carbon Storage permits are currently under review.

The EET Hydrogen Stanlow Manufacturing Complex is anticipated to start operation in 2027 and will employ a combination of Gas Heated Reforming (GHR) and Auto Thermal Reforming (ATR). In these processes, natural gas reacts with steam and oxygen in the presence of a catalyst to produce synthesis gas (a mixture of hydrogen, carbon monoxide, and carbon dioxide), which is further processed to produce Blue Hydrogen. This site is 350 MW in size and will employ a Carbon Capture system to capture the 600,000 tonnes of CO_2 per year produced as a result of the SMR process. This CO_2 will then be transported via Eni's carbon capture pipeline for permanent storage in the depleted natural gas fields.

Figure 10 - Current Extent of the HyNet Project with Carbon Capture Pipeline included



Hydrogen pipeline: Cadent, HyNet North West Hydrogen Pipeline interactive map. 2024. Available from: Cadent Hynet NWHP
Carbon dioxide pipeline: Onshore portion- WSP on behalf of Liverpool Bay CCS Limited, 2022. Available from: LocaTion Plan
Offshore portion- eni, HyNet carbon dioxide transportation and storage project – Offshore. Available from: HyNet Offshore

Existing Air Quality in the HyNet Area

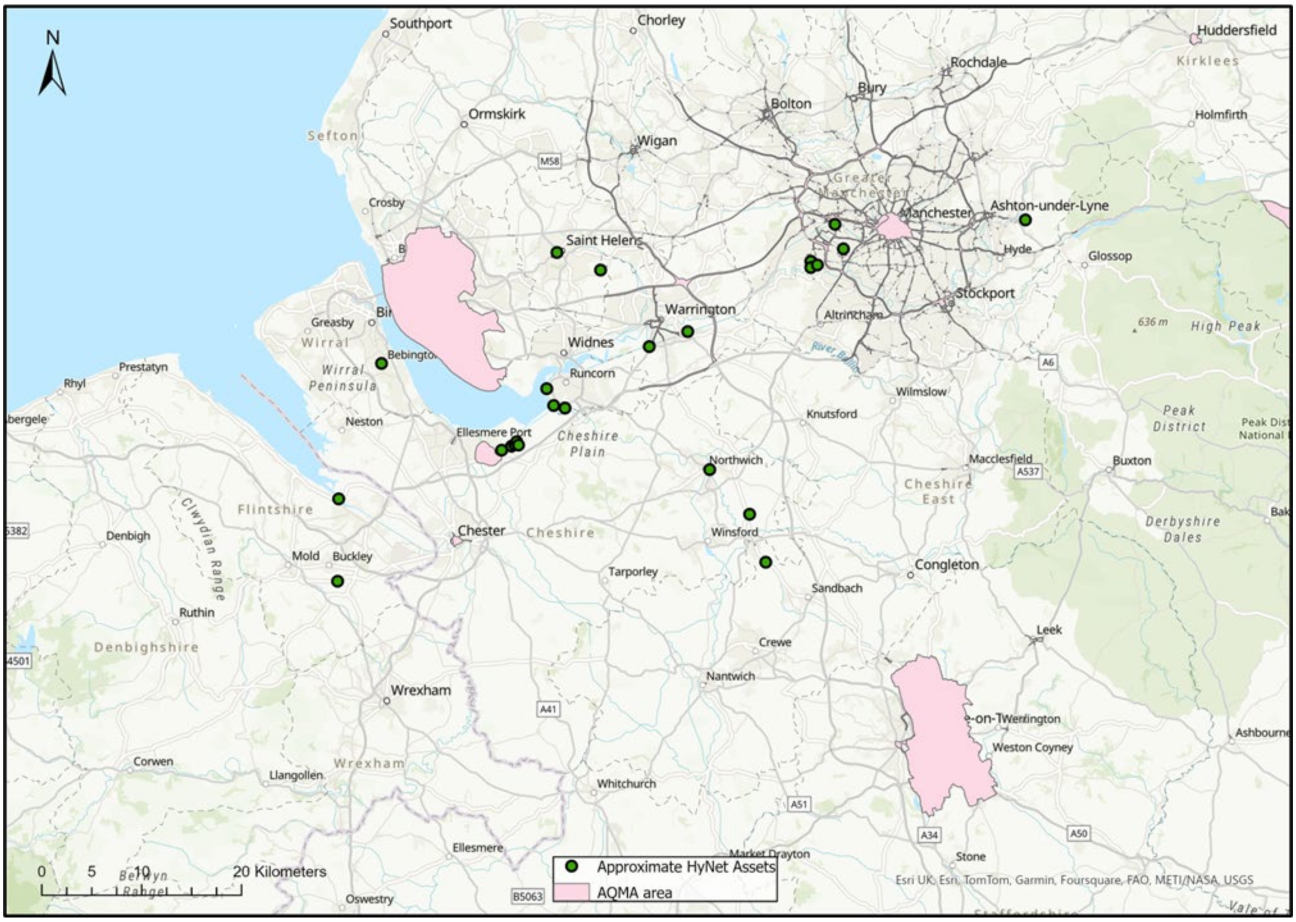
In the UK, the responsibility for meeting air quality limits is assigned by the UK Government to the national administrations in England, Wales, and Northern Ireland. The Department for Environment, Food and Rural Affairs (Defra) coordinates the assessment and development of air quality plans for the entire UK.

Under the Environment Act 1995, the UK is required to establish a national AQS, which outlines air quality standards, objectives, and measures for improving ambient air quality. This strategy details the UK's AQS objectives, and the actions needed at both national and local levels to address air quality issues. Part IV of the Environment Act 1995 mandates that local authorities in the UK regularly review air quality in their areas and designate an AQMA where AQS objectives are exceeded at locations with relevant human exposure. Following the declaration of an AQMA an air quality action plan must be developed, outlining measures to reduce pollution. These plans are essential for achieving air quality limit values at the local level.

The councils that have an asset site planning to be connected to the Hynet Industrial Cluster are Cheshire West and Chester; Cheshire East; St Helens; Halton; Warrington;

Wirral; Tameside and Trafford (the latter two are part of the Greater Manchester Combined Authority (GMCA)). Table 11 presents the details of the AQMAs which have been declared by the councils that fall within the HyNet Industrial Cluster as illustrated in Figure 11 below. Halton Borough Council had declared two AQMAs due to NO_2 exceedances, but both of these were revoked in November 2023. Wirral does not have any AQMA's declared.

Figure 11 – AQMA's in and around the HyNet Industrial Cluster extent



DEFRA, UK Air Information Resource (AIR). Available from: AQMAs interactive map

Table 11. AQMAs declared by Councils within the HyNet Industrial Cluster

Local Authority	AQMA Name	Pollutants	Date Declared	Date Amended
Cheshire West and Chester Council	Whitby Rd/Station Rd AQMA	NO_2	16/05/2005	-
	Frodsham AQMA Cheshire West and Chester	NO_2	27/11/2015	-
	Thornton le Moors AQMA No. 4	SO_2	30/09/2016	-
	Chester City Centre AQMA (No.5)	NO_2	23/05/2017	-
	M6 AQMA No.1	NO_2	30/04/2009	-

St Helens Metropolitan Borough Council	Newton High Street AQMA (No.2)	NO_2	30/04/2009	-
	AQMA No. 3 Borough Rd	NO_2	30/11/2011	-
	AQMA No.4 (Reflection Court)	NO_2	30/11/2011	-
Trafford Metropolitan Borough Council	Greater Manchester Combined Authority AQMA	NO_2	01/01/2005	01/05/2016
Cheshire East Borough Council	AQMA West Road	NO_2	01/05/2005	Intended to be revoked
	AQMA A34/A54 Rood Hill	NO_2	01/05/2005	Intended to be revoked
	AQMA Lower Heath	NO_2	01/04/2008	Intended to be revoked
	AQMA A5022/A534	NO_2	01/04/2008	Intended to be revoked
	AQMA Hospital Street	NO_2	16/12/2006	Intended to be revoked
	AQMA A6 Market Street	NO_2	01/04/2010	-
	AQMA A523 London Road	NO_2	01/04/2010	Intended to be revoked
	AQMA Chester Road, Middlewich	NO_2	01/10/2017	Intended to be revoked
	AQMA Hibel Road, Macclesfield	NO_2	01/10/2017	Intended to be revoked
	AQMA Broken Cross, Macclesfield	NO_2	01/10/2017	Intended to be revoked
	AQMA A533 Lewin Street, Middlewich	NO_2	10/10/2019	Intended to be revoked
	AQMA A537 Chelford Road, Knutsford	NO_2	10/10/2019	Intended to be revoked
Tameside Metropolitan Borough Council	Greater Manchester Combined Authority AQMA	NO_2	01/01/2005	01/05/2016
Warrington Borough Council	Motorway AQMA	NO_2	2001	Intended to be revoked
	Warrington AQMA	NO_2	2016	Intended to be revoked

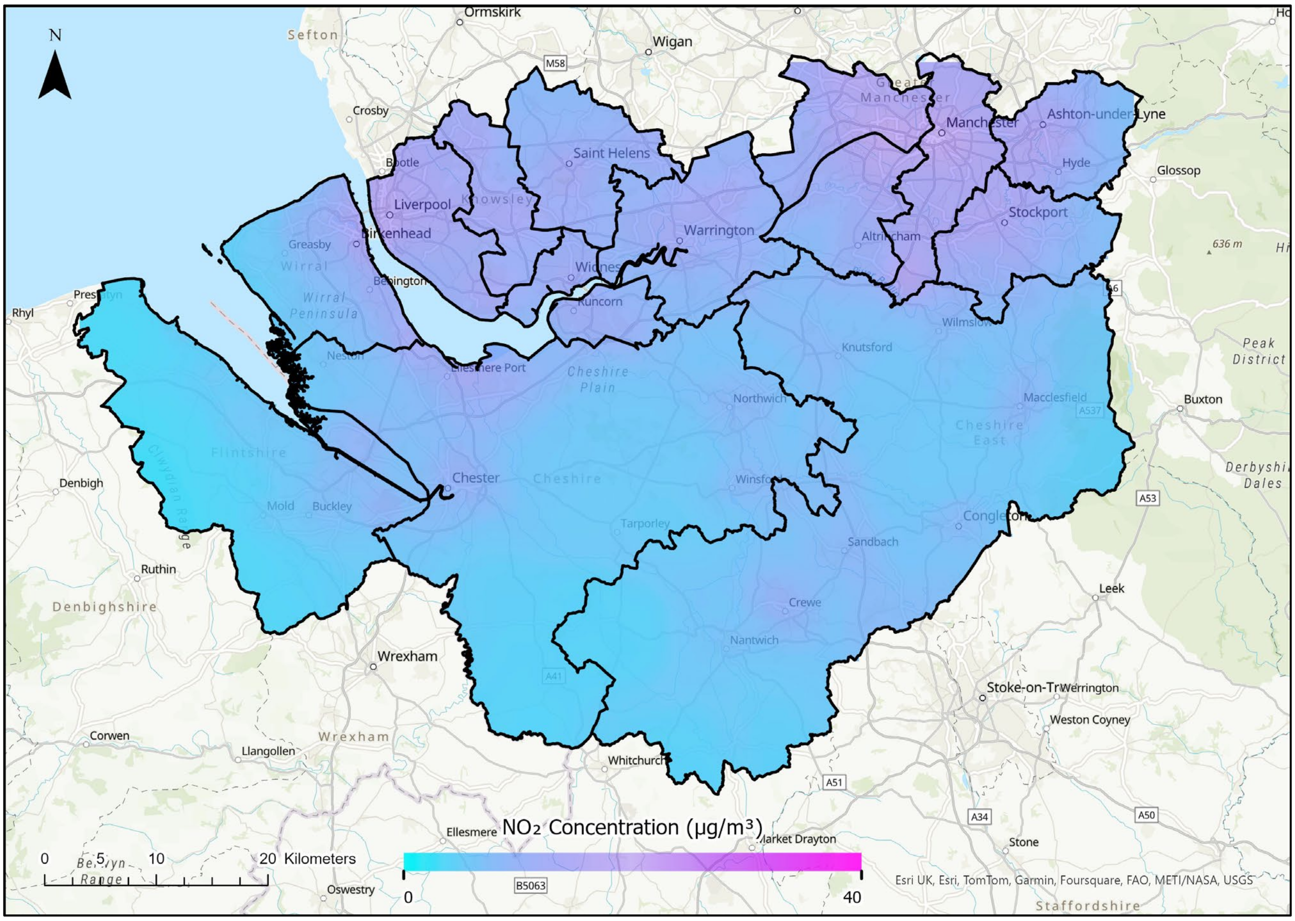
Figures 12 to 15 present a series of maps generated using ArcGIS Pro, illustrating the background concentrations of key pollutants associated with industrial activities in the

HyNet area, including council areas adjacent to those that contain existing or proposed HyNet assets. These maps depict annual mean concentrations and offer a detailed geographic assessment of pollution levels, with a spatial resolution of 1 km x 1 km. The background data were sourced from Defra's website as .csv files, which were subsequently processed in the GIS software and converted into point shapefiles. To create the continuous spatial coverage shown in the figures, interpolation tools were applied, and the resulting data were clipped to align with the relevant HyNet borough boundaries.

The data used for Figures 12 to 15 are derived from Defra's background maps, which include projections for 2024 based on a base year of 2021. These maps are periodically updated by Defra to incorporate changes in underlying datasets, such as emission factors and policy developments. However, the projections for 2024 are based on assumptions made during the COVID-19 pandemic and may not fully account for the short- or long-term impacts on emissions caused by behavioural changes during national or local lockdowns.

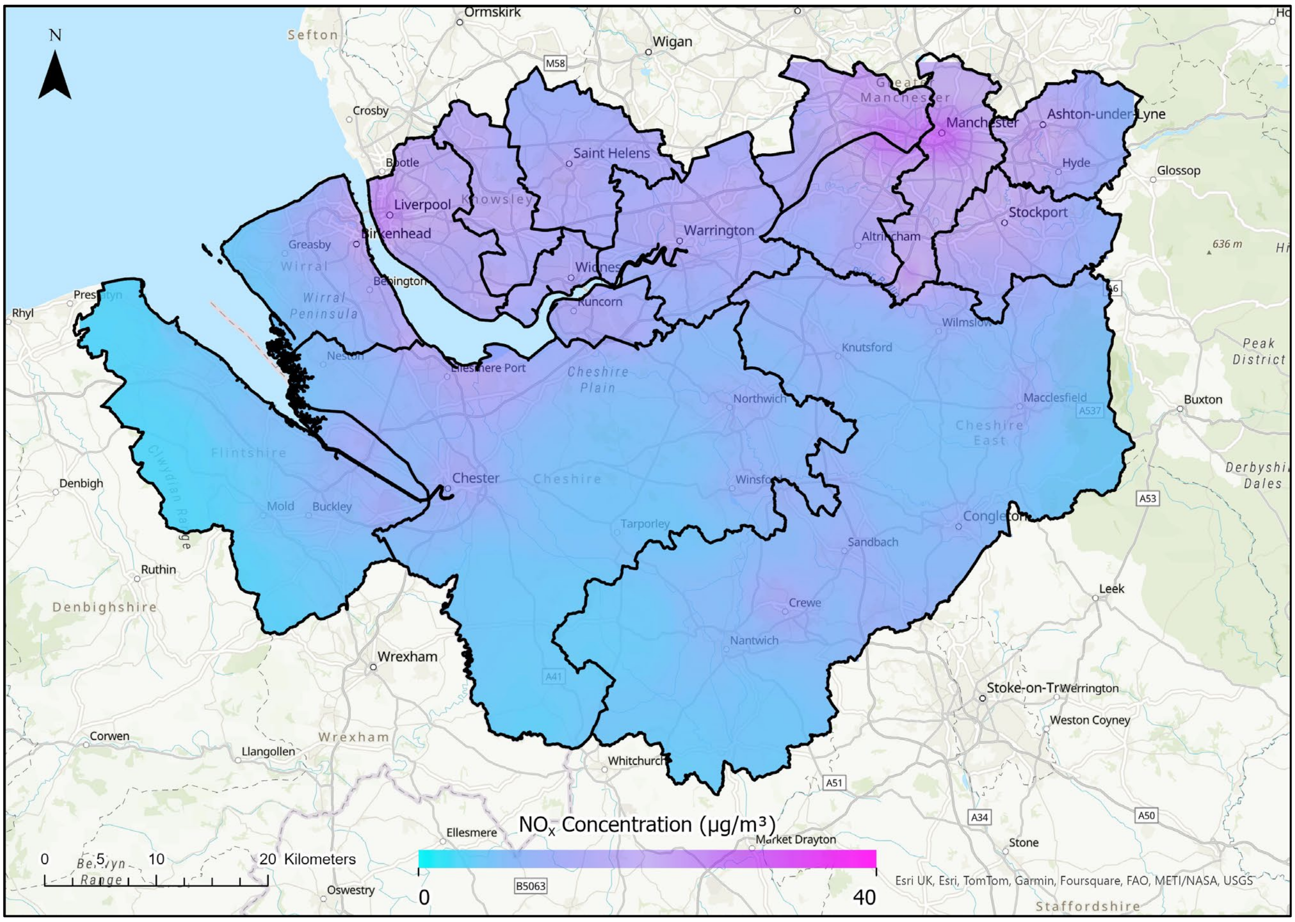
The primary purpose of these background maps is to provide estimates of pollutant concentrations, specifically NO_x, NO_2, PM_{10}, and $PM_{2.5}$, for air quality assessments. These estimates are essential for understanding the contribution of local sources to overall pollution levels, supporting comprehensive evaluations of air quality across the HyNet area.

Figure 12 - Background NO_2 Concentrations (annual mean)



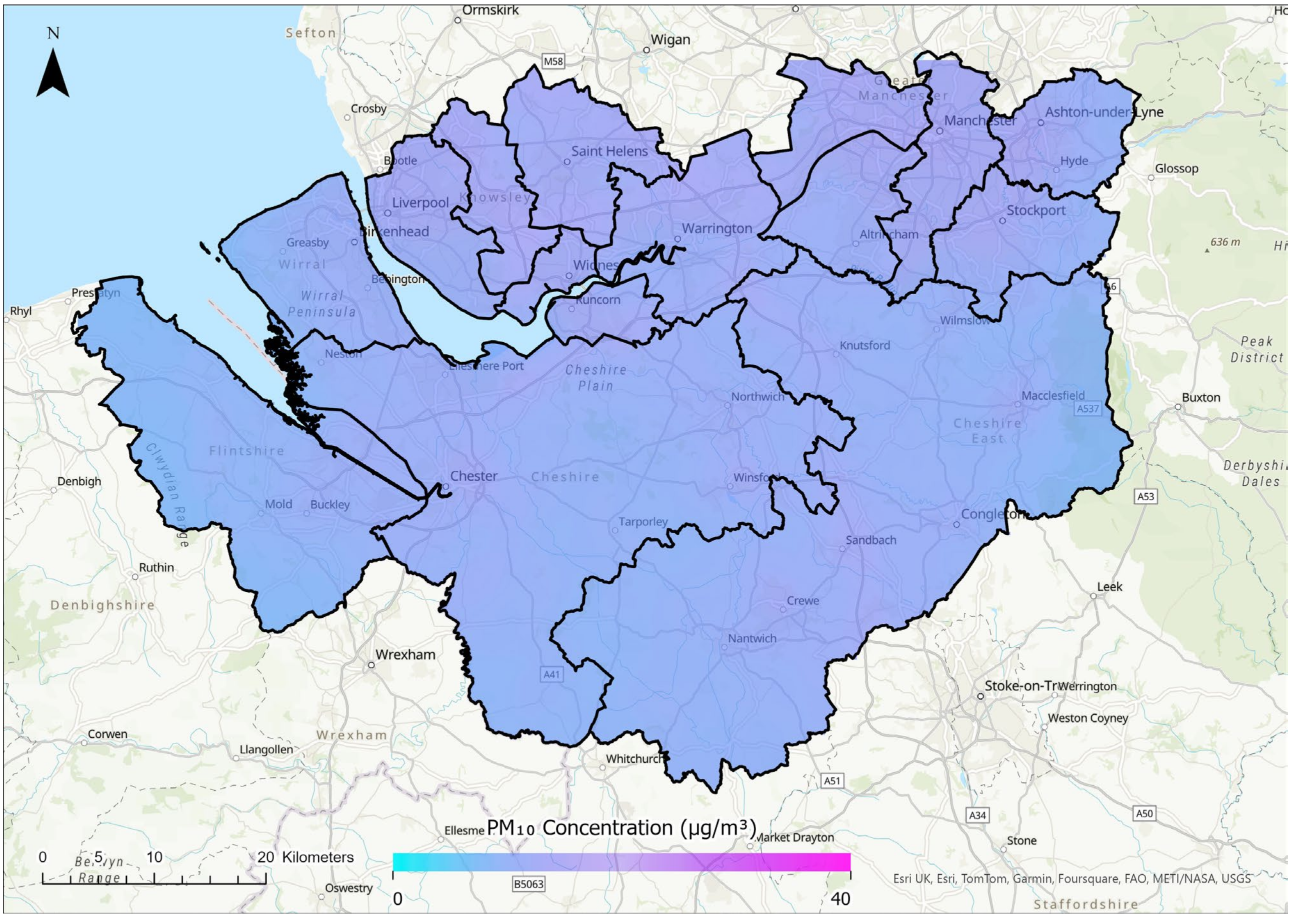
DEFRA, UK Air Information Resource (AIR). Available from: [Background Mapping data for local authorities - Defra, UK]

Figure 13 - Background NO_X Concentrations (annual mean)



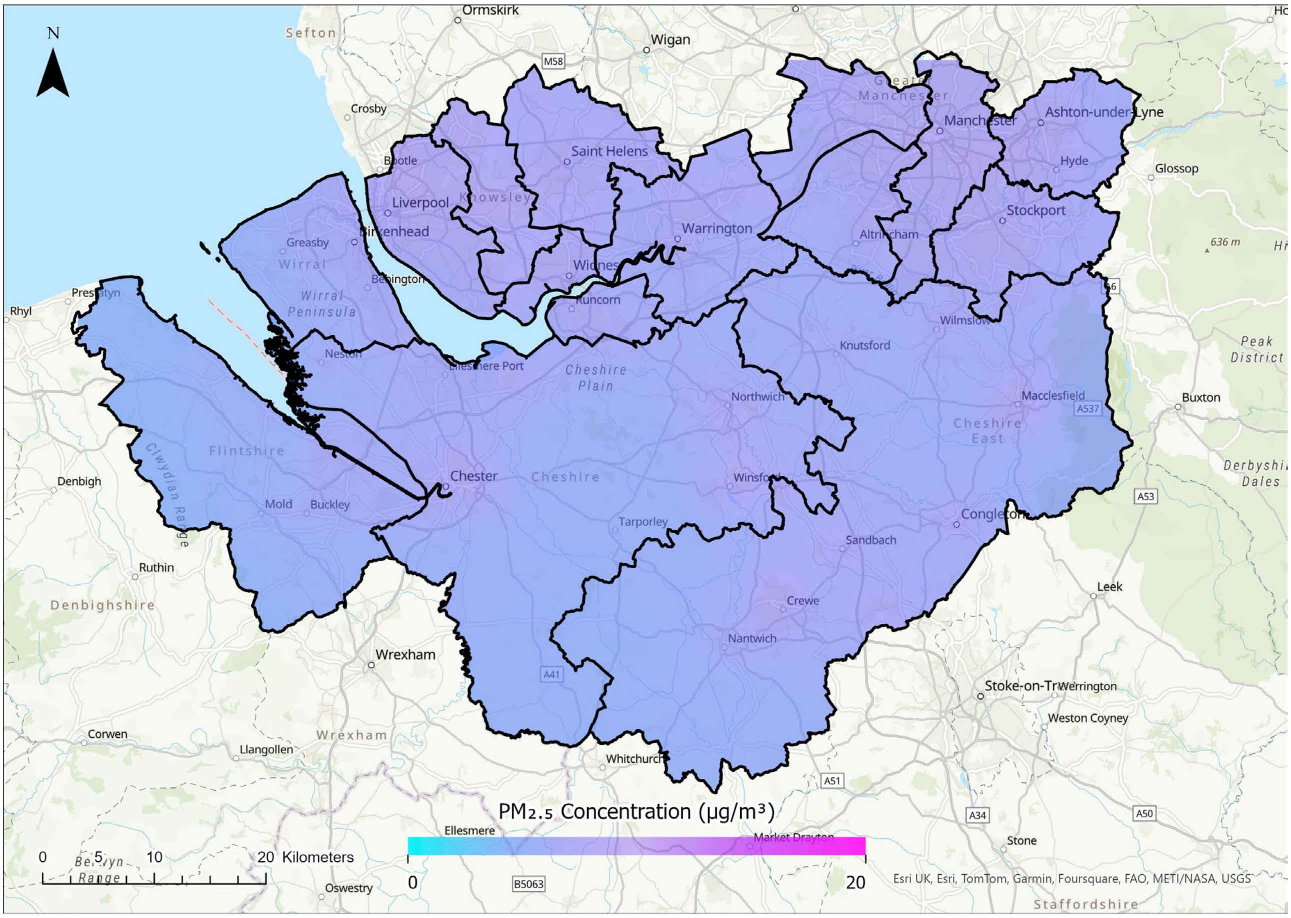
DEFRA, UK Air Information Resource (AIR). Available from: [Background Mapping data for local authorities - Defra, UK]

Figure 14 - Background PM_{10} Concentrations (annual mean)



DEFRA, UK Air Information Resource (AIR). Available from: [Background Mapping data for local authorities - Defra, UK]

Figure 15 - Background $PM_{2.5}$ Concentrations (annual mean)



DEFRA, UK Air Information Resource (AIR). Available from: [Background Mapping data for local authorities - Defra, UK]

Figure 16 and Figure 17 were generated using background data downloaded from the Air Pollution Information System (APIS) and are based on the three-year mean of estimated concentration for 2020 to 2022[1]. These pollutants are critically important to evaluate due to their potential impact on human health and sensitive ecological habitats.

[1] The selection of the years 2020 to 2022 for analysis acknowledges the potential variability in emissions due to the Covid-19 pandemic and its aftermath. Contrary to many regions globally where air quality data might have been significantly influenced by the pandemic due to changes in industrial activity and transportation patterns, it was determined that such effects were not pronounced in this area.

Figure 16 - Background SO_2 Concentrations

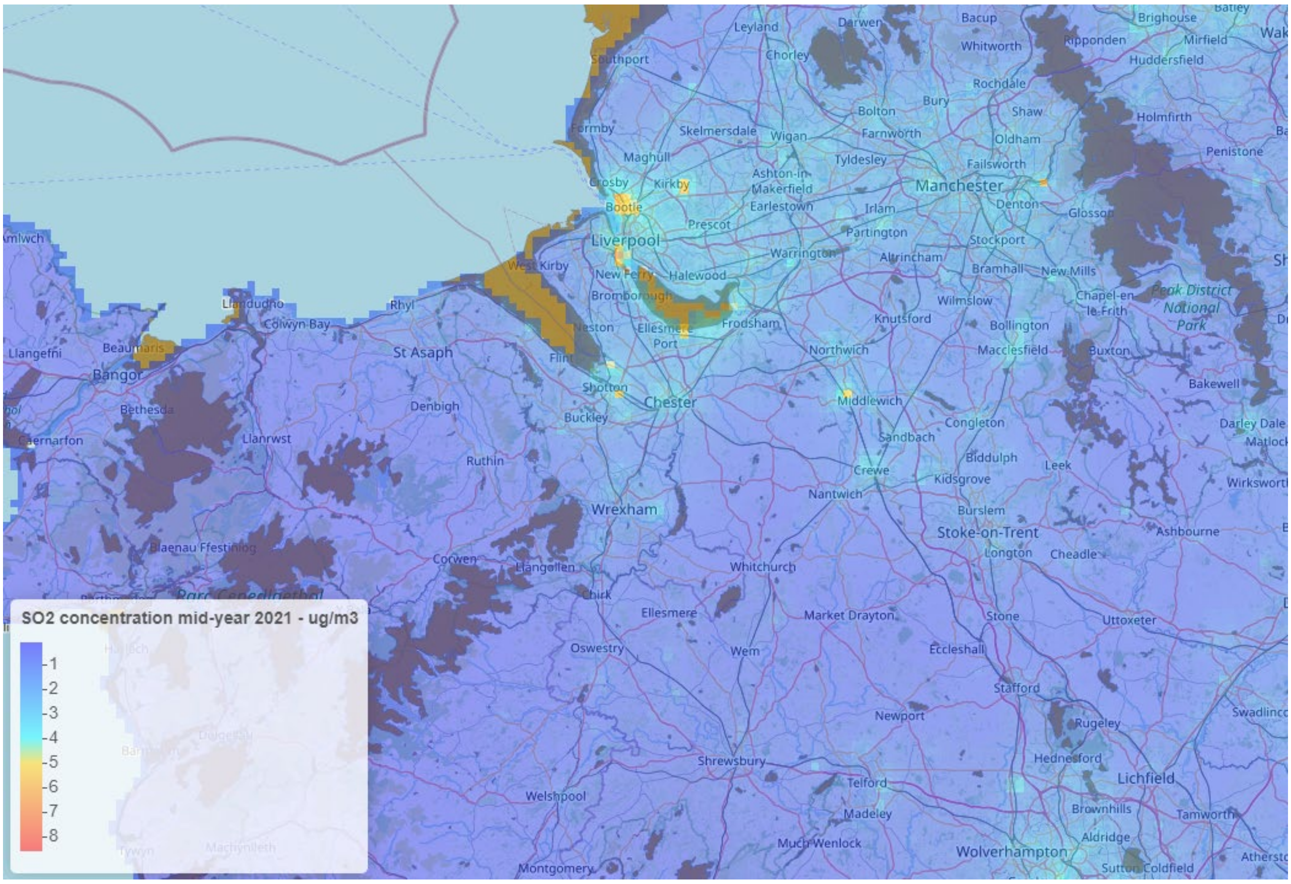
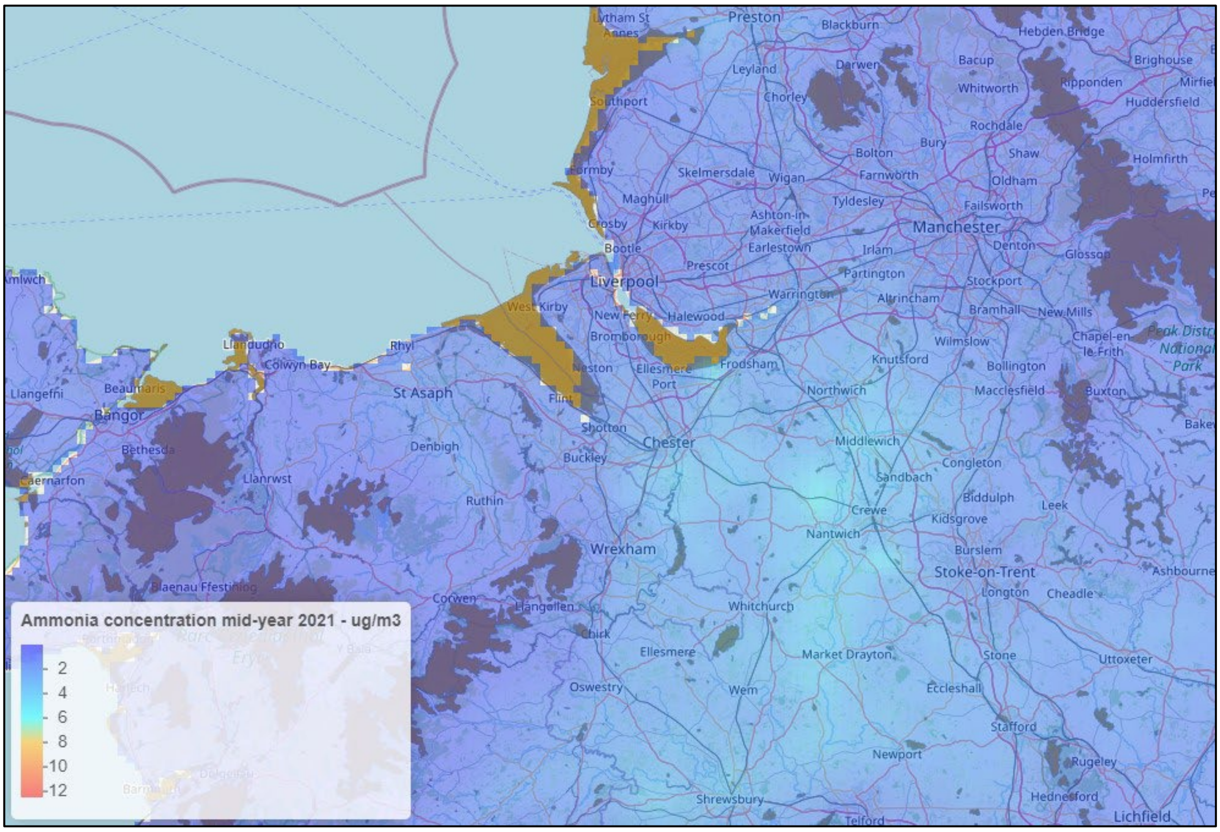


Figure 17 - Background NH_3 Concentrations



Background concentrations across the full extent of the HyNet Industrial Cluster, as illustrated in Figure 12 to Figure 17, fall below the relevant AQS objectives for all background pollutants.

Across much of the HyNet Cluster extent, NO_2 concentrations are typically below 10 µg/m³. In rural areas surrounding Cheshire, background concentrations remain at approximately 5 µg/m³, increasing only near urban centres such as Manchester and Liverpool. The highest recorded NO_2 concentration, just under 20 µg/m³, is observed in Manchester city centre—well below the AQS objective of 40 µg/m³. A similar trend is observed for NO_x concentrations, which are slightly higher than NO_2 but follow the same spatial distribution. The highest background NO_x concentration, 28.6 µg/m³, is also recorded in Manchester city centre, remaining well below the NO_2 AQS objective.

In contrast, the spatial distribution of particulate matter (PM_{10} and $PM_{2.5}$) concentrations is more uniform across the HyNet extent. Background PM_{10} levels range from 7 to 14 µg/m³, significantly below the AQS objective of 40 µg/m³. Similarly, $PM_{2.5}$ concentrations range from 4 to 9 µg/m³, comfortably below the AQS objective of 20 µg/m³.

Notably, no existing or proposed HyNet assets are located within 5 km of Manchester or Liverpool city centres. Therefore, it can be concluded with confidence that background concentrations of NO_2, NO_x, PM_{10}, and $PM_{2.5}$ are not expected to impose environmental capacity challenges on the HyNet project.

SO_2 concentrations within the area are observed to range between 2 µg/m³ and 6 µg/m³, which, while elevated relative to adjacent regions, also stay within acceptable AQS objectives. Concentrations of PM_{10} and $PM_{2.5}$ are relatively consistent across the area with PM_{10} concentrations of approximately 10 µg/m³ and $PM_{2.5}$ concentrations of approximately 6 µg/m³. This uniformity across the geographical scope indicates a widespread dispersal of particulate matter with no significant increase within the HyNet area.

Emissions to the air from fuel combustion, e.g. burning natural gas, oil, coal, hydrogen, NH_3, biomass, biogas etc, and subsequent emissions controls, e.g. carbon capture and selective and non-selective catalytic reduction (SCR and SNCR) of NO_x affect air quality, posing impacts on human health and the wider environment, particularly in terms of potential harm to sensitive habitats or species. In areas like Ellesmere Port, Runcorn, Manchester and Liverpool, historical air quality issues have largely stemmed from rapid industrial expansion during the late 19th and early to mid-20th centuries (Science and Industry Museum, 2021 [41]; Runcorn Historical Society, 2024 [42]; Cheshire West and Chester Council, 2024 [43]), where densely situated industries emitted high levels of smoke and SO_2 due to the combustion of sulphur-containing fossil fuels. Presently, the main pressure on air quality arises from vehicular traffic, which emits a variety of pollutants including CO, NO_x, volatile organic compounds (VOC’s), and PM_{10}/$PM_{2.5}$. These pollutants not only influence local air quality but can also be transported over longer distances, affecting air quality in adjacent regions.

Local Air Quality Management in the HyNet Area

The local authorities within the HyNet Area conduct air quality monitoring through the use of active and passive methods. Table 12 presents a summary of the air quality monitoring undertaken in the HyNet area.

Active sampling methods, typically referred to as automatic monitoring, involve the use of automatic continuous air quality monitors which actively collect and analyse air samples from ambient air. These offer greater accuracy and better time resolution, typically providing a reading every 15 minutes. but are relatively expensive, need to be installed in locations where power can be provided and the more accurate one stake up a significant amount of space, require frequent cleaning and calibration using calibration gasses and/or the changeover of sampling equipment by a trained operator. Due to the size and cost of these units LAs typically only have one or two of them, if any, located at areas of greatest concern e.g. in AQMAs.

Passive sampling, also referred to as non-automatic monitoring, typically consists of diffusion tubes which are small plastic tubes approximately 7 cm long, with a cap at each end. The top cap contains a sample media while the bottom cap is removed once the sampler has been affixed to an appropriate structure, e.g. lamppost, to allow ambient pollutants to diffuse into the tube and be absorbed by the sample media. The pollutant absorbed is dependent on the sample media in the tube. The tube is left in place with the bottom cap removed for approximately one month before the cap is replaced and the tube is sent to a laboratory for chemical analysis to determine the amount of pollutant absorbed, allowing the average pollutant concentration in the air to be determined based on the time the tube was exposed. As the tubes need to be exposed for a prolonged period, so are useful for assessing long-term concentrations, e.g. annual concentrations, but cannot be used to assess short-term pollutant concentrations. They are also less accurate than active sampling methods and due to the need for laboratory analysis there is also a delay in producing the measurements. However, they are relatively cheap, small in size and can be located anywhere with minimal training as long as there is a suitable place to mount them.

Table 12 - Air Quality Monitoring across Local Authorities in the HyNet Area

Council	Annual Status Report (ASR) Year (publication date in brackets)	Number of Automatic monitors (pollutants sampled provided in brackets)	Number of Non-automatic monitors (pollutants sampled provided in brackets)
Cheshire West and Chester Council	2023 (Jun 2023)	6 (NO_2, PM_{10} & SO_2)	86 (NO_2)
Halton Borough Council	2023 (Apr 2024)	2 (NO_2 & PM_{10})	15 (NO_2)
St Helens Metropolitan Borough Council	2023 (Jun 2024)	4 (NO_2 & PM_{10})	26 (NO_2)
Trafford Metropolitan Borough Council*	2023 (Jun 2024)	3 (NO_2 & PM_{10})	15 (NO_2)
Cheshire East Council	2023 (Jun, 2024)	1 (NO_2, PM_{10} & $PM_{2.5}$)	88 (NO_2)
Tameside Metropolitan Borough Council*	2023 (Jun 2024)	2 (NO_2, PM_{10} & $PM_{2.5}$)	53 (NO_2)
Warrington Borough Council	2023 (Jun 2024)	4 (NO_2, PM_{10}, $PM_{2.5}$)	38 (NO_2)
Wirral Council	2023 (Jun 2024)	2 (NO_2, PM_{10}, $PM_{2.5}$, O_3)	56 (NO_2)

* included as part of the Greater Manchester Combined Authority ASR.

As shown in Table 12, there are several automatic monitors in operation within the HyNet area. The annual mean pollutant concentrations as measured by these monitors for 2019 to 2023 are reported in Table 13 and graphed in Figure 18 to Figure 20.

Table 13 – Annual Mean Pollutant Concentrations across the Automatic Monitoring Network in the HyNet Area (2019 – 2023)

Pollutant	Council	Site ID & Site Name	Type	Annual Mean Concentration ($\mu g/m^3$)				
				2019	2020	2021	2022	2023
Nitrogen dioxide (NO_2)	Cheshire West and Chester	Boughton	Roadside	23.1	16.6	18.5	18.3	16.7
		Chester Bus Interchange	Roadside	38.5	29.0	29.7	32.2	31.6
		Frodsham	Urban Background	15.1	12.7	14.8	13.9	9.7
		Thorton-le-Moors, Park Road	Industrial	13.0	9.0	11.0	11.0	10.6
		Whitby Road	Roadside	34.7	27.5	29.2	28.5	28.0
	Halton	Marzahn Way	Roadside	27.0	24.0	31.2	-	-
	St Helens	St Helens Linkway	Roadside	33.0	25.0	26.0	28.0	23.0
		St Helens Southworth Road	Roadside	43.0	34.0	34.0	37.0	31.0

Pollutant	Council	Site ID & Site Name	Type	Annual Mean Concentration (µg/m³) 2019	2020	2021	2022	2023
		St Helens High Street	Roadside	31.0	30.0	30.0	27.0	25.1
		St Helens Borough Road	Roadside	29.0	26.0	24.0	25.0	25.8
	Trafford	Trafford A56	Urban Traffic	30.0	21.0	23.0	24.0	21.0
	Trafford	Trafford Moss Park	Urban Background	19.0	14.0	15.0	15.0	14.0
	Trafford	Trafford Wellacre Academy	Urban Background	15.0	11.0	13.0	11.0	11.0
	Cheshire East	Market Street, Disley	Kerbside	35.0	25.0	27.0	25.0	26.0
	Tameside	A635 Manchester Road	Roadside	-	29.2	34.0	32.0	30.0
	Tameside	Mottram Moor	Roadside	40.0	30.0	36.0	34.0	33.0
	Warrington	Selby Street	Urban Background	21.0	15.0	15.0	15.0	13.0
	Warrington	Parker Street	Roadside	41.0	28.0	32/0	32.0	31.0
	Warrington	Chester Road	Roadside	30.0	22.0	23.0	24.0	23.0
	Warrington	Sankey Way	Roadside	-	-	21.0	21.0	19.0
	Warrington	Liverpool Road	Roadside	-	-	-	-	18.0
	Wirral	Wirral Tranmere	Urban Background	16.0	9.6	12.6	13.4	12.8
	Wirral	Wirral Birkenhead	Urban Centre	23.0	13.1	18.3	16.8	17.9
Particulate Matter (PM_{10})	Cheshire West and Chester Council	Chester Bus Interchange	Roadside	21.3	22.7	22.2	20.4	18.3
Particulate Matter (PM_{10})	Cheshire West and Chester Council	Frodsham	Urban Background	15.5	12.3	12.7	14.9	13.6
Particulate Matter (PM_{10})	Cheshire West and Chester Council	Thorton-le-Moors, Park Road	Industrial	14.0	13.0	13.0	13.0	11.9
Particulate Matter (PM_{10})	Halton	Marzahn Way	Roadside	22.0	22.0	23.1	-	-
Particulate Matter (PM_{10})	Halton	Milton Road	Roadside	18.0	21.0	23.6	-	-
Particulate Matter (PM_{10})	St Helens	St Helens Linkway	Roadside	20.0	18.0	18.0	19.0	18.0
Particulate Matter (PM_{10})	Trafford	Trafford A56	Urban Traffic	17.0	14.0	14.0	16.0	13.0
Particulate Matter (PM_{10})	Trafford	Trafford Moss Park	Urban Background	15.0	13.0	13.0	17.0	11.0
Particulate Matter (PM_{10})	Cheshire East	Market Street, Disley	Kerbside	-	-	-	-	16.3
Particulate Matter (PM_{10})	Tameside	A635 Manchester Road	Roadside	-	15.8	20.0	20.0	17.0
Particulate Matter (PM_{10})	Tameside	Mottram Moor	Roadside	18.0	17.0	15.0	15.0	11.0
Particulate Matter (PM_{10})	Warrington	Selby Street	Urban Background	17.0	15.0	13.0	15.0	14.0
Particulate Matter (PM_{10})	Warrington	Sankey Way	Roadside	-	-	13.0	11.0	10.0
Particulate Matter (PM_{10})	Warrington	Liverpool Road	Roadside	-	-	-	-	13.0
Particulate Matter (PM_{10})	Wirral	Wirral Tranmere	Urban Background	-	11.5	11.3	12.8	10.9
Particulate Matter ($PM_{2.5}$)	Cheshire East	Market Street, Disley	Kerbside	-	-	-	-	4.0
Particulate Matter ($PM_{2.5}$)	Tameside	A635 Manchester Road	Roadside	-	8.4	11.0	11.0	8.0
Particulate Matter ($PM_{2.5}$)	Warrington	Selby Street	Urban Background	5.0	1.0	1.0	1.0	0.0
Particulate Matter ($PM_{2.5}$)	Warrington	Sankey Way	Roadside	-	-	2.0	1.0	0.0
Particulate Matter ($PM_{2.5}$)	Warrington	Liverpool Road	Roadside	-	-	-	-	0.0

Pollutant	Council	Site ID & Site Name	Type	Annual Mean Concentration (µg/m^3)				
				2019	2020	2021	2022	2023
	Wirral	Wirral Tranmere	Urban Background	8.2	7.1	7.0	7.8	6.6
Sulphur dioxide (SO_2)	Cheshire West and Chester Council	Elton	Industrial	2.5	3.1	2.6	2.4	3.4
		Thorton-le-Moors, Park Road	Industrial	4.8	4.1	3.5	2.6	2.4

Source: Source: Cheshire West and Chester 2024 Air Quality ASR [44]; Cheshire East Council 2024 Air Quality ASR [45]; Flintshire County Council 2023 Air Quality ASR [46]; Halton Borough Council 2024 Air Quality ASR [47]; Knowsley Council 2024 Air Quality ASR [48]; Greater Manchester Combined Authority 2024 Air Quality ASR; St Helens Borough Council 2024 Air Quality ASR; Stockport Council 2024 Air Quality ASR; Warrington Borough Council 2024 Air Quality ASR; Wirral Council 2024 Air Quality ASR.

Figure 18 - Annual Mean NO_2 Concentrations at Automatic Monitoring Sites in the HyNet Area (2019 - 2023)

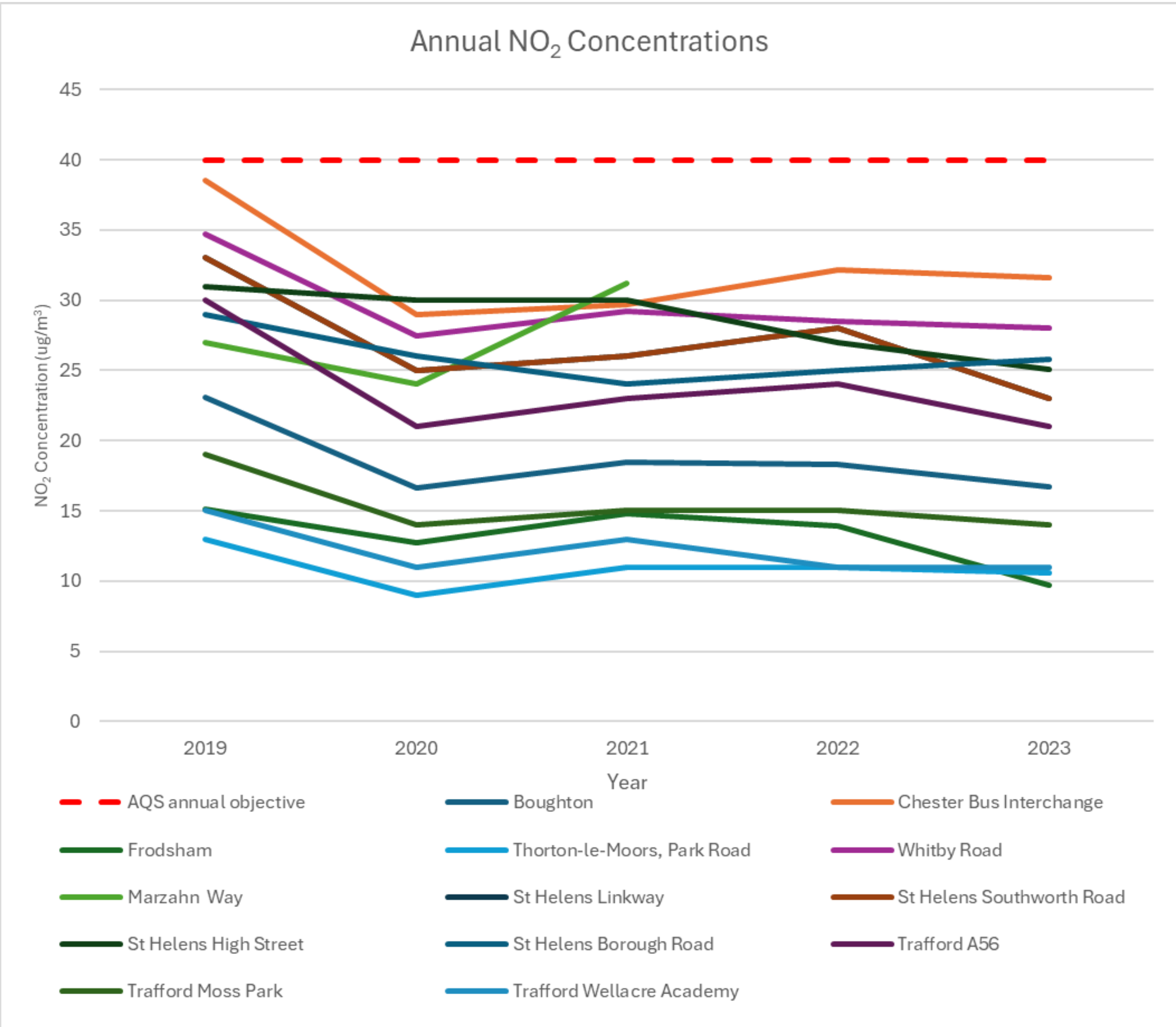


Figure 19 - Annual Mean PM_{10} Concentrations at Automatic Monitoring Sites in the HyNet Area (2019 - 2023)

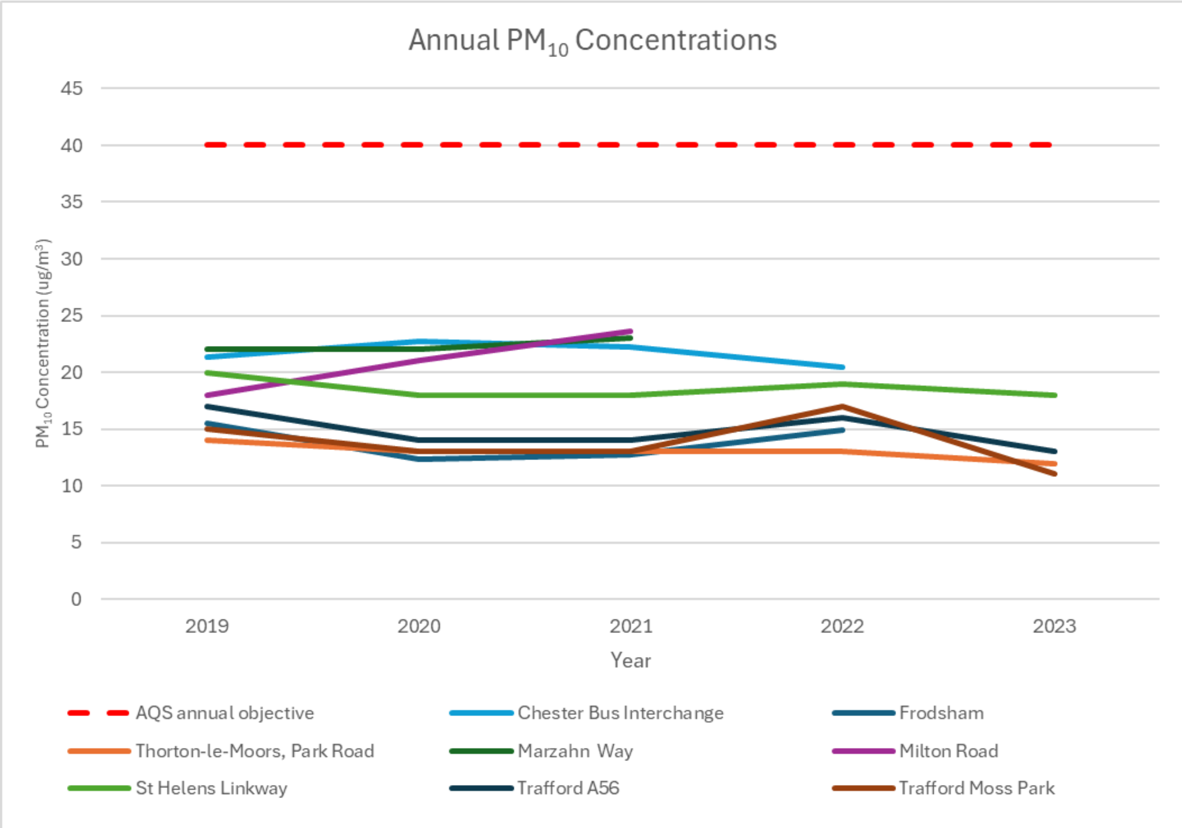


Figure 20 - Annual Mean SO_2 Concentrations at Automatic Monitoring Sites in the HyNet Area (2019 - 2023)

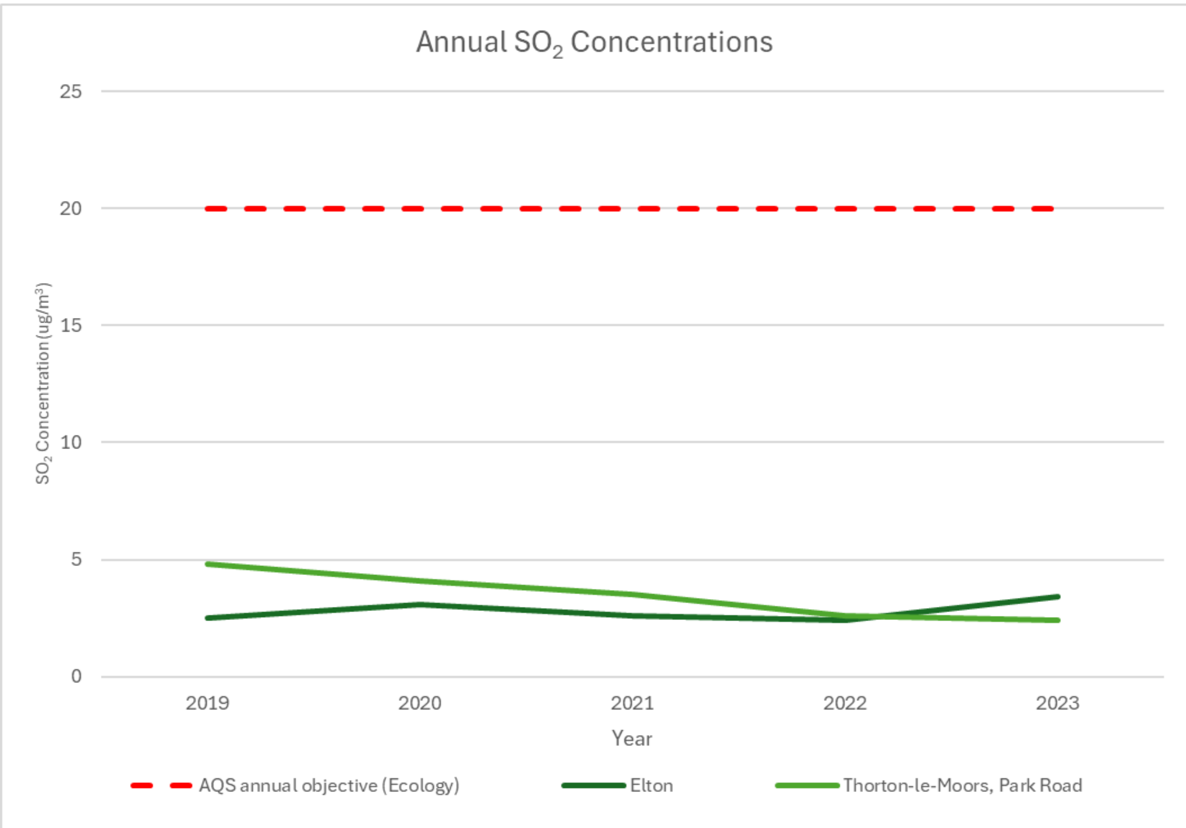


Figure 21Figure 18 to Figure 20 show that there has been a reduction in NO_2, PM_{10} and SO_2 concentrations at automatic monitoring sites operated by all local councils within the HyNet extent. The applicable AQS objective for each pollutant monitored is predicted to be achieved at all presented monitoring stations.

Annual mean NO_2 concentrations associated with non-automatic monitors (diffusion tubes) from 2019 to 2023 are shown in Table 14.

Table 14 – Annual Mean NO_2 Concentrations by type across the Non-Automatic (Diffusion Tube) Monitoring Network in the HyNet Area (2019 – 2023)

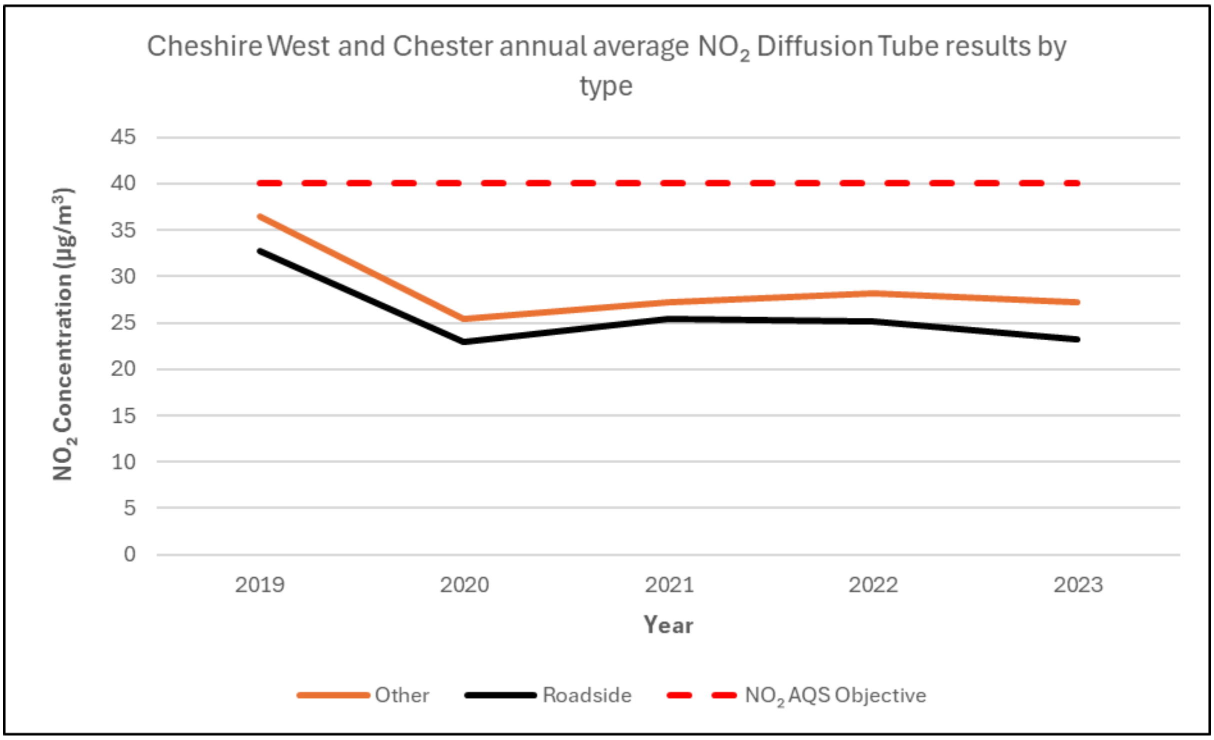
Council	Type	Annual Mean NO_2 Concentration (µg/m^3)				
		2019	2020	2021	2022	2023
Cheshire West and Chester	Roadside	32.7	22.9	25.4	25.1	23.2
	Other	36.4	25.4	27.2	28.3	27.2
Cheshire East	Roadside	31.0	23.2	25.5	24.6	22.5
	Kerbside	33.3	26.6	28.5	27.0	25.0
	Rural	9.1	7.0	7.7	7.5	6.5
	Urban Background	12.1	9.6	10.8	10.3	9.2
	Other	27.2	22.1	25.2	24.6	21.3
Flintshire	Roadside	18.1	13.5	13.9	13.6	-
	Kerbside	19.0	14.6	15.0	15.5	-
	Rural	14.8	10.5	10.5	11	-
	Urban Background	20.1	14.2	15.1	14.7	-
	Industrial	21.9	13.9	14.5	15.7	-
Halton	Roadside	28.6	22.9	26.9	24.1	22.6
	Urban Background	-	-	24.2	17	15.7
Knowsley	Roadside	32.5	27.2	29.2	24.6	22.6
	Kerbside	48	42.2	46.1	38	33
	Suburban	26.4	21.2	28.9	23.5	21.5
Manchester	Roadside	39.0	28.6	31.7	32.7	31.0
	Kerbside	42.8	30.0	34.4	34.6	33.2
	Urban Background	31.8	22.1	25.1	25.9	24.2
	Surburban	18.9	13.8	14.1	15.2	14.2
Salford	Roadside	37.8	28.3	30.2	30.1	27.9
	Kerbside	-	-	44	45.2	43.2
	Rural	14.2	11.2	11.5	11.9	10.8
	Urban Background	24.4	17.7	19.4	19.5	18.0

Council	Type	Annual Mean NO_2 Concentration (μg/m³)				
		2019	2020	2021	2022	2023
St Helens	Roadside	27.0	23.9	28.1	20.8	23.5
	Urban Background	14.3	11.2	14.0	10.0	15.1
	Suburban	20.0	17.5	20.0	15.9	16.0
Stockport	Roadside	33.0	23.7	27.0	27.1	24.9
	Kerbside	39.5	26.3	25.9	26.4	25.0
	Rural	11.2	8.0	10.3	9.0	8.5
	Urban Background	22.0	15.6	17.1	16.5	16.2
Tameside	Roadside	37.2	27.9	29.9	30.0	29.1
	Kerbside	37.2	29.7	31.4	30.3	29.7
	Urban Background	26.4	19.4	20.6	20.9	19.9
	Suburban	24.7	17.2	18.1	18.4	17.8
Trafford	Roadside	30.7	20.7	21.9	20.9	20.7
	Kerbside	28.9	22.1	24.2	24.9	24.6
	Urban Background	20.6	15	16.4	16.5	16.7
Warrington	Roadside	33.6	25.0	28.7	24.6	23.4
	Rural	16.3	10.4	11.7	10	8.6
	Urban Background	20.1	13.3	15.1	14.3	13.5
Wirral	Roadside	28.5	22.3	23.2	20.2	19.9
	Kerbside	25.3	21.3	20.7	20.2	19.8

Source: Cheshire West and Chester 2024 Air Quality ASR [44]; Cheshire East Council 2024 Air Quality ASR [45]; Flintshire County Council 2023 Air Quality ASR [46]; Halton Borough Council 2024 Air Quality ASR [47]; Knowsley Council 2024 Air Quality ASR [48]; Greater Manchester Combined Authority 2024 Air Quality ASR; St Helens Borough Council 2024 Air Quality ASR; Stockport Council 2024 Air Quality ASR; Warrington Borough Council 2024 Air Quality ASR; Wirral Council 2024 Air Quality ASR.

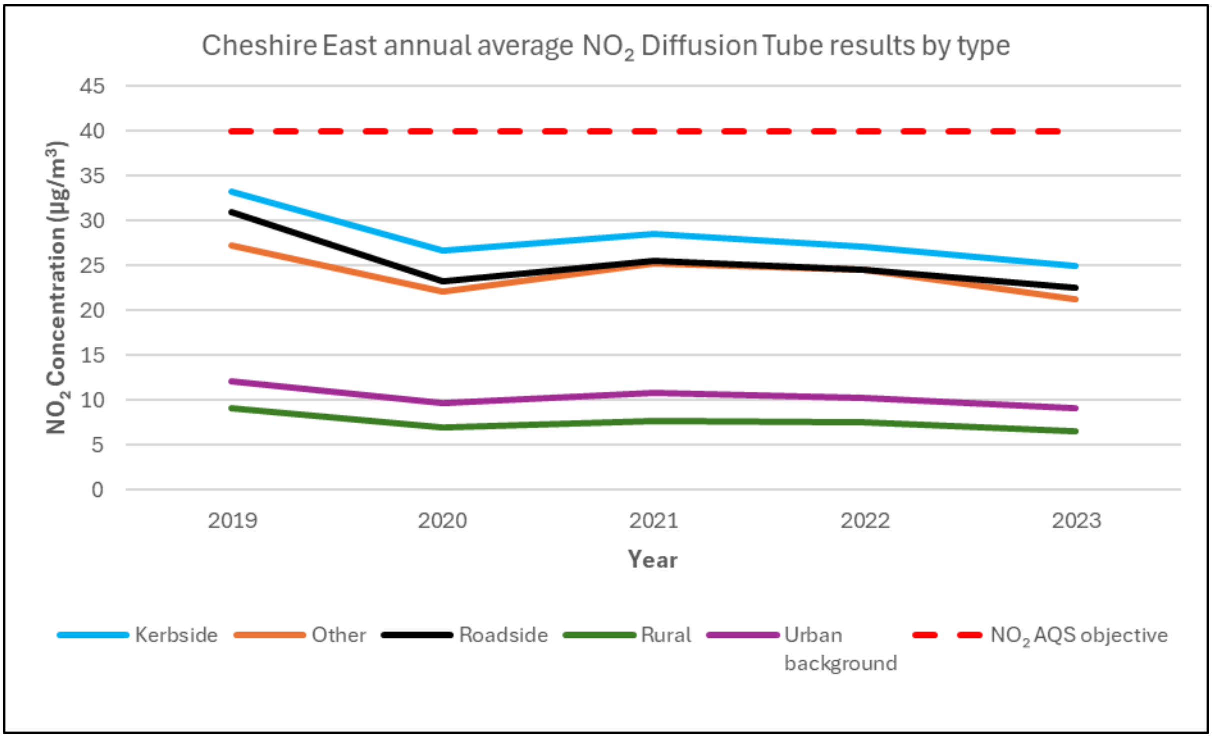
Annual mean NO_2 concentrations in the HyNet area have exhibited a steady downward trend (see Figure 21 to Figure 33 and Table 14) between 2019 and 2023. In almost all cases, concentrations were below the annual mean AQS objective for NO_2 (40 μg/m³) in 2023, apart from an exceedance of a kerbside diffusion tube location in Salford. This was the only kerbside location monitored in Salford in 2023 and displayed a 2 μg/m³ decrease in annual mean NO_2 concentration from 2022. With distance correction factors applied, there would be an annual mean NO_2 concentration of 32 μg/m³ at the closest sensitive receptor from this location, firmly under the AQS objective. There are no other exceedances of the 40 μg/m³ threshold. However, it should be noted that the data associated with 2020 and 2021 are likely to have been influenced by reductions in traffic volumes and other restrictions associated with the COVID-19 pandemic. In this context, Table 15 summarises the key industrial projects across the HyNet cluster, highlighting their locations.

Figure 21 - Annual Mean NO_2 Concentrations by Diffusion Tube type in Cheshire West and Chester



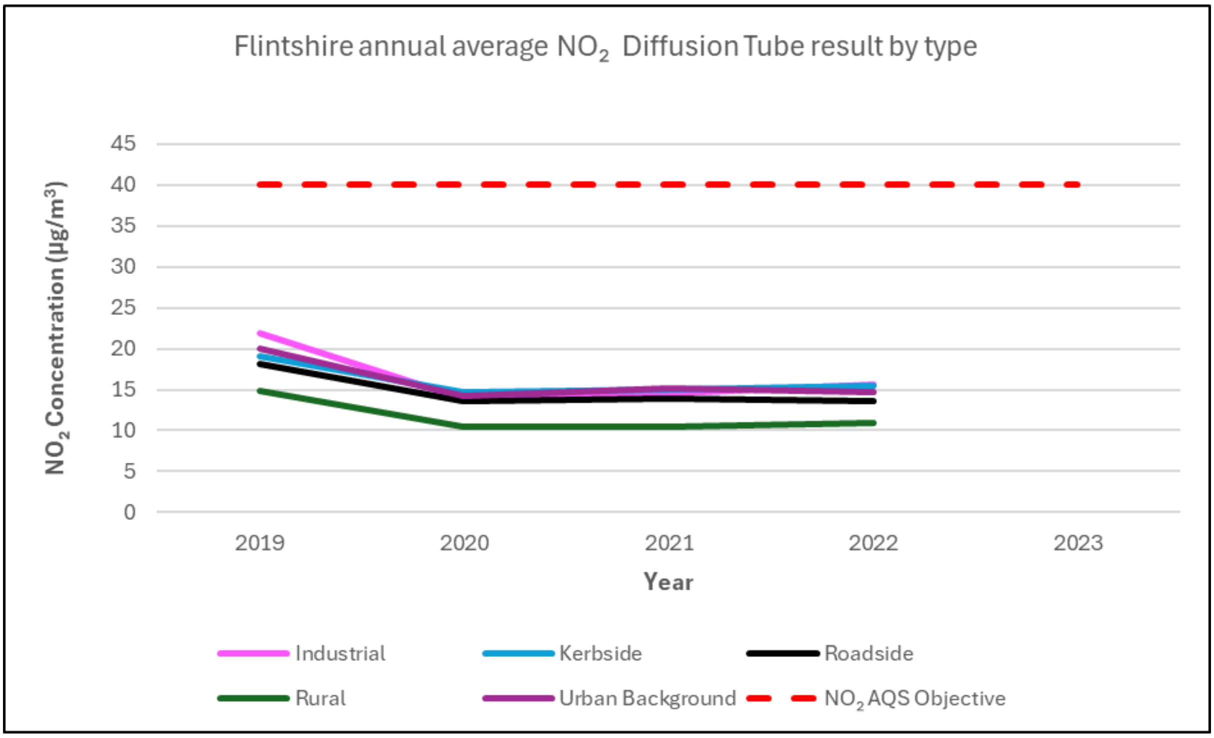
Cheshire West and Chester 2024 Air Quality ASR

Figure 22 - Annual Mean NO_2 Concentrations by Diffusion Tube type in Chesire East



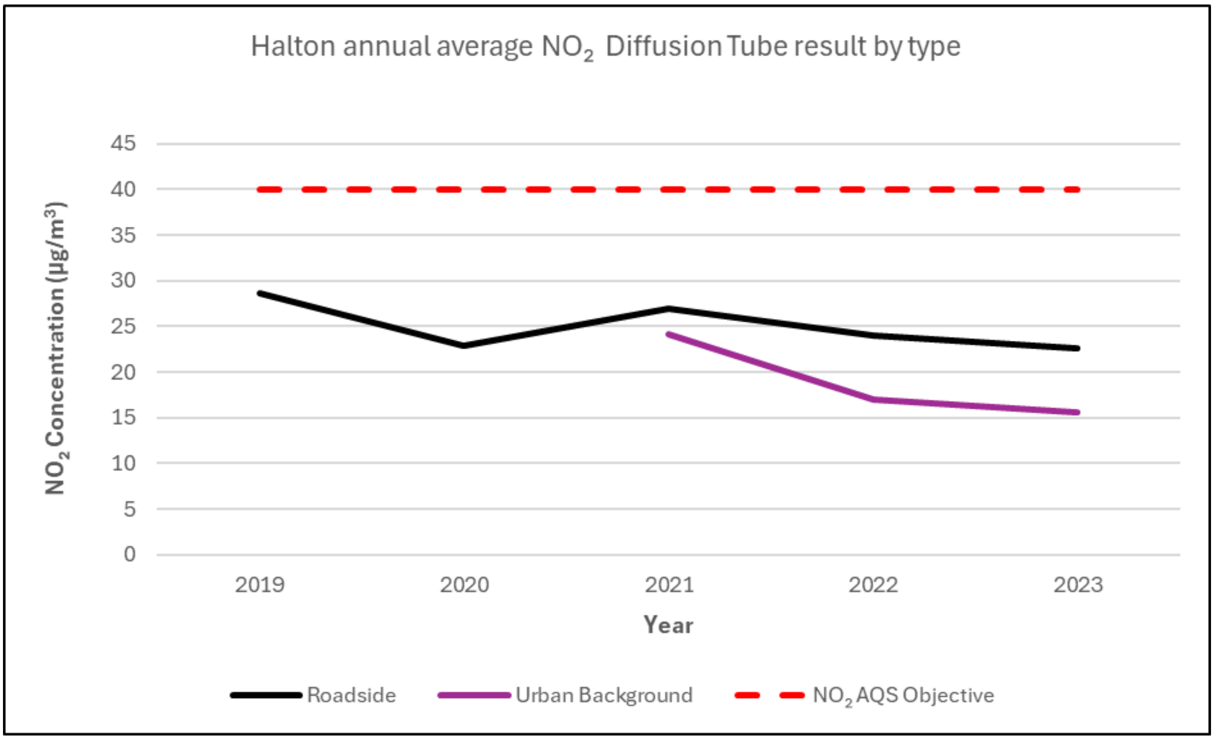
Cheshire East Council 2024 Air Quality ASR

Figure 23 - Annual Mean NO_2 Concentrations by Diffusion Tube type in Flintshire



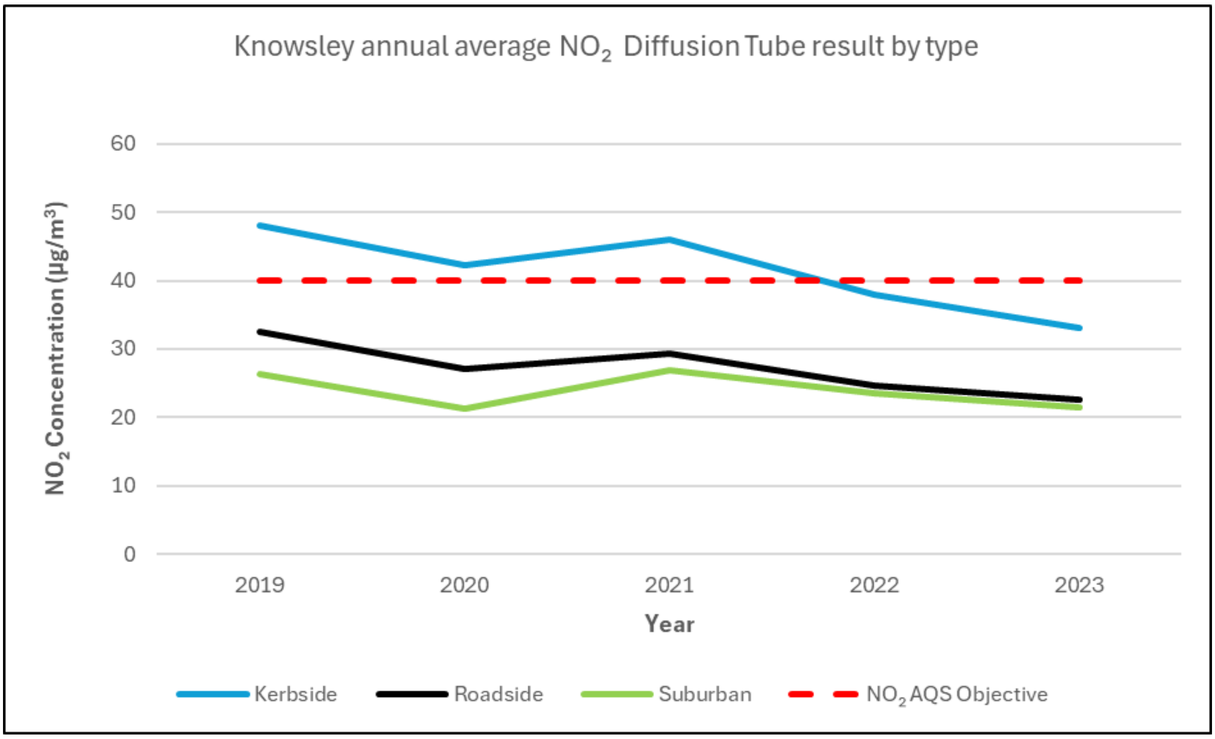
Flintshire County Council 2023 Air Quality ASR

Figure 24 - Annual Mean NO_2 Concentrations by Diffusion Tube type in Halton



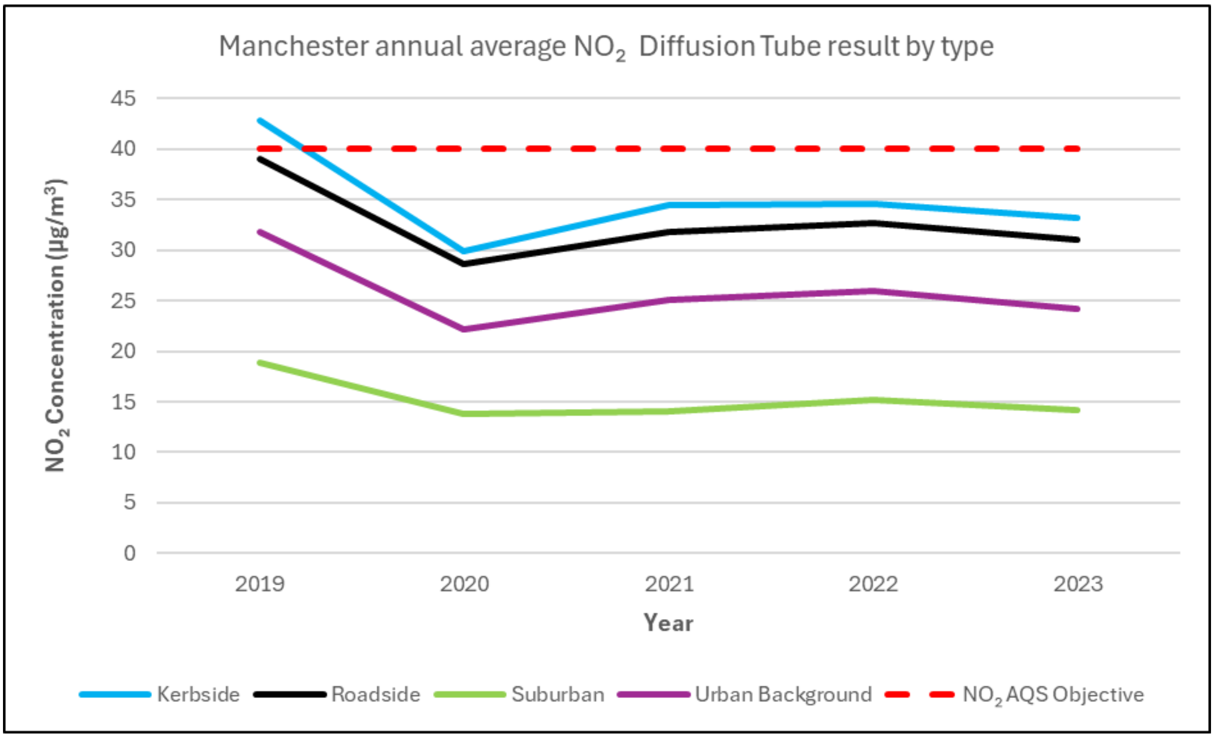
Halton Borough Council 2024 Air Quality ASR

Figure 25 - Annual Mean NO_2 Concentrations by Diffusion Tube type in Knowsley



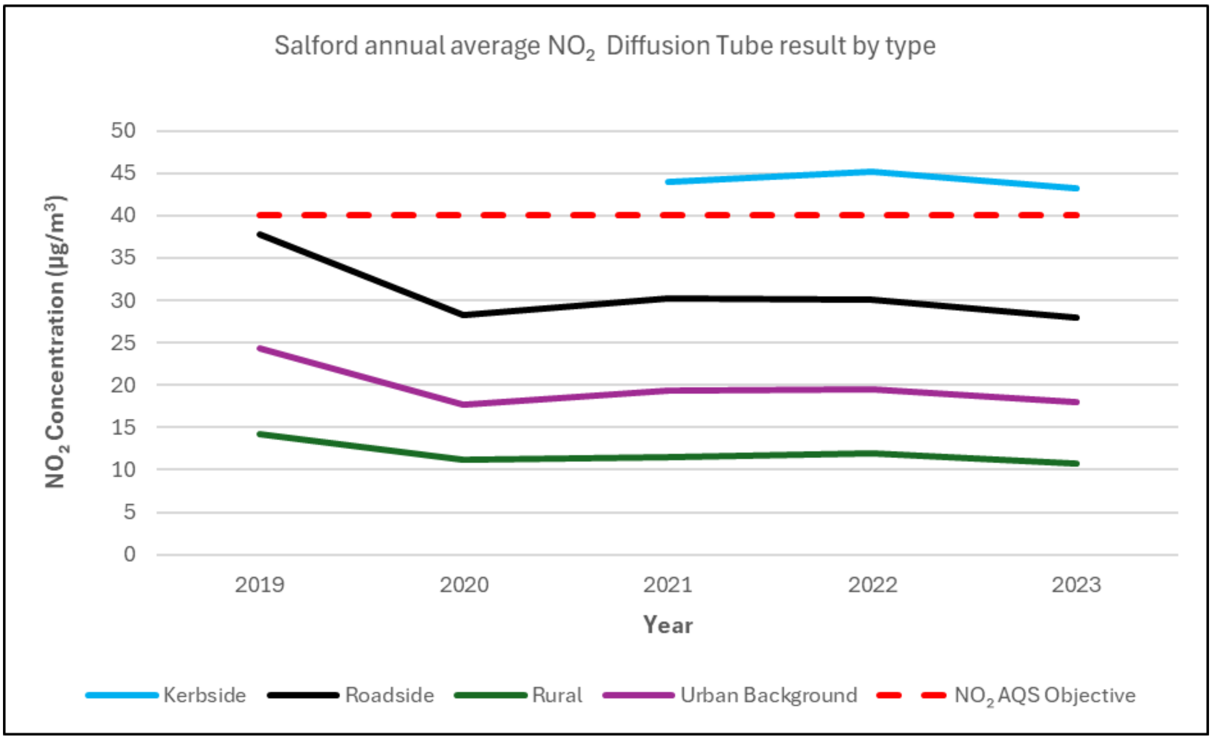
Knowsley Council 2024 Air Quality ASR

Figure 26 - Annual Mean NO_2 Concentrations by Diffusion Tube type in Manchester



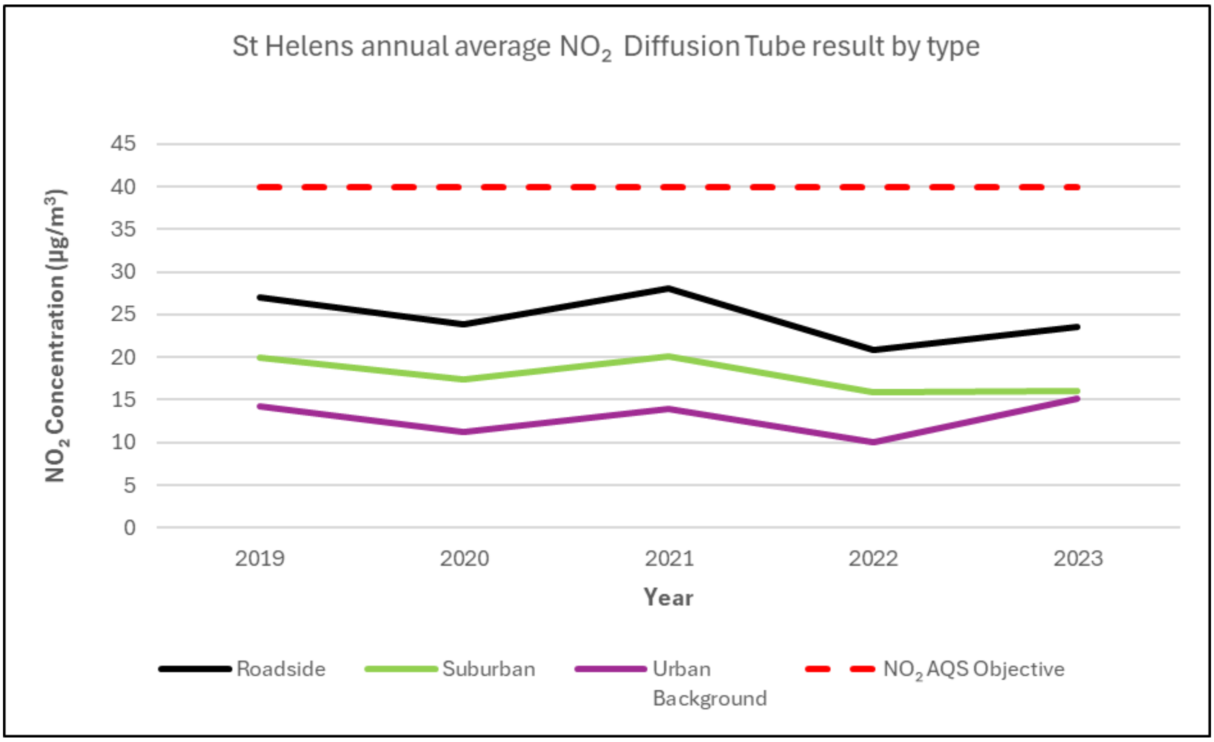
Greater Manchester Combined Authority 2024 Air Quality ASR

Figure 27 - Annual Mean NO_2 Concentrations by Diffusion Tube type in Salford



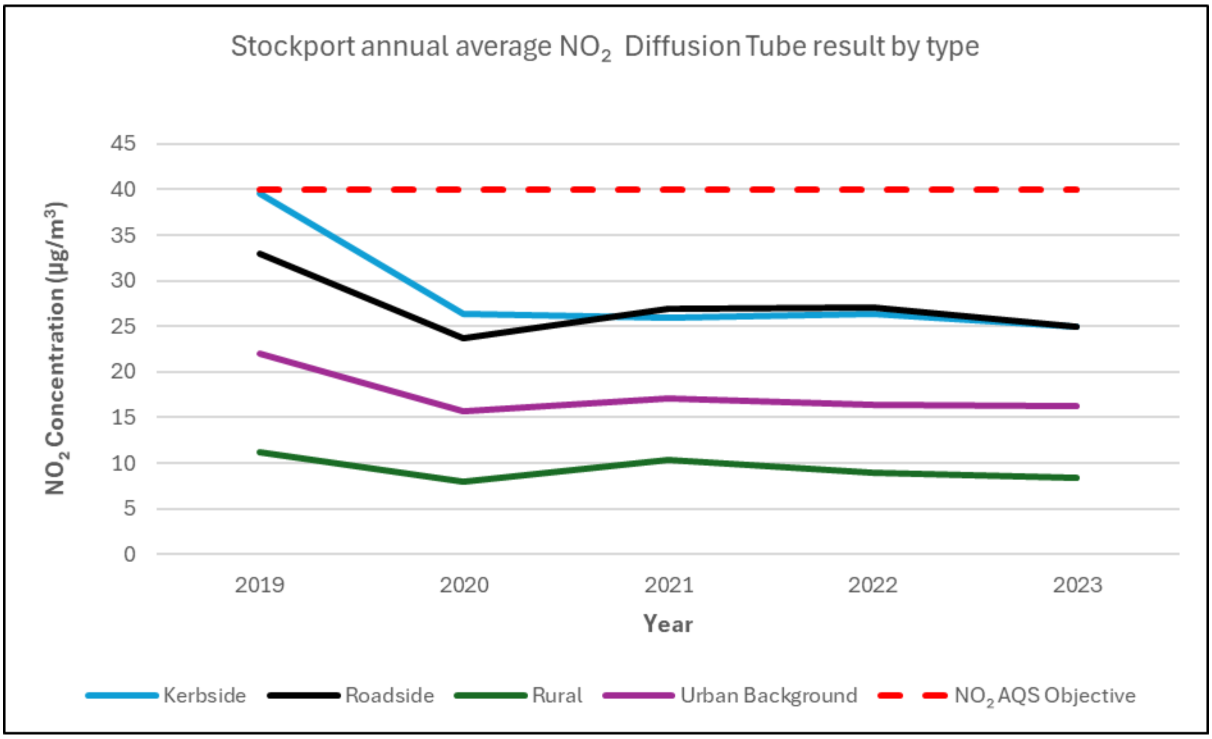
Greater Manchester Combined Authority 2024 Air Quality ASR

Figure 28 - Annual Mean NO2 Concentrations by Diffusion Tube type in St Helens



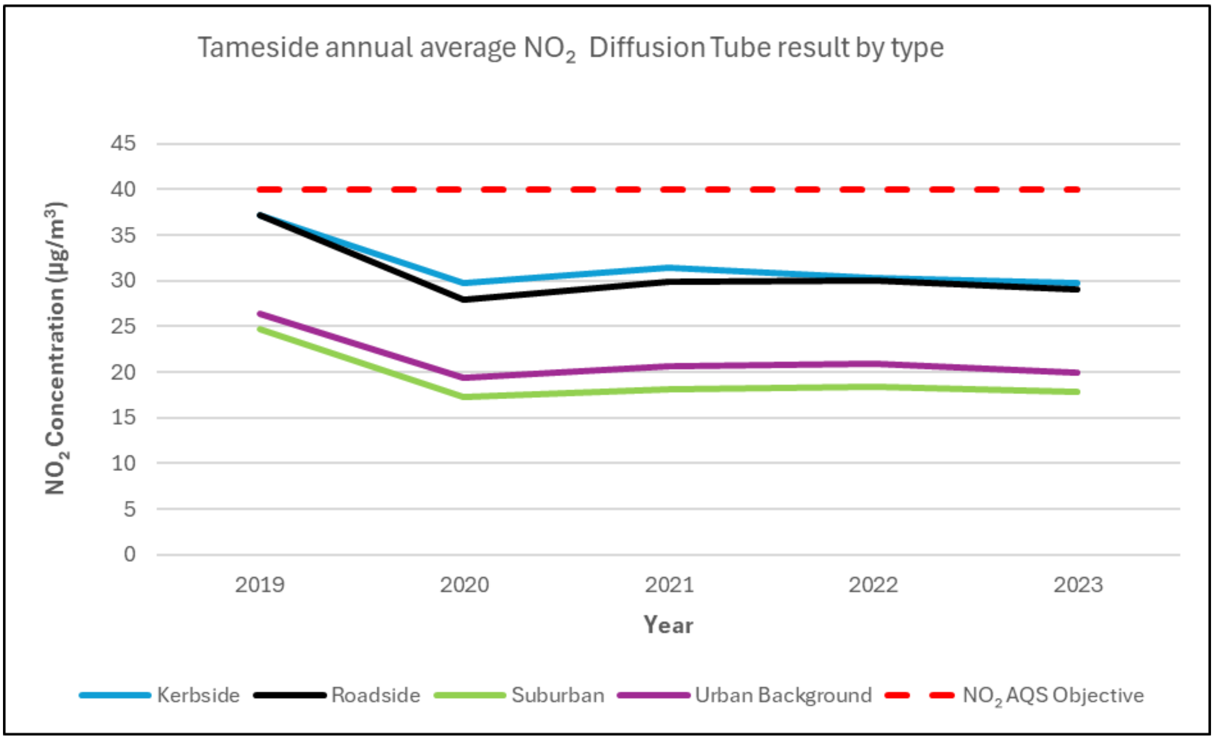
St Helens Borough Council 2024 Air Quality ASR

Figure 29 - Annual Mean NO2 Concentrations by Diffusion Tube type in Stockport



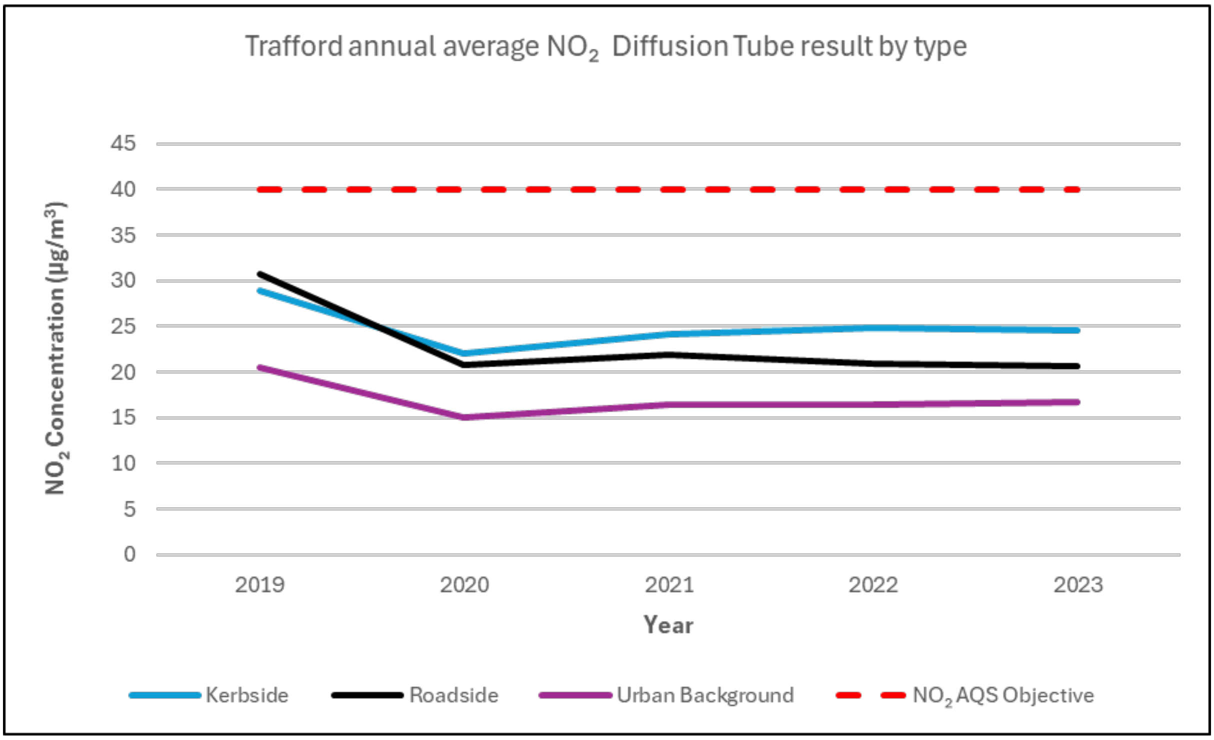
Stockport Council 2024 Air Quality ASR

Figure 30 - Annual Mean NO2 Concentrations by Diffusion Tube type in Tameside



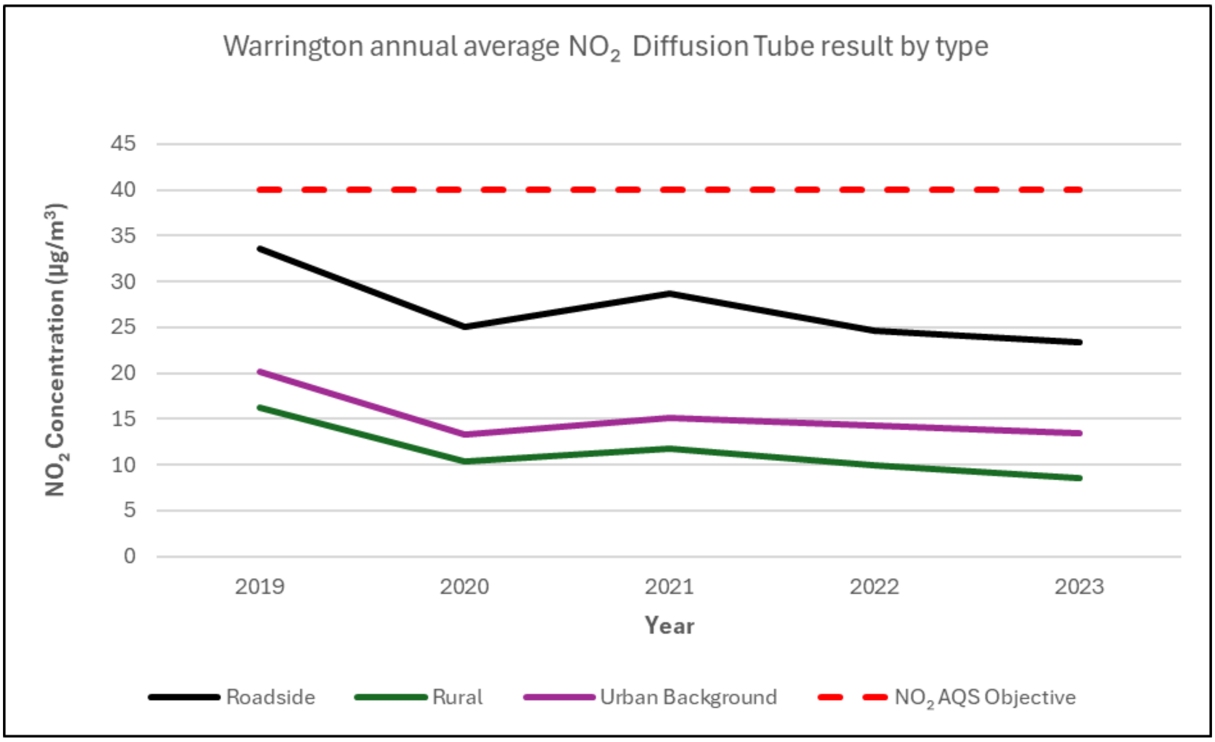
Greater Manchester Combined Authority 2024 Air Quality ASR

Figure 31 - Annual Mean NO2 Concentrations by Diffusion Tube type in Trafford



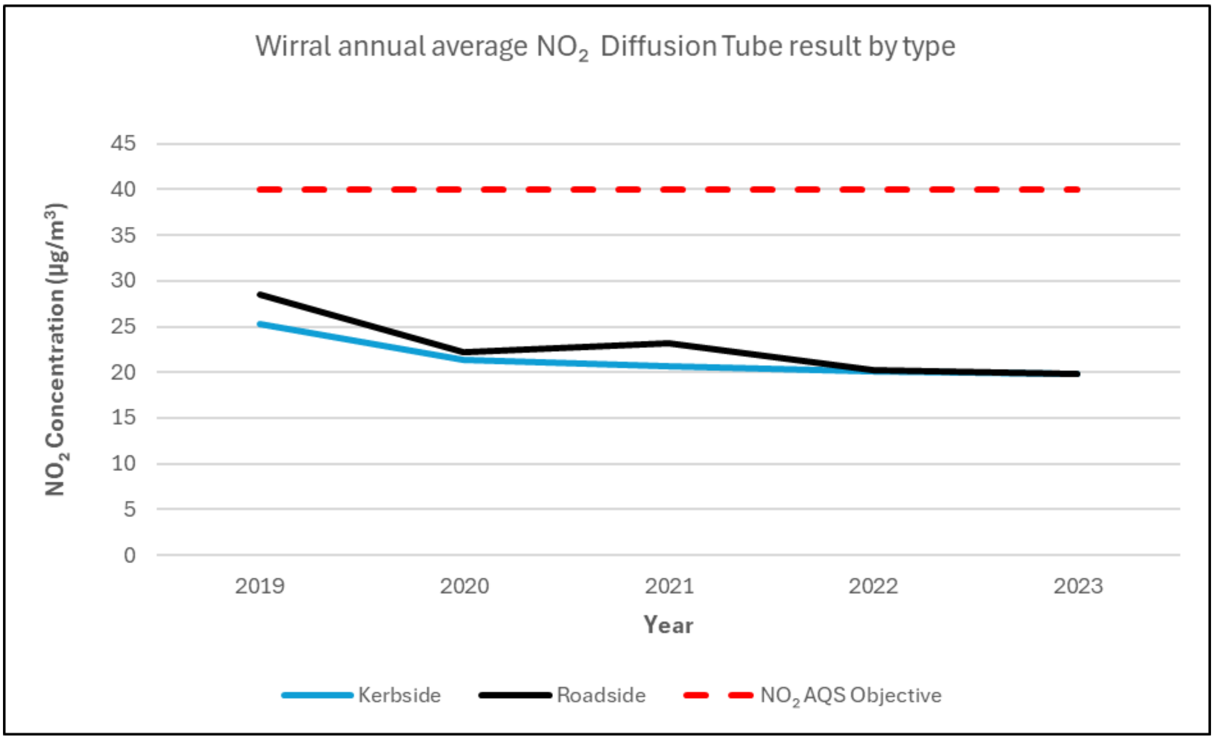
Greater Manchester Combined Authority 2024 Air Quality ASR

Figure 32 - Annual Mean NO2 Concentrations by Diffusion Tube type in Warrington



Warrington Borough Council 2024 Air Quality ASR

Figure 33 - Annual Mean NO2 Concentrations by Diffusion Tube type in Wirral



Wirral Council 2024 Air Quality ASR

Table 15 - Key industrial projects in the HyNet cluster and their respective locations

Project name	Location
Essar / Vertex, Phase 1	Cheshire West and Chester
Protos Encyclis ERF	Cheshire West and Chester
Runcorn Viridor ERF	Halton
Cheshire Green hydrogen, Protos, Ince	Cheshire West and Chester
Evero EfW and MHI, BECCS project, Protos, Ince	Cheshire West and Chester
Ince Low Carbon Power Project, Ince Marshes, Marsh Lane	Cheshire West and Chester
Carlton Power	Trafford
Winnington CHP with CCU	Cheshire West and Chester
Keuper Gas Storage Ltd	Cheshire West and Chester
Inovyn CV, Runcorn – Project Quill 2	Halton
Runcorn Membrane Chlorine Plant	Halton
Padeswood cement works	Flintshire
Carrington Power Station	Trafford
Rocksavage Power Station	Halton
Encirc Glass	Cheshire West and Chester
Unilever, Port Sunlight, Sulphonation plant	Wirral

Project name	Location
Novelis, Thelwall Lane	Warrington
Pilkington Glass	St Helens
Kellogs, Trafford Park	Trafford
Winnington CHP	Cheshire West and Chester
British Salt	Cheshire East
HJ Heinz, Manufacturing	Greater Manchester
Cargill PLC	Trafford
Thomas Hardy Burtonwood Ltd	Warrington
Ingevity, Baronet Road	Warrington
Stepan UK Ltd, Stalybridge. Surfactant production	Tameside
United Utilities	Trafford

Defra Automatic Urban Rural Network Monitoring Locations within the HyNet Area

Table 16 presents the monitoring results from the Defra Automatic Urban Rural Network (AURN) monitoring locations within the HyNet Industrial cluster. The location of these monitoring sites is illustrated in Figure 34. Data for some pollutants in certain years is unavailable as either monitoring was not conducted or data was not reported.

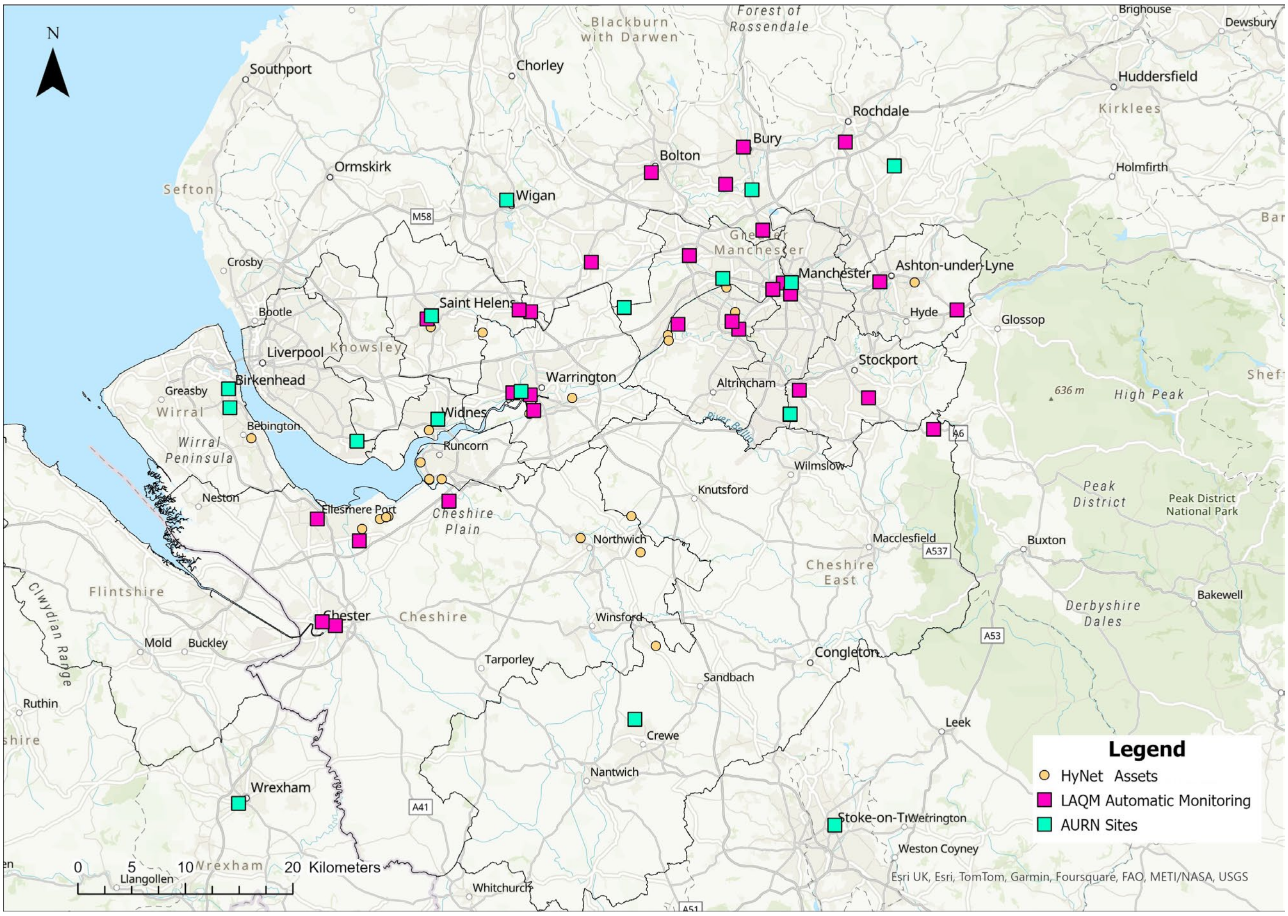
Table 16 – Monitored Pollutant Concentrations across the AURN Network in the HyNet Area (2019 – 2023)

Site	ID	Type	Pollutants	Annual Mean Concentration (µg/m^3)				
				2019	2020	2021	2022	2023
Glazebury	UKA00170	Rural Background	NO_2	14.6	10.9	11.7	11.1	12.1
			PM_{10}	-	-	-	-	10.7
			$PM_{2.5}$	-	-	-	-	6.5
Liverpool Speke	UKA00247	Urban Industrial	NO_2	19.5	-	-	14.9	13.9
			PM_{10}	16.7	-	-	14.9	14.1
			$PM_{2.5}$	9.1	-	-		7.9
			SO_2	1.7	-	-	1.8	1.2
Manchester Piccadilly	UKA00248	Urban Background	NO_2	36.3	27.0	29.5	29.0	26.8
			PM_{10}	22.6	14.4	15.6	15.5	14.6
			$PM_{2.5}$	11.5	8.2	8.8	9.6	8.5
			SO_2	2.5	1.2	0.9	0.7	0.7
Manchester Sharston	UKA00617	Suburban Industrial	NO_2	22.6	14.4	15.6	15.5	14.6

Site	ID	Type	Pollutants	Annual Mean Concentration (µg/m³)				
				2019	2020	2021	2022	2023
Salford Eccles	UKA00339	Urban Background	NO_2	25.5	20.3	22.8	21.8	19.6
			PM_{10}	15.3	14.2	15.0	16.6	15.1
			$PM_{2.5}$	9.5	8.3	8.9	9.7	8.6
St Helens Linkway	UKA00627	Urban Traffic	NO_2	33.4	24.9	26.5	27.5	23.1
			PM_{10}	20.5	18.3	18.3	18.7	17.8
Warrington	UKA00538	Urban Background	NO_2	20.5	14.9	15.1	-	12.9
			PM_{10}	17.0	14.5	12.8	15.1	13.7
			$PM_{2.5}$	-	8.2	7.6	7.2	7.1
Widnes Milton Road	UKA00603	Urban Traffic	NO_2	33.9	24.2	29.5	29.5	27.0
Wirral Tranmere	UKA00406	Urban Background	NO_2	16.4	11.7	12.7	13.4	12.8
			PM_{10}	-	11.5	11.3	12.8	10.8
			$PM_{2.5}$	8.0	7.1	7.1	7.8	6.6

Source: https://uk-air.defra.gov.uk/networks/search-site-info

Figure 34 – AURN and LAQM Automatic Monitoring Locations



Automatic Monitoring locations: Cheshire West and Chester 2024 Air Quality ASR [44]; Cheshire East Council 2024 Air Quality ASR [45]; Flintshire County Council 2023 Air Quality ASR [46]; Halton Borough Council 2024 Air Quality ASR [47]; Knowsley Council 2024 Air Quality ASR [48]; Greater Manchester Combined Authority 2024 Air Quality ASR; St Helens Borough Council 2024 Air Quality ASR; Stockport Council 2024 Air Quality ASR; Warrington Borough Council 2024 Air Quality ASR; Wirral Council 2024 Air Quality ASR. AURN sites: DEFRA, UK Air Information Resource (AIR). Available from: Interactive monitoring networks map - Defra, UK

Ecological Sites in the HyNet Area

All the UK protected area datasets were downloaded from Defra's Data Services Platform [49]. Table 17 outlines all the protected areas located within 5 km from the cluster (i.e. site boundaries), which are illustrated in Figure 9 and Figure 10.

Figure 35 - Protected habitats near HyNet Industrial Cluster

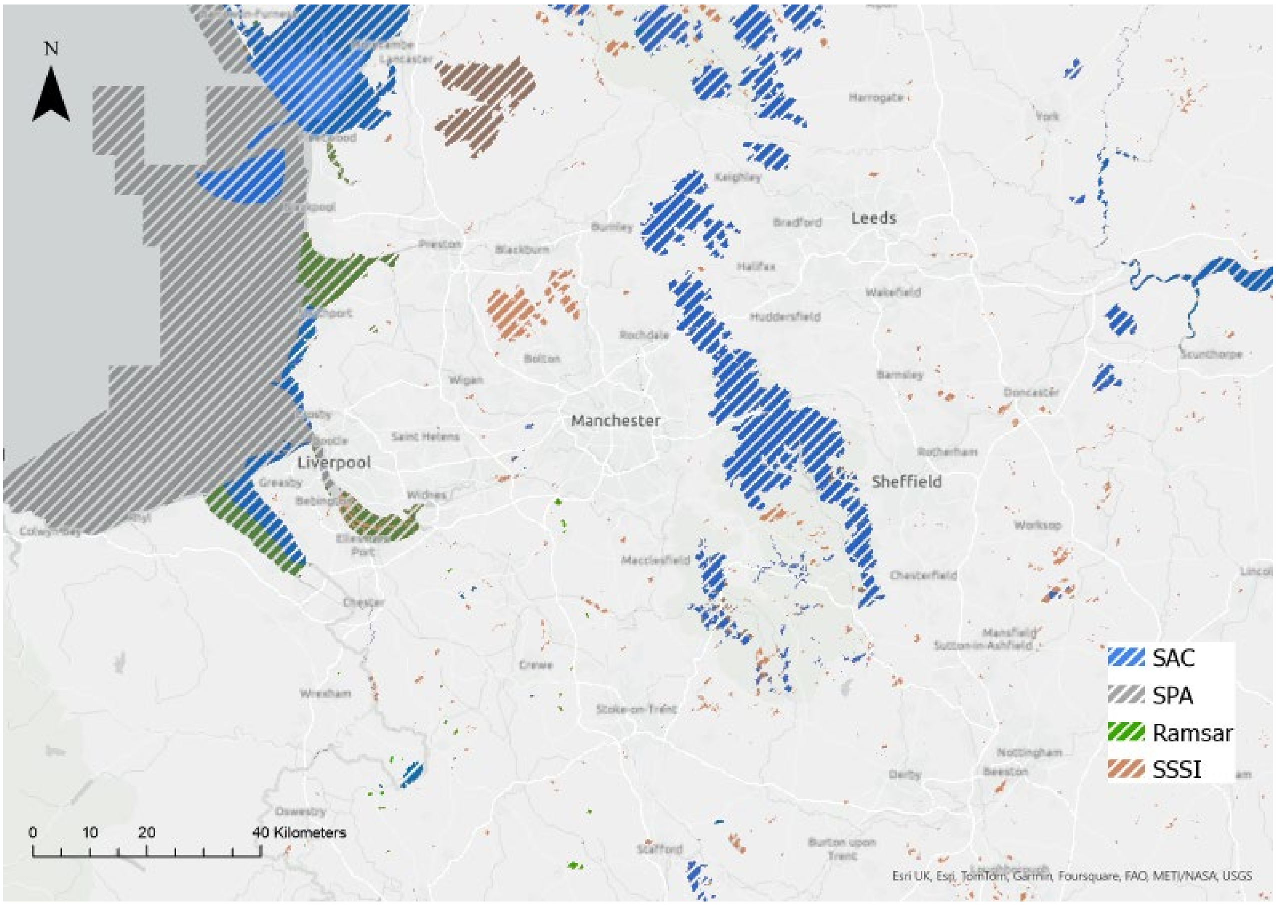


Table 17 - Ecological sites within 5 km of the HyNet Industrial Cluster

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
The Dee Estuary	RAMSAR/SPA/ SAC/SSSI	Dry heaths / Moist and wet dune slacks	5 - 15	Min: 7.63 Max: 11.595 Average: 10.085	Min 201.70% Max 67.23%	Dwarf shrub heath	Min N: 0.412 / 0.892 Max N: 1.329 / 4.972 Max S: 0.45 / 4.12	Min: 0.663 Max: 1.109 Average: 0.884	Min 66.52% Max 17.78%
Mersey Estuary	RAMSAR/SPA/ SSSI	Atlantic upper-mid & mid-low salt marshes	10 - 20	Min: 10.887 Max: 14.706 Average: 12.764	Min 127.64% Max 63.82%	Calcareous grassland (using base cation)	Min N: 0.856 / 1.071 Max N: 4.856 / 5.071 Max S: 4 / 4	Min: 1.005 Max: 1.257 Average: 1.124	Min 23.15% Max 22.17%
Rostherne Mere	RAMSAR/SSSI/ NNR	Atlantic upper-mid & mid-low salt marshes	10 - 20	Min: 12.632 Max: 12.831 Average: 12.731	Min 127.31% Max 63.66%	Freshwater	N/A	Min: 1.044 Max: 1.056 Average: 1.052	N/A
South Pennine Moors	SAC	Raised and blanket bogs	5 - 10	Min: 13.129 Max: 23.393 Average: 18.9	Min 378.00% Max 189.00%	Bogs	Min N: 0.321 / 0.321 Max N: 0.569 / 1.181 Max S: 0.248 / 0.86	Min: 1.019 Max: 1.714 Average: 1.431	Min 251.49% Max 121.17%
Deeside and Buckley Newt Sites	SAC	Acidophilous Quercus forest	10 - 15	Min: 10.523 Max: 13.024 Average: 11.971	Min 119.71% Max 79.81%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.142 / 0.357 Max N: 1.72 / 2.999 Max S: 1.448 / 2.642	Min: 0.946 Max: 1.081 Average: 1.023	Min 59.48% Max 34.11%

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Manchester Mosses	SAC	Raised and blanket bogs	5 - 10	Min: 11.11 Max: 12.101 Average: 11.436	Min 228.72% Max 114.36%	Bogs	Min N: 0.321 / 0.321 Max N: 0.564 / 0.58 Max S: 0.243 / 0.259	Min: 0.975 Max: 1.055 Average: 1.006	Min 178.37% Max 173.45%
West Midlands Mosses	SAC	Raised and blanket bogs / Transition mires and quaking bogs	5 - 10	Min: 9.342 Max: 14.271 Average: 11.17	Min 223.40% Max 111.70%	Bog woodland / Transition mires and quaking bogs	Min N: 0.321 / 0.321 Max N: 0.511 / 0.621 Max S: 0.19 / 0.3	Min: 9.342 Max: 14.271 Average: 11.17	Min 223.40% Max 111.70%
Rochdale Canal	SAC/SSSI	Permanent oligotrophic lakes, ponds and pools (including softwater lakes)	2 - 10	Min: 13.731 Max: 16.921 Average: 15.013	Min 750.65% Max 150.13%	Freshwater	N/A	Min: 13.731 Max: 16.921 Average: 15.013	Min 750.65% Max 150.13%
Oak Mere	SAC/SSSI	Permanent oligotrophic lakes, ponds and pools (including softwater lakes)	2 - 10	Min: 14.925 Max: 15.758 Average: 15.251	Min 762.55% Max 152.51%	Bogs	Min N: 0.321 / 0.321 Max N: 0.54 / 0.549 Max S: 0.219 / 0.228	Min: 14.925 Max: 15.758 Average: 15.251	Min 762.55% Max 152.51%
Rixton Clay Pits	SAC/SSSI/LNR	No comparable habitat with established critical load estimate available		Min: 11.078 Max: 11.162 Average: 11.12	N/A	Freshwater	N/A	Min: 0.956 Max: 0.971 Average: 0.963	N/A
Liverpool Bay	SPA	Coastal dune grasslands (grey dunes)	5 - 15	Min: 8.098 Max: 13.844 Average: 10.662	Min 213.24% Max 71.08%	Calcareous grassland (using base cation)	Min N: 0.856 / 1.071 Max N: 4.856 / 5.071 Max S: 4 / 4	Min: 0.677 Max: 1.157 Average: 0.894	Min 18.41% Max 17.63%

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Peak District Moors (South Pennine Moors Phase 1)	SPA	Raised and blanket bogs	5 - 10	Min: 14.952 Max: 23.393 Average: 19.761	Min 395.22% Max 197.61%	Bogs	Min N: 0.321 / 0.321 Max N: 0.72 / 1.181 Max S: 0.399 / 0.86	Min: 1.019 Max: 1.714 Average: 1.466	Min 203.61% Max 124.13%
Abbots Moss	SSSI	Valley mires, poor fens and transition mires	5 - 15	Min: 13.63 Max: 14.271 Average: 13.927	Min 278.54% Max 92.85%	Bogs	Min N: 0.321 / 0.321 Max N: 0.552 / 0.582 Max S: 0.231 / 0.261	Min: 1.129 Max: 1.166 Average: 1.146	Min 207.61% Max 196.91%
Astley & Bedford Mosses	SSSI	Raised and blanket bogs	5 - 10	Min: 11.182 Max: 12.101 Average: 11.685	Min 233.70% Max 116.85%	Bogs	Min N: 0.321 / 0.321 Max N: 0.564 / 0.58 Max S: 0.243 / 0.259	Min: 0.975 Max: 1.055 Average: 1.02	Min 180.85% Max 175.86%
Beechmill Wood and Pasture	SSSI	Low and medium altitude hay meadows	10 - 20	Min: 11.91 Max: 12.094 Average: 12.002	Min 120.02% Max 60.01%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.771 / 1.775 Max S: 1.414 / 1.418	Min: 0.996 Max: 1.013 Average: 1.005	Min 56.75% Max 56.62%
Black Lake, Delamere	SSSI	Raised and blanket bogs	5 - 10	Min: 14.429 Max: 14.429 Average: 14.429	Min 288.58% Max 144.29%	Bogs	Min N: 0.321 / 0.321 Max N: 0.533 / 0.533 Max S: 0.212 / 0.212	Min: 1.153 Max: 1.153 Average: 1.153	Min 216.32% Max 216.32%

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Brookheys Covert	SSSI	Carpinus and Quercus mesic deciduous forest	15 - 20	Min: 12.048 Max: 12.24 Average: 12.144	Min 80.96% Max 60.72%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.431 / 1.433 Max S: 1.074 / 1.076	Min: 1.026 Max: 1.047 Average: 1.037	Min 72.47% Max 72.37%
Buckley Claypits and Commons	SSSI	Non-mediterranean dry acid and neutral closed grassland	6 - 10	Min: 11.451 Max: 13.024 Average: 12.354	Min 205.90% Max 123.54%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.828 / 2.999 Max S: 1.471 / 2.642	Min: 0.982 Max: 1.081 Average: 1.037	Min 56.73% Max 34.58%
Connah's Quay Ponds and Woodland	SSSI	Non-mediterranean dry acid and neutral closed grassland	6 - 10	Min: 10.523 Max: 11.65 Average: 11.096	Min 184.93% Max 110.96%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.142 / 0.357 Max N: 1.72 / 1.818 Max S: 1.448 / 1.578	Min: 0.946 Max: 1.037 Average: 0.988	Min 57.44% Max 54.35%
Cotteril Clough	SSSI	Carpinus and Quercus mesic deciduous forest	15 - 20	Min: 12.789 Max: 12.974 Average: 12.867	Min 85.78% Max 64.34%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.968 / 1.968 Max S: 1.611 / 1.611	Min: 1.081 Max: 1.097 Average: 1.087	Min 55.23% Max 55.23%
Dibbinsdale	SSSI	Broadleaved deciduous woodland	10 - 15	Min: 9.081 Max: 11.378 Average: 10.181	Min 101.81% Max 67.87%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.721 / 1.727 Max S: 1.364 / 1.37	Min: 0.818 Max: 1.029 Average: 0.919	Min 53.40% Max 53.21%
Dunham Park	SSSI	No comparable habitat with established critical load estimate available		Min: 12.516 Max: 12.728 Average: 12.642	N/A	No Comparable Acidity Class		Min: 1.043 Max: 1.065 Average: 1.054	N/A

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Dunsdale Hollow	SSSI	Carpinus and Quercus mesic deciduous forest	15 - 20	Min: 12.49 Max: 12.49 Average: 12.49	Min 83.27% Max 62.45%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.142 / 0.142 Max N: 1.144 / 1.144 Max S: 1.002 / 1.002	Min: 1.055 Max: 1.055 Average: 1.055	Min 92.22% Max 92.22%
Flaxmere Moss	SSSI	Raised and blanket bogs	5 - 10	Min: 14.704 Max: 14.704 Average: 14.704	Min 294.08% Max 147.04%	Bogs	Min N: 0.321 / 0.321 Max N: 0.552 / 0.552 Max S: 0.231 / 0.231	Min: 1.185 Max: 1.185 Average: 1.185	Min 214.67% Max 214.67%
Flood Brook Clough	SSSI	Carpinus and Quercus mesic deciduous forest	15 - 20	Min: 11.776 Max: 12.029 Average: 11.902	Min 79.35% Max 59.51%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.142 / 0.142 Max N: 1.148 / 1.15 Max S: 1.006 / 1.008	Min: 1.015 Max: 1.043 Average: 1.029	Min 89.63% Max 89.48%
Frodsham Railway and Road Cuttings	SSSI	No Information Available		Min: 11.414 Max: 12.237 Average: 11.861	N/A	No Information Available		Min: 0.974 Max: 1.054 Average: 1.017	N/A
Hallwood Farm Marl Pit	SSSI	No critical load has not assigned for this feature, please seek site specific advice		Min: 8.896 Max: 8.896 Average: 8.896	N/A	No critical load has not assigned for this feature, please seek site specific advice		Min: 0.802 Max: 0.802 Average: 0.802	N/A
Hatch Mere	SSSI	No comparable habitat with established critical load estimate available		Min: 14.638 Max: 15.046 Average: 14.796	N/A	Freshwater	N/A	Min: 1.176 Max: 1.207 Average: 1.19	N/A

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Hatton's Hey Wood, Whittle's Corner and Bank Rough	SSSI	Carpinus and Quercus mesic deciduous forest	15 - 20	Min: 10.693 Max: 11.726 Average: 11.231	Min 74.87% Max 56.16%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.831 / 1.834 Max S: 1.474 / 1.477	Min: 0.897 Max: 0.98 Average: 0.94	Min 51.34% Max 51.25%
Highfield Moss	SSSI	Raised and blanket bogs	5 - 10	Min: 10.878 Max: 10.963 Average: 10.921	Min 218.42% Max 109.21%	Bogs	Min N: 0.321 / 0.321 Max N: 0.57 / 0.572 Max S: 0.249 / 0.251	Min: 0.974 Max: 0.981 Average: 0.978	Min 171.58% Max 170.98%
Holcroft Moss	SSSI	Raised and blanket bogs	5 - 10	Min: 11.301 Max: 11.331 Average: 11.316	Min 226.32% Max 113.16%	Bogs	Min N: 0.321 / 0.321 Max N: 0.571 / 0.574 Max S: 0.25 / 0.253	Min: 0.995 Max: 1.001 Average: 0.998	Min 174.78% Max 173.87%
Huddersfield Narrow Canal	SSSI	No comparable habitat with established critical load estimate available		Min: 14.208 Max: 16.327 Average: 15.271	N/A	Freshwater	N/A	Min: 1.265 Max: 1.346 Average: 1.293	N/A
Inner Marsh Farm	SSSI	Atlantic upper-mid & mid-low salt marshes	10 - 20	Min: 8.856 Max: 9.599 Average: 9.301	Min 93.01% Max 46.51%	Freshwater	N/A	Min: 0.82 Max: 0.913 Average: 0.873	N/A
Linmer Moss	SSSI	Rich fens	15 - 25	Min: 14.5 Max: 14.5 Average: 14.5	Min 96.67% Max 58.00%	No Information Available		Min: 1.16 Max: 1.16 Average: 1.16	N/A
Little Budworth Common	SSSI	Dry Heaths	5 - 15	Min: 13.101 Max: 14.316 Average: 13.651	Min 273.02% Max 91.01%	Dwarf shrub heath	Min N: 0.892 / 1.035 Max N: 1.245 / 1.352 Max S: 0.21 / 0.46	Min: 1.061 Max: 1.146 Average: 1.096	Min 88.03% Max 81.07%

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Abram Flashes	SSSI	Broadleaved deciduous woodland	10 - 15	Min: 11.458 Max: 12.032 Average: 11.759	Min 117.59% Max 78.39%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.866 / 1.88 Max S: 1.509 / 1.523	Min: 1.023 Max: 1.076 Average: 1.05	Min 56.27% Max 55.85%
Alderley Edge	SSSI	No Information Available		Min: 13.437 Max: 14.24 Average: 13.853	N/A	No Information Available		Min: 1.099 Max: 1.165 Average: 1.133	N/A
Compstall Nature Reserve	SSSI	Broadleaved deciduous woodland	10 - 15	Min: 14.849 Max: 14.943 Average: 14.896	Min 148.96% Max 99.31%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 3.174 / 3.181 Max S: 2.817 / 2.824	Min: 1.238 Max: 1.241 Average: 1.239	Min 39.04% Max 38.95%
Dark Peak	SSSI	Raised and blanket bogs	5 - 10	Min: 15.964 Max: 22.324 Average: 20.056	Min 401.12% Max 200.56%	Bogs	Min N: 0.321 / 0.321 Max N: 0.72 / 1.181 Max S: 0.399 / 0.86	Min: 1.308 Max: 1.692 Average: 1.52	Min 211.11% Max 128.70%
New Ferry	SSSI	Atlantic upper-mid & mid-low salt marshes	10 - 20	Min: 10.887 Max: 11.972 Average: 11.28	Min 112.80% Max 56.40%	Freshwater	N/A	Min: 1.005 Max: 1.09 Average: 1.038	N/A
Maes y Grug	SSSI	Non-mediterranean dry acid and neutral closed grassland	6 - 10	Min: 12.486 Max: 12.864 Average: 12.675	Min 211.25% Max 126.75%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.834 / 2.961 Max S: 1.477 / 2.604	Min: 1.055 Max: 1.074 Average: 1.064	Min 58.02% Max 35.93%

		Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
Name	**Designation**	**Lowest applicable Critical Load class**	**Critical Load Range**	**Baseline (site average)**	**Ave Baseline % of Min/Max Critical Load**	**Lowest applicable Critical Load class**	**Min/Max Critical Load (site average)**	**Baseline Deposition (site average)**	**Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)**
Mynydd Y Fflint / Flint Mountain	SSSI	Non-mediterranean dry acid and neutral closed grassland	6 - 10	Min: 11.277 Max: 11.776 Average: 11.591	Min 193.18% Max 115.91%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.811 / 1.822 Max S: 1.454 / 1.465	Min: 0.996 Max: 1.018 Average: 1.003	Min 55.38% Max 55.05%
Pettypool Brook Valley	SSSI	Valley mires, poor fens and transition mires	5 - 15	Min: 12.674 Max: 13.172 Average: 12.946	Min 258.92% Max 86.31%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.142 / 0.285 Max N: 1.077 / 1.283 Max S: 0.792 / 1.141	Min: 1.08 Max: 1.105 Average: 1.091	Min 101.30% Max 85.04%
Plumley Lime Beds	SSSI	Broadleaved deciduous woodland	10 - 15	Min: 12.403 Max: 12.587 Average: 12.494	Min 124.94% Max 83.29%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.886 / 1.887 Max S: 1.529 / 1.53	Min: 1.018 Max: 1.036 Average: 1.027	Min 54.45% Max 54.43%
Red Brow Cutting	SSSI	No Information Available		Min: 10.674 Max: 10.674 Average: 10.674	N/A	No Information Available		Min: 0.925 Max: 0.925 Average: 0.925	N/A
Old Pulford Brook Meadows	SSSI	Low and medium altitude hay meadows	10 - 20	Min: 10.047 Max: 10.1 Average: 10.074	Min 100.74% Max 50.37%	No critical load has not assigned for this feature, please seek site specific advice		Min: 0.814 Max: 0.819 Average: 0.816	N/A
River Dane	SSSI	No Information Available		Min: 12.474 Max: 12.843 Average: 12.587		No Information Available		Min: 1.009 Max: 1.035 Average: 1.017	N/A

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Sandbach Flashes	SSSI	Raised and blanket bogs	5 - 10	Min: 11.583 Max: 12.393 Average: 12.117	Min 242.34% Max 121.17%	Bogs	Min N: 0.321 / 0.321 Max N: 0.537 / 0.559 Max S: 0.216 / 0.238	Min: 0.976 Max: 1.067 Average: 1.029	Min 191.62% Max 184.08%
Shotton Lagoons and Reedbeds	SSSI	Coastal dune grasslands (grey dunes) - acid type	5 - 10	Min: 9.694 Max: 10.373 Average: 10.038	Min 200.76% Max 100.38%	Calcareous grassland (using base cation)	Min N: 1.071 / 1.071 Max N: 5.071 / 5.071 Max S: 4 / 4	Min: 0.913 Max: 0.978 Average: 0.944	Min 18.62% Max 18.62%
Stanley Bank Meadow	SSSI	Inland sanddrift and dune with siliceous grassland	5 - 15	Min: 12.027 Max: 12.197 Average: 12.112	Min 242.24% Max 80.75%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.842 / 1.848 Max S: 1.485 / 1.491	Min: 1.073 Max: 1.09 Average: 1.082	Min 58.74% Max 58.55%
Wettenhall and Darnhall Woods	SSSI	Broadleaved deciduous woodland	10 - 15	Min: 10.758 Max: 12.093 Average: 11.293	Min 112.93% Max 75.29%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.142 / 0.357 Max N: 1.229 / 2.973 Max S: 1.087 / 2.616	Min: 0.863 Max: 0.984 Average: 0.909	Min 73.96% Max 30.58%
Tabley Mere	SSSI	No comparable habitat with established critical load estimate available		Min: 12.668 Max: 12.854 Average: 12.78	N/A	Freshwater	N/A	Min: 1.031 Max: 1.05 Average: 1.041	N/A
Tatton Meres	SSSI	No comparable habitat with established critical load estimate available		Min: 12.693 Max: 13.106 Average: 12.881	N/A	Freshwater	N/A	Min: 1.043 Max: 1.069 Average: 1.055	N/A
The Mere, Mere	SSSI	No comparable habitat with established critical load estimate available		Min: 12.91 Max: 12.92 Average: 12.915	N/A	Freshwater	N/A	Min: 1.058 Max: 1.06 Average: 1.059	N/A

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Warburton's Wood and Well Wood	SSSI	Broadleaved deciduous woodland	10 - 15	Min: 11.726 Max: 12.471 Average: 12.098	Min 120.98% Max 80.65%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.833 / 1.835 Max S: 1.476 / 1.478	Min: 0.98 Max: 1.031 Average: 1.005	Min 54.83% Max 54.77%
Wimboldsley Wood	SSSI	Broadleaved deciduous woodland	10 - 15	Min: 12.727 Max: 13.042 Average: 12.884	Min 128.84% Max 85.89%	Unmanaged Broadleafed/ Coniferous Woodland	Min N: 0.357 / 0.357 Max N: 1.856 / 1.858 Max S: 1.499 / 1.501	Min: 1.045 Max: 1.068 Average: 1.057	Min 56.95% Max 56.89%
Witton Lime Beds	SSSI	Semi-dry Perennial calcareous grassland (basic meadow steppe).	10 - 20	Min: 12.54 Max: 12.626 Average: 12.57	Min 125.70% Max 62.85%	Calcareous grassland (using base cation)	Min N: 1.071 / 1.071 Max N: 5.071 / 5.071 Max S: 4 / 4	Min: 1.053 Max: 1.067 Average: 1.06	Min 20.90% Max 20.90%
Woolston Eyes	SSSI	Low and medium altitude hay meadows / Atlantic upper-mid & mid-low salt marshes	10 - 20	Min: 10.703 Max: 11.045 Average: 10.889	Min 108.89% Max 54.45%	Calcareous grassland (using base cation)	Min N: 1.071 / 1.071 Max N: 5.071 / 5.071 Max S: 4 / 4	Min: 0.923 Max: 0.963 Average: 0.943	Min 18.60% Max 18.60%
Lindow Common	SSSI/LNR	Dry Heaths	5 - 15	Min: 13.051 Max: 13.056 Average: 13.053	Min 261.06% Max 87.02%	Dwarf shrub heath	Min N: 0.714 / 0.714 Max N: 1.214 / 1.614 Max S: 0.5 / 0.9	Min: 1.087 Max: 1.094 Average: 1.09	Min 89.79% Max 67.53%

Name	Designation	Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
		Lowest applicable Critical Load class	Critical Load Range	Baseline (site average)	Ave Baseline % of Min/Max Critical Load	Lowest applicable Critical Load class	Min/Max Critical Load (site average)	Baseline Deposition (site average)	Baseline % of Min/Max Critical Load (calculated based on site average N/Acid dep)
Risley Moss	SSSI/LNR	Raised and blanket bogs	5 - 10	Min: 11.11 Max: 11.274 Average: 11.183	Min 223.66% Max 111.83%	Bogs	Min N: 0.321 / 0.321 Max N: 0.57 / 0.574 Max S: 0.249 / 0.253	Min: 0.982 Max: 1.002 Average: 0.991	Min 173.86% Max 172.65%
Hollinwood Branch Canal	SSSI/LNR	No comparable habitat with established critical load estimate available		Min: 13.843 Max: 13.93 Average: 13.887	N/A	No critical load has not assigned for this feature, please seek site specific advice		Min: 1.251 Max: 1.255 Average: 1.253	N/A

Note: APIS Mid-year Selection 2021 (2020 to 2022)

The information displayed in Table 17 highlights designated habitats within the Hynet industrial area showing the total nitrogen and sulphur deposition, the minimum and maximum nitrogen critical loads and the critical load acid deposition at habitat features sensitive to acidity. The critical load is defined as 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge' [50].

Critical loads are habitat and feature-specific within the ecological site, reflecting the sensitivity and resilience of different ecosystems to pollutants. They are estimated by considering the tolerance thresholds of the most sensitive elements within each habitat, aligning with the classifications of the European Union Nature Information System (EUNIS) to ensure consistent terminology and understanding across Europe. Critical loads are expressed as ranges to account for the variation in ecosystem responses observed across different geographical regions. Furthermore, these ranges are accompanied by an uncertainty rating—reliable, quite reliable, or expert judgment to indicate the confidence level in these estimates. The Air Pollution Information System (APIS) provides a table of critical loads for use in impact assessments, such as those part of planning applications or environmental permit applications, to guide decision-making processes in environmental management.

In a detailed examination of the impact on the HyNet area's ecosystems, Table 18 and Table 19 presents total nitrogen and sulphur deposition in the HyNet cluster by source type. The data indicates a diverse array of pollution sources, with notable variations in the contribution to nitrogen and sulphur deposition by industry, traffic, and other transportation means. However, “Other” sources such as livestock, fertilisers, imports, etc. represent the largest source in terms of both nitrogen and sulphur deposition.

Individual development air quality impact assessments may report insignificant effects following the Environment Agency’s insignificance screening criteria however the in combination impacts on sensitive ecological sites from industrial, transport and other sources can contribute to a potential risk of harm from increased air pollution [17]. The nature of an industrial cluster promotes industrial development within a specific area. An increase in industrial emissions alongside in combination emissions from traffic and other sources could increase the potential risk of harm on these sensitive sites. Holcroft Moss (SSSI) part of the Manchester Mosses (SAC) is within the HyNet cluster and has been identified as at risk from in combination impacts. Strategic solutions and measures to restore the site have been identified to combat these risks and include additional air quality assessment measures for new developments and mitigation set out in the Holcroft Moss Habitat Mitigation Plan with proposed funding by contributions from relevant developments [51].For nitrogen deposition transport is the next most significant source with road traffic typically contributing the most to nitrogen deposition, but there are some areas where other transportation sources i.e. shipping and railways contribute more, i.e. Liverpool Bay. Industrial activities have a variable impact on different habitats, contributing more to sulphur deposition than to nitrogen, as evident from Table 19. Energy production and transformation processes (e.g., electricity generation at power plants, the refining of crude oil into petroleum products, the processing of coal or natural gas, etc.) also contribute to both nitrogen and sulphur depositions, although to a lesser extent than transportation and industrial activities, suggesting room for optimisation and control in these sectors.

Table 18 - Source Attribution for Total Nitrogen Deposition

Protected Habitats	% Industry (combustion and processes)[1]	% Road Traffic	% Other Transport (i.e., aircraft, shipping, railways)	% Energy Production and Transformation[2]	% Other (e.g., livestock, fertilisers, import, etc.)
The Dee Estuary	1.1	7.7	5.7	0.5	84.9
Mersey Estuary	1.4	7.9	6.6	0.6	83.5
Rostherne Mere	1.2	9.0	6.0	0.4	83.5
South Pennine Moors	0.9	5.4	2.5	0.4	90.8
Deeside and Buckley Newt Sites	0.9	6.5	3.1	0.3	89.2
Manchester Mosses	1.3	10.3	4.1	0.6	83.7
West Midlands Mosses	1.1	6.1	4.6	0.5	87.7
Rochdale Canal	0.9	7.1	3.4	0.3	88.3
Oak Mere	1.1	6.1	2.9	0.5	89.5
Rixton Clay Pits	1.4	12.0	4.6	0.7	81.3
Liverpool Bay	0.7	5.3	12.2	0.4	81.5
Peak District Moors (South Pennine Moors Phase 1)	1.0	5.9	2.7	0.5	89.9
Abbots Moss	1.1	6.2	3.1	0.5	89.1
Astley & Bedford Mosses	1.3	10.5	4.2	0.5	83.5
Beechmill Wood and Pasture	1.2	8.8	4.4	0.5	85.1
Black Lake, Delamere	1.0	6.2	2.9	0.5	89.4
Brookheys Covert	1.4	12.0	4.6	0.5	81.5
Buckley Claypits and Commons	0.9	6.5	3.1	0.3	89.2
Connah's Quay Ponds and Woodland	1.0	7.2	3.5	0.4	88.0
Cotteril Clough	0.9	7.0	9.9	0.4	81.7
Dibbinsdale	1.4	10.3	4.0	0.6	83.7
Dunham Park	1.1	10.5	3.7	0.3	84.3
Dunsdale Hollow	1.2	8.8	4.4	0.5	85.1
Flaxmere Moss	1.0	6.7	3.1	0.3	89.0

Protected Habitats	% Industry (combustion and processes)[1]	% Road Traffic	% Other Transport (i.e., aircraft, shipping, railways)	% Energy Production and Transformation[2]	% Other (e.g., livestock, fertilisers, import, etc.)
Flood Brook Clough	1.3	8.3	4.9	0.5	85.1
Frodsham Railway and Road Cuttings	1.2	8.8	4.4	0.5	85.1
Hallwood Farm Marl Pit	1.6	10.3	4.5	0.7	82.9
Hatch Mere	1.0	6.1	2.9	0.5	89.5
Hatton's Hey Wood, Whittle's Corner and Bank Rough	1.3	8.4	5.4	0.4	84.4
Highfield Moss	1.6	13.4	6.4	0.6	78.0
Holcroft Moss	1.5	12.3	4.7	0.6	80.8
Huddersfield Narrow Canal	1.2	9.3	5.8	0.4	83.4
Inner Marsh Farm	1.4	8.9	7.1	0.4	82.2
Linmer Moss	1.0	6.2	2.9	0.5	89.4
Little Budworth Common	1.1	6.1	2.9	0.5	89.5
Abram Flashes	1.4	11.4	5.5	0.6	81.0
Alderley Edge	1.1	7.1	4.4	0.4	87.1
Compstall Nature Reserve	1.0	7.6	3.9	0.4	87.1
Dark Peak	1.2	7.0	3.1	0.6	88.1
New Ferry	1.5	8.4	3.9	0.7	85.6
Maes y Grug	1.0	7.2	3.5	0.4	88.0
Mynydd Y Fflint / Flint Mountain	1.1	7.0	4.1	0.4	87.4
Pettypool Brook Valley	1.1	7.5	4.6	0.5	86.3
Plumley Lime Beds	1.4	9.3	4.1	0.5	84.7
Red Brow Cutting	1.4	11.6	5.9	0.5	80.5
Old Pulford Brook Meadows	1.2	7.7	4.0	0.3	86.8
River Dane	1.0	6.9	3.9	0.3	87.8
Sandbach Flashes	1.1	7.1	5.5	0.4	86.0
Shotton Lagoons and Reedbeds	1.3	7.7	5.8	0.3	84.9
Stanley Bank Meadow	1.5	11.0	5.2	0.6	81.8
Wettenhall and Darnhall Woods	0.8	5.6	4.6	0.5	88.5
Tabley Mere	1.0	9.6	3.8	0.4	85.2

Protected Habitats	% Industry (combustion and processes)[1]	% Road Traffic	% Other Transport (i.e., aircraft, shipping, railways)	% Energy Production and Transformation[2]	% Other (e.g., livestock, fertilisers, import, etc.)
Tatton Meres	1.2	8.9	5.9	0.4	83.6
The Mere, Mere	1.0	9.2	3.4	0.4	86.0
Warburton's Wood and Well Wood	1.3	8.4	5.4	0.4	84.4
Wimboldsley Wood	0.9	5.6	4.6	0.3	88.7
Witton Lime Beds	1.2	8.3	5.1	0.4	85.0
Woolston Eyes	1.3	11.8	5.7	0.5	80.7
Lindow Common	0.9	7.0	9.9	0.4	81.7
Risley Moss	1.5	12.3	4.7	0.6	80.8
Hollinwood Branch Canal	1.5	11.6	7.2	0.4	79.3

Note:
[1] Industry (combustion and processes) refers to emissions from industrial activities that include the burning of fuels for process heat as well as emissions from chemical and manufacturing processes.
[2] Energy Production and Transformation,' on the other hand, relates to the generation of electricity or heat in power stations and district heating plants, and the conversion of primary energy into secondary forms (e.g., coal into electricity) or into energy carriers (e.g., oil refining).
This classification is derived from the source attribution methodologies used by the APIS which often follows standard European or national emission inventory categories.

Table 19 - Source Attribution for Total Sulphur Deposition

Protected Habitats	% Industry (combustion and processes)[1]	% Road Traffic (i.e., car, bus, LGV, HGV)	% Other Transport (i.e., aircraft, shipping, railways)	% Energy Production and Transformation[2]	% Other (e.g., livestock, fertilisers, import, etc.)
The Dee Estuary	10.8	0.7	11.8	2.7	74.0
Mersey Estuary	11.4	0.5	11.7	4.6	71.8
Rostherne Mere	10.4	0.4	5.7	2.5	80.9
South Pennine Moors	9.6	0.6	1.3	1.8	86.8
Deeside and Buckley Newt Sites	11.4	0.5	0.8	2.3	84.9
Manchester Mosses	10.2	0.6	1.8	4.0	83.4
West Midlands Mosses	10.5	0.6	1.0	2.6	85.3
Rochdale Canal	10.0	0.7	1.4	2.4	85.5
Oak Mere	10.5	0.3	1.0	2.4	85.9
Rixton Clay Pits	10.5	0.5	1.0	4.0	84.0
Liverpool Bay	3.8	0.3	61.1	1.1	33.6
Peak District Moors (South Pennine Moors Phase 1)	9.8	0.6	1.0	1.7	86.8
Abbots Moss	11.1	0.5	1.2	2.4	84.7

Protected Habitats	% Industry (combustion and processes)[1]	% Road Traffic (i.e., car, bus, LGV, HGV)	% Other Transport (i.e., aircraft, shipping, railways)	% Energy Production and Transformation[2]	% Other (e.g., livestock, fertilisers, import, etc.)
Astley & Bedford Mosses	10.8	0.7	1.9	3.1	83.6
Beechmill Wood and Pasture	10.8	0.5	3.2	4.3	81.2
Black Lake, Delamere	10.0	0.0	1.8	3.2	85.0
Brookheys Covert	10.2	0.4	0.6	3.2	85.7
Buckley Claypits and Commons	11.4	0.5	0.8	2.3	84.9
Connah's Quay Ponds and Woodland	12.1	0.3	0.8	2.5	84.2
Cotteril Clough	8.8	0.3	10.8	2.1	78.1
Dibbinsdale	8.7	0.4	2.5	3.2	85.2
Dunham Park	9.8	0.7	1.5	2.8	85.2
Dunsdale Hollow	10.8	0.5	3.2	4.3	81.2
Flaxmere Moss	10.9	0.5	1.6	2.8	84.2
Flood Brook Clough	12.4	0.6	4.3	4.3	78.5
Frodsham Railway and Road Cuttings	10.8	0.5	3.2	4.3	81.2
Hallwood Farm Marl Pit	10.1	0.0	2.2	3.2	84.5
Hatch Mere	10.1	0.5	1.8	3.5	84.1
Hatton's Hey Wood, Whittle's Corner and Bank Rough	10.1	0.5	1.7	3.2	84.4
Highfield Moss	10.4	0.4	1.7	2.3	85.2
Holcroft Moss	10.3	0.4	0.9	3.8	84.7
Huddersfield Narrow Canal	11.5	0.7	1.2	2.1	84.5
Inner Marsh Farm	12.5	0.0	2.3	2.9	82.3
Linmer Moss	10.0	0.0	1.8	3.2	85.0
Little Budworth Common	10.5	0.3	1.0	2.4	85.9
Abram Flashes	10.0	0.6	1.7	2.7	84.9
Alderley Edge	11.3	0.4	2.6	1.7	83.9
Compstall Nature Reserve	11.2	0.3	1.0	1.7	85.7
Dark Peak	9.5	0.5	1.0	1.7	87.4
New Ferry	9.0	0.6	3.9	3.9	82.6
Maes y Grug	12.1	0.3	0.8	2.5	84.2
Mynydd Y Fflint / Flint Mountain	13.1	0.8	1.6	2.3	82.2

Protected Habitats	% Industry (combustion and processes)[1]	% Road Traffic (i.e., car, bus, LGV, HGV)	% Other Transport (i.e., aircraft, shipping, railways)	% Energy Production and Transformation[2]	% Other (e.g., livestock, fertilisers, import, etc.)
Pettypool Brook Valley	12.0	0.5	1.2	2.1	84.3
Plumley Lime Beds	13.2	0.4	1.3	1.8	83.3
Red Brow Cutting	11.5	0.6	2.1	2.9	82.8
Old Pulford Brook Meadows	13.0	0.4	1.4	1.8	83.4
River Dane	12.8	0.5	0.9	1.8	84.1
Sandbach Flashes	13.9	0.4	0.9	2.2	82.6
Shotton Lagoons and Reedbeds	13.7	0.5	2.4	2.6	80.8
Stanley Bank Meadow	11.5	0.4	2.4	2.4	83.3
Wettenhall and Darnhall Woods	12.1	0.5	1.1	1.9	84.3
Tabley Mere	12.0	0.5	1.4	1.8	84.3
Tatton Meres	10.8	0.4	5.4	2.4	80.9
The Mere, Mere	10.6	0.5	0.9	1.9	86.1
Warburton's Wood and Well Wood	10.1	0.5	1.7	3.2	84.4
Wimboldsley Wood	12.0	0.6	0.8	2.0	84.6
Witton Lime Beds	13.3	0.8	1.6	2.8	81.5
Woolston Eyes	11.2	0.5	1.3	3.8	83.2
Lindow Common	8.8	0.3	10.8	2.1	78.1
Risley Moss	10.3	0.4	0.9	3.8	84.7
Hollinwood Branch Canal	11.2	0.6	1.2	2.1	84.8

Note:
[1] Industry (combustion and processes) refers to emissions from industrial activities that include the burning of fuels for process heat as well as emissions from chemical and manufacturing processes.
[2] Energy Production and Transformation,' on the other hand, relates to the generation of electricity or heat in power stations and district heating plants, and the conversion of primary energy into secondary forms (e.g., coal into electricity) or into energy carriers (e.g., oil refining).
This classification is derived from the source attribution methodologies used by the APIS which often follows standard European or national emission inventory categories.

Low Carbon Technology Projects in the HyNet Industrial Cluster

Table 20 presents a summary of the existing and proposed hydrogen production projects, new industrial development with carbon capture or existing sites which are proposing to introduce carbon capture or new sites that are proposing to use hydrogen (either pure hydrogen or a hydrogen/natural gas blend) or existing sites proposing to switch to hydrogen/hydrogen blends as a fuel. These are illustrated in Figure 36 which shows all the schemes within the HyNet Cluster and Figure 37 which focuses on those schemes that are located in and around Ellesmere Port.

Table 20 - Existing and New Industrial Projects within the HyNet Industrial Cluster

Site name	Status of the project	Project information	Technology/Approach
Essar / Vertex, Phase 1		Designed to produce compressed hydrogen, greater than 99.9% purity by volume, from a feedstock of natural gas, Refinery Off-Gas (ROG), water and oxygen and to capture the CO_2 produced by the reforming process. The CO_2 is separated from syngas process stream instead of being separated from a flue-gas stream post combustion. Captured CO_2 is compressed and exported to off-site geological storage using HyNet infrastructure.	Blue Hydrogen Production
Protos Encyclis ERF		The CCS plant proposed for Protos ERF will capture upwards of 380,000 tonnes of CO2 per year, utilising the planned HyNet pipeline that will transport CO2 for storage in depleted gas fields in Liverpool Bay	Power Generation with Carbon Capture and Storage
Runcorn Viridor ERF		Uses amine-based carbon capture to capture approximately 900,000 tonnes of CO_2 annually.	Power Generation with Carbon Capture and Storage
Cheshire Green hydrogen, Protos, Ince		Designed to have a capacity of up to 12,940 kg of hydrogen per day. The electrolysers will draw up to 30MW of electricity and will be powered by 100% renewable electricity.	Green Hydrogen Production
Evero EfW and MHI, BECCS project, Protos, Ince		Uses amine-based carbon capture to capture up to 250,000 tonnes of CO_2 per year.	Power Generation with Carbon Capture and Storage
Ince Low Carbon Power Project, Ince Marshes, Marsh Lane, Chester		Two unit low carbon combined cycle gas turbine (CCGT) generating station with a total generating capacity of around 1700-1800 Mwe. Unit 1 will be either a hydrogen fired plant, or a natural gas fired plant with post-combustion carbon capture and compression plant installed. The second unit would be a hydrogen fired CCGT.	Power Generation with Carbon Capture and Storage
Carlton Power, Trafford		Designed to have an ultimate capacity of 200MW once fully operational.	Green Hydrogen Production
Winnington CHP with CCU	Existing	Uses amine-based carbon capture to generate ~ 40,000t/annum of CO_2	Power Generation with Carbon Capture and Storage
Keuper Gas Storage Ltd		Previously designed to store up to 500 million cubic meters of natural gas within approximately 19 brine caverns. This will be amended to allow for storage of up to 1,300 GWh of hydrogen gas instead.	Hydrogen Storage
Inovyn CV, Runcorn – Project Quill 2		Electrolytic production of hydrogen with an Initial Production Capacity of 8MW	Green Hydrogen Production

Site name	Status of the project	Project information	Technology/Approach
Runcorn Membrane Chlorine Plant		produces high-purity hydrogen as a byproduct of chlorine and caustic soda production using membrane electrolysis technology. As part of HyNet's decarbonisation initiative, the plant aims to expand hydrogen distribution for use in transportation and power generation, contributing to the UK's net-zero goals; its hydrogen production capacity supports regional clean energy integration efforts.	Green Hydrogen Production
Padeswood cement works		Intended to capture up to 800,000 tonnes of CO_2 per year.	Cement Production with Carbon Capture and Storage
Carrington Power Station		The station operates with an 884.6 MW capacity, sufficient to power approximately one million homes. Plans are underway to establish a green hydrogen production facility with a 10 MW capacity, capable of producing around 4 tonnes of hydrogen daily.	Potential Hydrogen Usage
Rocksavage Power Station		This combined cycle natural gas-fired power plant has a generating capacity of 810 MW, meeting the needs of over 800,000 households. InterGen plans to modify the existing plant to blend hydrogen with natural gas by 2028, aiming for a 100% hydrogen operation as technology advances.	Potential Hydrogen Usage
Encirc Glass		Encirc, in partnership with Diageo, plans to build a new furnace at its Elton plant, set to begin production in 2027. The furnace aims to produce up to 200 million net-zero glass bottles annually by 2030, utilising low-carbon hydrogen supplied by Vertex Hydrogen.	Potential Hydrogen Usage
Unilever, Port Sunlight, Sulphonation plant	Trialled Hydrogen Usage	Switching to hydrogen fuel usage within on site boilers	Potential Hydrogen Usage
Novelis, Thelwall Lane, Warrington		To trial hydrogen usage within aluminium smelting furnaces.	Potential Hydrogen Usage
Pilkington Glass, St Helens	Trialled Hydrogen Usage	Switching to hydrogen fuel usage for glass furnaces	Potential Hydrogen Usage
Kellogs, Trafford Park, Manchester		Kellogg's has been awarded over £3 million by the UK government to trial the use of hydrogen in its cereal-making process at the Manchester factory. This initiative aims to reduce carbon emissions by transitioning from natural gas to hydrogen fuel.	Potential Hydrogen Usage
Winnington CHP		Exploring the potential to utilise hydrogen as a fuel source to decarbonise its operations.	Potential Hydrogen Usage
British Salt, Middlewich		Switching to hydrogen fuel usage within on site boilers	Potential Hydrogen Usage
HJ Heinz, Manufacturing, Wigan		Switching to hydrogen fuel usage within on site boilers	Potential Hydrogen Usage
Cargill PLC, Trafford		Switching to hydrogen fuel usage within on site boilers	Potential Hydrogen Usage
Thomas Hardy Burtonwood Ltd		In the early stages of discussions to implement hydrogen technologies within its facilities.	Potential Hydrogen Usage

Site name	Status of the project	Project information	Technology/Approach
Ingevity, Baronet Road, Warrington		Ingevity is considering the use of hydrogen for process heating and other operational needs.	Potential Hydrogen Usage
Stepan UK Ltd, Stalybridge. Surfactant production		Switching to hydrogen fuel usage within on site boilers	Potential Hydrogen Usage
United Utilities, Davyhulme		Switching to hydrogen fuel usage within on site boilers associated with anaerobic digestion	Potential Hydrogen Usage

Figure 36 – Project within the HyNet Cluster

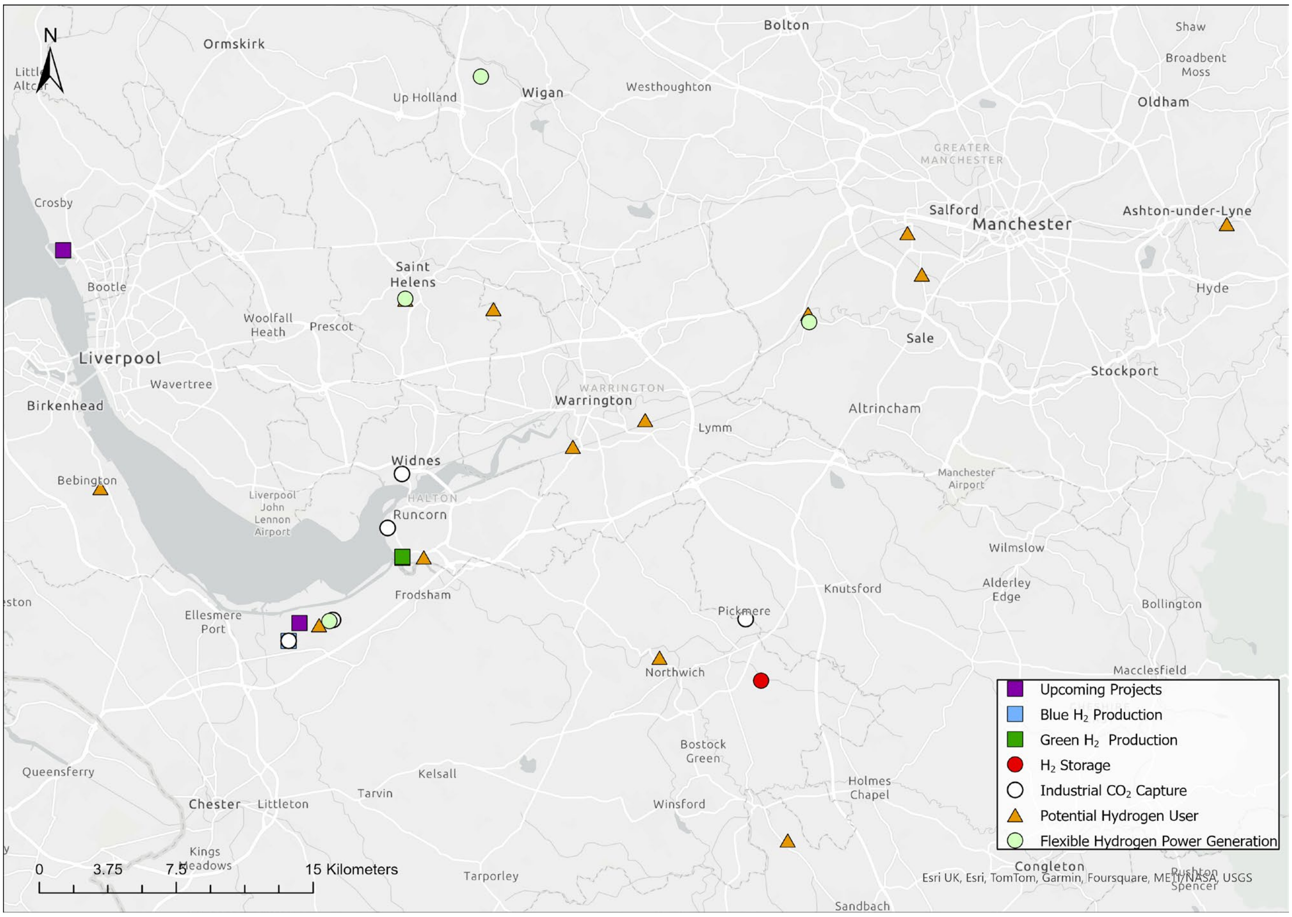
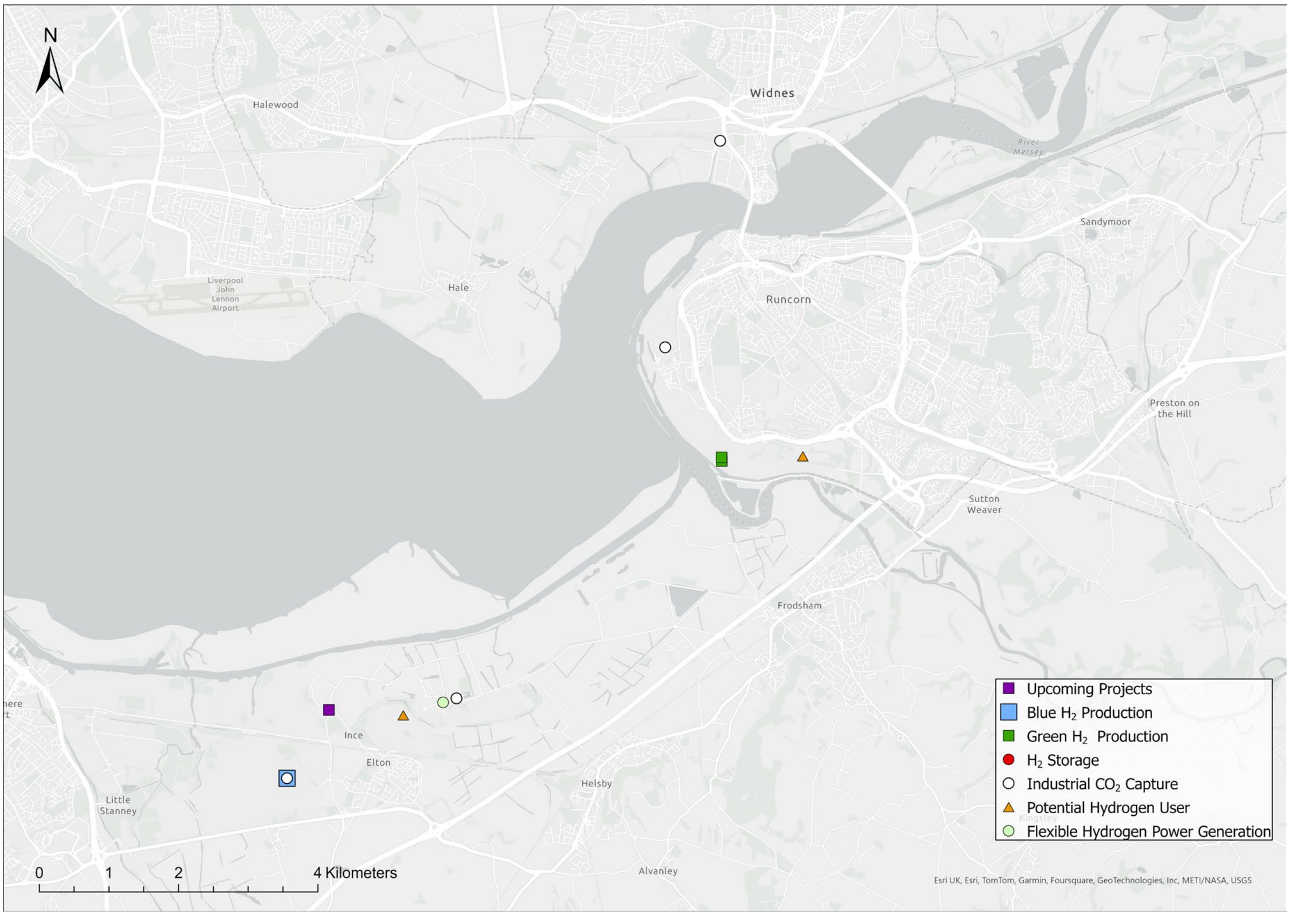


Figure 37 – Project within the Ellesmere Port Area



Low Carbon Technology Emissions and Potential Human Health Impacts

Low-carbon technologies are pivotal in mitigating climate change and reducing greenhouse gas (GHG) emissions. However, their implementation presents varying environmental and health impacts that require detailed consideration (Environment Agency, 2024 [9]). This section synthesises findings from multiple studies to evaluate the emissions and human health implications of key low-carbon technologies, including hydrogen production and combustion, carbon capture utilisation and storage (CCUS), and associated innovations.

Innovations such as advanced solvents, algae-based CCUS, and optimised hydrogen systems present opportunities to mitigate risks while maximising benefits (Environment Agency, 2024 [52]). But stringent monitoring, effective regulations, and continued research are essential to ensure that these technologies contribute positively to both environmental sustainability and public health.

Emissions from Low-Carbon Technologies

Hydrogen Production and Combustion

Hydrogen is a cornerstone of low-carbon energy solutions, with its use significantly reducing CO_2 emissions when replacing fossil fuels. Pure hydrogen combustion eliminates direct CO_2 emissions, but it often increases NO_x due to high flame temperatures. NO_x emissions from hydrogen burners can reach 102 mg/kWh, compared to 55 mg/kWh for methane combustion. Similarly, blending hydrogen with natural gas can increase NO_x emissions by up to 154%, depending on the hydrogen concentration and burner design (Zhou et al., 2024 [53]; Chen et al., 2022 [54]).

Hydrogen production methods, such as green hydrogen (via electrolysis using renewable energy) and blue hydrogen (via steam methane reforming with CCS), differ in environmental impacts. Green hydrogen produces zero direct CO_2 emissions but requires significant electricity input compared to traditional methane reforming with CCS. Blue hydrogen can capture up to 93% of CO_2 emissions; however, methane leakage rates ranging from 0.3% to 20% during production and transportation remain a significant challenge to its overall greenhouse gas footprint (Gür, 2022 [55]; Chen et al., 2022 [54]; Lin et al., 2022 [56]).

Hydrogen leakage across its lifecycle poses additional indirect warming effects, influencing methane, ozone, and stratospheric water vapor concentrations. Leakage rates from electrolysis and transport infrastructure are highly variable, with emissions from certain processes reaching as high as 10% of total production (Gür, 2022 [55]; Lin et al., 2022 [56]).

Carbon Capture Utilisation and Storage

CCUS(technologies play a crucial role in decarbonising industrial sectors. Amine-based solvents, such as MEA, are widely used for post-combustion CO_2 capture, achieving capture efficiencies up to 95%. However, the degradation of these solvents leads to emissions of nitrosamines and nitramines, compounds with carcinogenic potential. Annual amine emissions from large-scale CCS plants are estimated at 40–160 tonnes, with implications for air quality and public health (Reuters Events, 2023 [57]; Tham et al., 2020 [58]).

Innovative solvents like CESAR-1 and OASE blue reduce energy penalties by 20–25%, enhancing the economic and environmental viability of CCUS systems. Algae-based CCS provides a natural alternative, achieving up to 96% CO_2 consumption efficiency while producing valuable biomass (Environment Agency, 2024 [52]; Reuters Events, 2023 [57]).

However, stakeholder engagement (detailed in Annex 2) showed that several operators, including Encyclis, Viridor and Evero, have structured their permit applications around MEA due to its established regulatory acceptance and well-understood degradation chemistry. Tata’s site at Winnington continues to use MEA due to its well-understood degradation chemistry, which is critical for ensuring the safety of CO_2 used in pharmaceutical applications. Encyclis has a draft permit for an incinerator-based carbon capture facility using MEA but anticipates transitioning to proprietary solvents in the future, pending regulatory approvals. Similarly, Viridor’s energy-from-waste plant has an MEA-based permit in principle, with a planned variation in March 2025 to adopt a proprietary solvent from a commercial partner, though concerns remain regarding disclosure requirements and public accessibility of proprietary solvent data. Evero, in contrast, plans to deploy proprietary MHR technology solvents from the outset but faces challenges in regulatory approval, monitoring of degradation products, and understanding cumulative air quality impacts.

The industry's cautious approach reflects ongoing regulatory and technical barriers in permitting novel solvents, despite their potential advantages in reducing energy consumption and emissions.

Potential Human Health Impacts

Air Quality and Respiratory Health

Hydrogen combustion's NO_x emissions can exacerbate respiratory conditions, particularly in urban areas where air quality is already compromised. Studies indicate that transitioning to hydrogen for space heating and transport can lead to varying NO_x emissions, depending on system design and combustion conditions, with potential increases under high-temperature scenarios unless mitigated by low-NO_x burner technologies or advanced controls (Gür, 2022 [55]; Tham et al., 2020 [58]).

Nitrosamines and nitramines, byproducts of amine degradation, pose direct carcinogenic risks even at low exposure levels. Monitoring and mitigation strategies are essential to minimise these health risks (Environment Agency, 2024 [52]; Tham et al., 2020 [58]).

Occupational Hazards

Workers in hydrogen production and CCUS facilities face potential exposure to toxic substances. For instance, chronic exposure to MEA vapours has been linked to neurological effects and systemic toxicity. Additionally, hydrogen leakage poses significant risks due to its invisibility and flammability. For example, leaks in pressurised hydrogen storage or transport systems could lead to rapid gas accumulation in enclosed spaces, increasing the risk of explosions or asphyxiation for workers and nearby communities. Comprehensive safety protocols and regulatory standards are required to protect workers from long-term health risks (Environment Agency, 2024 [9] [52]; Reuters Events, 2023 [57]).

Ecosystem Impacts and Indirect Health Effects

Ecosystem degradation from nitrogen deposition and eutrophication indirectly affects human health by reducing biodiversity, compromising water quality, and amplifying respiratory and cardiovascular risks. Elevated nitrogen levels, particularly in regions like HyNet, which spans Greater Manchester, Merseyside, and Cheshire, disrupt sensitive habitats by favouring nitrogen-loving species, leading to biodiversity loss and diminished ecosystem services such as air purification, pollination, and carbon sequestration (Nitrogen Futures, 2020 [59]; Dragosits et al., 2020 [60]). Nitrogen runoff into water bodies drives eutrophication, resulting in algal blooms that deplete oxygen levels, create aquatic "dead zones," and increase the cost of water treatment for human consumption (Environment Agency, 2024 [9]). Contaminated drinking water, particularly with nitrates, poses health risks such as methemoglobinemia ("blue baby syndrome") and potential links to cancer (Nitrogen Futures, 2020 [59]; Dragosits et al., 2020 [60]). Furthermore, nitrogen emissions contribute to the formation of fine particulate matter ($PM_{2.5}$) and ground-level ozone, exacerbating respiratory and cardiovascular conditions in affected communities (Environment Agency, 2024 [9]). In industrial clusters like HyNet and Teesside, these challenges are intensified, showing the need for effective mitigation strategies to protect both ecological integrity and human health.

Carbon Capture Storage

Carbon Capture and Storage (CCS) is a critical technology for mitigating climate change, involving the capture of CO_2 emissions from industrial sources, its transportation, and subsequent storage in geological formations. While CCS has significant potential, risks associated with CO_2 leakage, particularly during start-up and shutdown phases, must be carefully managed to ensure environmental safety and public health.

Carbon Dioxide Leakage and Operational Risks

CO_2 leakage risks during storage primarily arise from faults, fractures, well integrity issues, and processes involved in CO_2 compression and injection. Poorly sealed wellbores are identified as the most likely pathways for CO_2 migration, particularly when high-pressure CO_2 is injected during compression. The compression phase increases CO_2 density for storage but also elevates pore pressure, which can induce mechanical stress, potentially damaging caprock integrity or creating fractures that facilitate leakage (Zheng et al., 2023 [61]). These pressure variations, combined with thermal stresses due to the temperature differences between injected CO_2 and the reservoir, can compromise the mechanical integrity of the wellbore environment (Roy et al., 2018 [62]). Additionally, chemical reactions between CO_2 and cement used in wellbore construction may weaken structural components over time, although in some cases, carbonate precipitation may mitigate leakage risks by sealing fractures (Wolterbeek et al., 2016 [63]). Experimental studies report leakage rates ranging from 5% to 93% of injected CO_2, influenced by geological conditions, injection depth, and operational protocols (Roberts & Stalker, 2020 [64]). Leakage pathways can be exacerbated by subsurface heterogeneities, including preferential flow paths created by faults and fractures (NRAP, 2024 [65]).

Start-up and shutdown phases present increased risks due to sudden pressure changes, which can destabilise infrastructure and amplify leakage risks. Rapid depressurisation, for instance, can cause brittleness in pipeline materials (HSE, 2024 [66]). Field experiments confirm that dynamic operational adjustments, such as injection rate fluctuations, can unpredictably alter CO_2 migration pathways (Roberts & Stalker, 2020 [64]; Turnbull et al., 2017 [67]). Studies using Well Leakage Assessment Tools indicate faster breakthrough in closer wells, with leakage observed within months of injection in high-risk scenarios (Doherty et al., 20217 [68]).

Accurate quantification of CO_2 leaks is vital for risk mitigation. Radiocarbon tracers have proven effective in detecting leaks as low as 1 ppm, while remote sensing techniques such as hyperspectral imaging enable real-time monitoring (Turnbull et al., 2017 [67]). Controlled field experiments demonstrated that mobile colorimetric sensors could detect soil CO_2 concentrations ranging from 0.1% to 30%, ensuring early detection of leakage hotspots (Ko et al., 2020 [69]).

Health and Environmental Impacts

Exposure to high concentrations of CO_2 can lead to hypercapnia, resulting in symptoms ranging from dizziness to death. Fatal incidents linked to natural CO_2 seeps in Italy illustrate the risks, with dangerous concentrations exceeding 5–10% CO_2 (Roberts et al., 2011 [70]). Even lower levels can displace oxygen in confined spaces, presenting suffocation hazards. Short-term exposure experiments indicate CO_2 fluxes of 400–2000 g/m²/day reduced bacterial diversity and enzyme activity in soil (Ma et al., 2017 [71]).

CO_2 leakage significantly impacts soil health and ecosystems. Controlled experiments reveal that soil gas concentrations exceeding 10% CO_2 or surface flux rates above 0.8 kg/m²/day can disrupt vegetation and microbial diversity. For example, experiments noted reduced soil bacterial diversity and enzyme activity changes within days of leakage (Turnbull et al., 2017 [67]; Roberts & Stalker, 2020 [64]). Marine ecosystems are also at risk, as CO_2 leakage alters pore water chemistry, affecting benthic organisms (Blackford et al., 2010 [72]). Experiments examining soil fauna exposed to CO_2 leakage reported significant declines in earthworm populations and activity, attributed to soil acidification and elevated CO_2 levels impacting respiration and nutrient cycles (Environment Agency, 2024 [52]).

Amines, used in carbon capture processes, present additional environmental and health risks. Degradation products such as nitrosamines and nitramines are known carcinogens, posing significant health concerns. Nitrosamines, for instance, exhibit acute toxicity with T25 values of 0.075 mg/kg/day. These byproducts can accumulate in the environment, with nitramines showing extended stability in soil and water. Atmospheric dispersion models have highlighted the elevated risks during stable winter conditions, where nitrosamine concentrations near emission sources are significantly higher. Mitigation strategies such as advanced photolysis systems and UV treatment have reduced these emissions by up to 90% (Environment Agency, 2025 [73]).

Amine degradation has also been linked to secondary emissions of volatile organic compounds and ammonia, further complicating environmental impacts. For example, operational conditions in poorly optimised systems can release up to 1.2 g of ammonia per kilogram of solvent processed. This denotes the need for stringent monitoring and advanced degradation management techniques (Environment Agency, 2025 [73]).

Accepted Practices for CO_2 Transfer and Storage

Containment Risk Assessments (CRA) using bowtie diagrams are essential tools for identifying and mitigating leakage risks (Risktec, 2024 [74]). Probabilistic models such as the NRAP-IAM-CS provide predictive insights into subsurface leakage pathways and inform effective monitoring strategies (Roberts & Stalker, 2020 [64]).

Continuous monitoring through isotopic tracers, hyperspectral imaging, and MMV frameworks ensures early detection and mitigation of leaks. Techniques such as Differential Absorption LIDAR and Fourier Transform Infrared Spectroscopy have enhanced real-time monitoring capabilities (Turnbull et al., 2017 [67]; Risktec, 2024 [74]). The integration of soil microbial assays provides a low-cost method for early warning of ecosystem degradation (Ma et al., 2017 [71]).

Proper design and maintenance of CCS infrastructure are critical for minimising risks. Strategies include:

- Ensuring multi-barrier well integrity through advanced materials and self-healing mechanisms (HSE, 2024 [66]).
- Designing pipelines to withstand supercritical CO_2 pressures, accounting for potential phase changes (Risktec, 2024 [74]).
- Establishing operational protocols to manage pressure fluctuations during start-up and shutdown phases.

Global regulatory frameworks, such as the EU Carbon Dioxide Capture and Geological Storage Directive, mandate stringent performance standards to minimise CO_2 losses. Guidelines require that leakage remains below 1% over 1000 years, emphasising continuous monitoring and robust risk assessments (HSE, 2024 [66]). Field studies recommend that groundwater monitoring well spacing not exceed 80 m in high-risk zones to ensure early detection (NRAP, 2024 [65]).

For amine-based systems, the implementation of advanced monitoring technologies like PTR-MS and chemometric models has significantly improved the detection of nitrosamines and nitramines. Operational adjustments, including optimised pressure and temperature parameters, are crucial to minimise solvent degradation and associated emissions. Pilot studies have shown that these measures can reduce nitrosamine emissions to undetectable levels in surrounding water bodies (Environment Agency, 2025 [73]).

Analysis of HyNet Workshops

Discussions were held with industrial stakeholders, the local councils, EA officers, HSE and NE in the HyNet area. A more detailed writeup of each workshop can be found in Annex 2, however, this section summarises the general points of discussion related to potential emissions and air quality impacts from developments within the HyNet Industrial Cluster, which highlighted several key issues, knowledge gaps, and challenges related to hydrogen production, carbon capture, and environmental permitting. These workshops provided valuable insights into the technical, environmental, and regulatory hurdles associated with low-carbon technology deployment and emphasised the importance of managing both direct and cumulative impacts on air quality and ecological receptors.

Hydrogen production and combustion were identified as critical components of the cluster, with discussions focusing on the potential emissions, technological requirements, and operational challenges. Hydrogen venting during emergencies was noted as a minor risk, with systems designed to minimise releases. However, uncertainties remain regarding the implications of fugitive emissions, particularly as hydrogen is a potent greenhouse gas. The blending of hydrogen with natural gas in combustion processes was considered viable up to 45% in current systems, but higher blends would require significant technological upgrades. Concerns were raised about the increase in NO_x emissions associated with hydrogen combustion, which may necessitate additional abatement measures such as water injection or SCR. High water demand for abatement and the potential for visible plumes from cooling systems were highlighted as operational challenges, especially when transitioning to higher hydrogen blends.

The workshops underscored the complexities of carbon capture technology, particularly regarding permitting, solvent selection, and emissions management. Amine-based solvents, such as MEA, were frequently discussed due to their established use and regulatory familiarity. However, proprietary solvents offering improved efficiency and lower energy demands remain underutilised due to challenges in permitting and the need for confidentiality. The degradation of amines into secondary pollutants, such as nitrosamines, and their potential impacts on human health and ecological receptors were highlighted as areas requiring further research and monitoring. Stakeholders emphasised the need for more comprehensive EALs and monitoring technologies to better quantify these emissions and assess their impacts.

Ecological impacts were a recurring concern, particularly in relation to sensitive sites such as the Mersey Estuary SSSI, Ramsar site, and nearby SPAs. Background nitrogen deposition in these areas already exceeds critical loads, making additional contributions from cluster developments a significant issue. Nutrient neutrality and aerial dispersion were noted as key factors in assessing the cumulative impacts of nitrogen deposition. Stakeholders emphasised the importance of addressing these concerns through stringent air quality assessments and enhanced monitoring of amines, nitrosamines, and other pollutants.

Monitoring and modelling limitations were identified as significant barriers to effective impact assessment. Current technologies for detecting low concentrations of amines and degradation products are insufficient, and there is a lack of validated methodologies for cumulative impact assessments. Stakeholders suggested exploring advanced modelling tools and improving data sharing through centralised databases to address these gaps. The absence of tools for predicting nitrogen deposition and its impacts on sensitive habitats further complicates ecological assessments. The development of area-wide modelling and digital twins was proposed as a means to improve the understanding of cumulative impacts within the cluster.

Permitting challenges remain a significant obstacle for low-carbon technology deployment. The lack of established BAT standards for carbon capture and hydrogen technologies has led to reliance on interim guidance, which stakeholders noted as inadequate for ensuring consistent regulatory outcomes. Delays in government policy and support mechanisms, such as hydrogen storage business models, were also identified as potential risks to project timelines and investment confidence. The need for clearer guidance on emissions offsetting and cumulative assessments was emphasised, alongside the importance of engaging with regulators early in the project lifecycle.

Stakeholders highlighted several recommendations for the EA to address these challenges. These included accelerating the development of EALs for amines and degradation products, improving guidance on solvent disclosure and permitting requirements, and fostering collaboration between industry and regulators to close knowledge gaps. Establishing a public solvent library and improving transparency in emissions data were proposed as measures to enhance understanding and support evidence-based decision-making. Additionally, stakeholders called for more robust monitoring networks and research into the long-term impacts of low-carbon technologies on air quality and sensitive ecological receptors.

Future Air Quality and Climate in the HyNet Industrial Cluster

The trajectory of air quality and ecological health within the HyNet Industrial Cluster reflects a synergistic response to national trends and localised strategic initiatives. The United Kingdom has witnessed substantial reductions in key air pollutants, with NO_x emissions decreasing by 63% and NH_3 by 12% from 2005 to 2022, signifying an overarching national movement towards a cleaner atmosphere (JNCC, 2020 [40]). These positive changes are echoed within the HyNet area, where, for instance, the annual average NO_2 concentration in Cheshire West and Chester has decreased from 26.5 $\mu g/m^3$ in 2019 to 19.8 $\mu g/m^3$ in 2023, demonstrating the effectiveness of air quality management strategies already in place (Table 11). Despite this progress, NH_3 emissions within the cluster, remain a persistent issue that requires targeted mitigation.

The multifaceted challenges posed by climate change, which are projected to affect air and water quality, necessitate the implementation of adaptive strategies to mitigate the resulting impacts (EPA, 2024 [75] [76]). Specifically, the potential for exacerbated air quality issues due to rising temperatures and changing precipitation patterns threatens to disproportionately affect vulnerable populations and ecosystems (IPCC, 2022 [77]).

The baseline in Table 21 is estimated from the Ringway meteorological station and projections are estimated for the 25km grid square where the meteorological station is located (Met Office, 2024 [78]).

The projected changes to temperature and precipitation patterns presented in Table 21 and illustrated graphicly in Figure 38 to Figure 43. These show estimates from the UK Climate Projections (UKCP) tool [79] from a 1981-2000 baseline for various GHG emission scenarios based on anthropogenic drivers.

Projections are presented for the following scenarios: a high emissions scenario (Figure 38 and Figure 41) where CO_2 emissions double from 2015 to 2050 (RCP5-8.5), an intermediate emissions scenario (Figure 39 and Figure 42) where CO_2 emissions levels are maintained at 2015 levels and then begin to decrease after 2050 (RCP2-4.5) and a low emissions scenario (Figure 40 and Figure 43) where CO_2 emissions drop to half of 2015 levels by 2050 (RCP1-2.6) (IPCC, 2024 [80]).

Table 21 – 50th, 10th and 90th Percentile Climate Projections within the HyNet Cluster

Climate Variable		Baseline	RCP1-2.6		RCP2-4.5		RCP5-8.5	
		1981-2000	2020-2039	2040-2059	2020-2039	2040-2059	2020-2039	2040-2059
Temperature	Mean Annual Maximum Daily Temperature	13.3 °C	+0.97 °C (+0.38 - +1.61 °C)	+1.20 °C (+0.52 - +1.99 °C)	+0.83 °C (+0.28 - +1.44 °C)	+1.29 °C (+0.48 - +2.19 °C)	+0.94 °C (+0.35 - +1.58 °C)	+1.73 °C (+0.79 - +2.66 °C)
	Mean Annual Minimum Daily Temperature	6.4 °C	+0.86 °C (+0.31 - +1.41 °C)	+1.08 °C (+0.46 - +1.82 °C)	+0.72 °C (+0.21 - +1.26 °C)	+1.15 °C (+0.48 - +1.91 °C)	+0.86 °C (+0.32 - +1.46 °C)	+1.55 °C (+0.73 - +2.45 °C)
	Highest Mean Monthly Temperature (July)	20.6 °C	+1.41 °C (+0.11 - +2.84 °C)	+1.92 °C (+0.41 - +3.52 °C)	+1.08 °C (-0.23 - +2.50 °C)	+1.69 °C (0.00 - +3.49 °C)	+1.32 °C (-0.16 - +2.71 °C)	+2.46 °C (+0.46 - +4.54 °C)
	Lowest Mean Monthly Temperature (January)	7.1 °C	+0.73 °C (-0.42 - +1.87 °C)	+0.92 °C (-0.41 - +2.40 °C)	+0.73 °C (-0.35 - +1.87 °C)	+1.17 °C (-0.15 - +2.62 °C)	+0.81 °C (-0.30 - +2.02 °C)	+1.49 °C (+0.04 - +3.16 °C)
	Annual Average Days of Air Frost	3.3	Met Office has projected a trend towards fewer air frost days.					
Precipitation	Mean Annual Rainfall	68.3 mm	+0.99% (-4.20 - +6.75%)	-0.68% (-6.12 - +4.68%)	+1.25% (-4.07 - +7.01%)	-0.39% (-5.87 - +5.41%)	+1.29% (-4.21% - +7.17%)	-0.45% (-6.74% - +5.81%)
	Wettest Rainfall Month (October)	96.3 mm	+4.14% (-18.54 - +30.36%)	+9.68% (-12.95 - +35.59%)	+4.33% (-17.61 - +29.01%)	+12.93% (-12.90 - +39.28%)	+4.92% (-19.59% - +30.98%)	+14.69% (-14.75% - +46.03%)
	Driest Rainfall Month (February)	47.1 mm	+1.96% (-13.32 - +18.85%)	+7.73% (-12.65 - +26.94%)	+0.86% (-13.01 - +14.88%)	+6.93% (-13.04 - +25.58%)	+1.62% (-12.76% - +16.48%)	+9.24% (-11.30% - +31.12%)

Figure 38 – Temperature Projections within the HyNet Cluster – High Emission Scenario

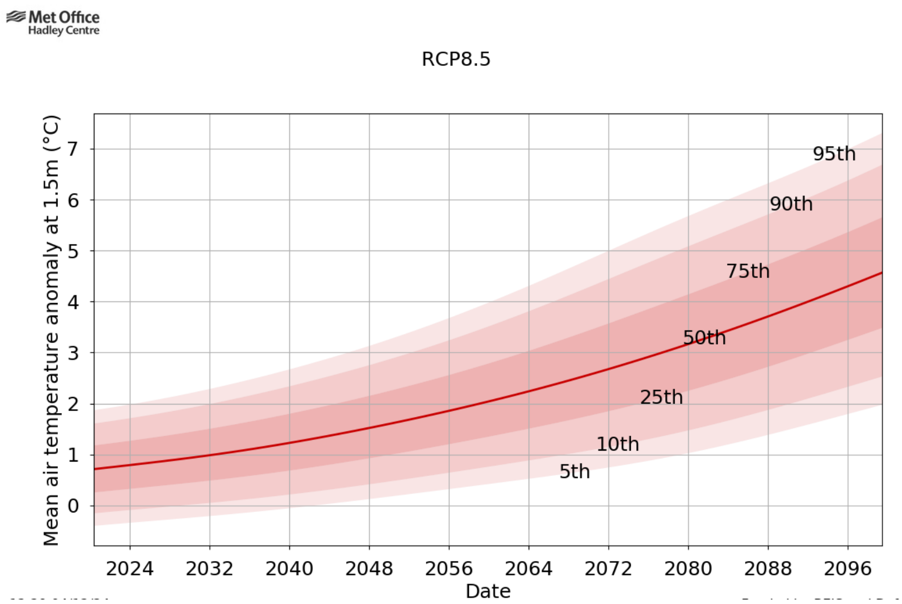


Figure 39 – Temperature Projections within the HyNet Cluster – Intermediate Emission Scenario

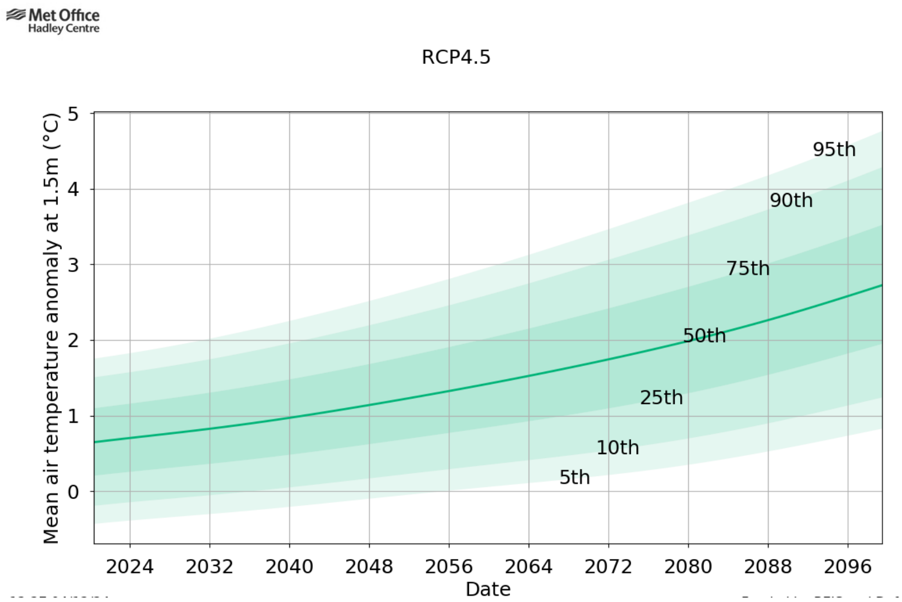


Figure 40 – Temperature Projections within the HyNet Cluster – Low Emission Scenario

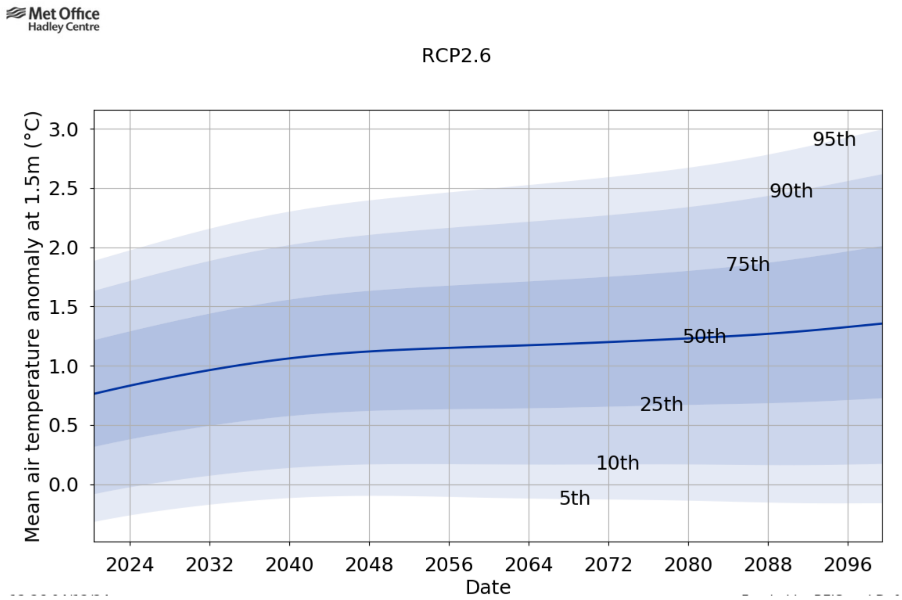


Figure 41 – Precipitation Projections of Air Pollutants in the UK – High Emission Scenario

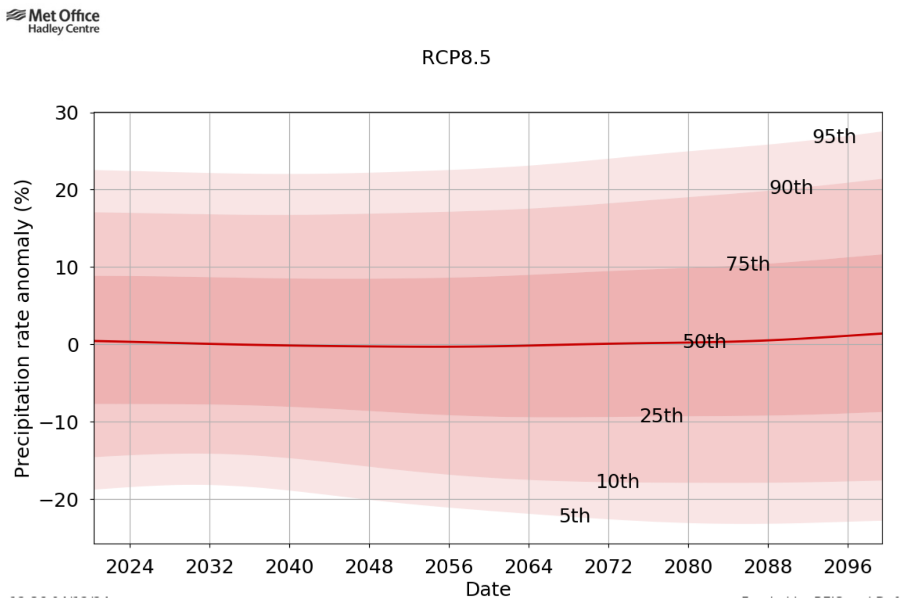


Figure 42 – Precipitation Projections of Air Pollutants in the UK – Intermediate Emission Scenario

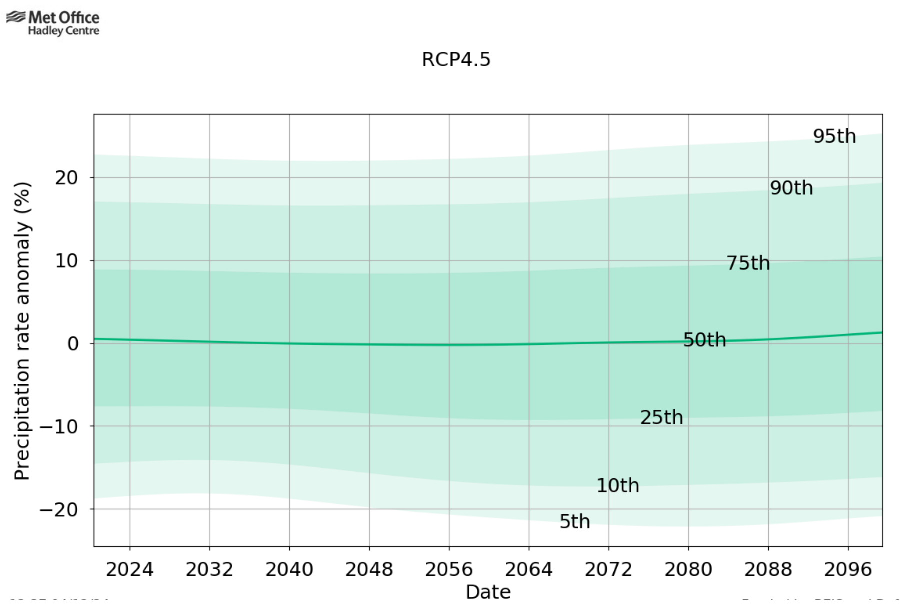
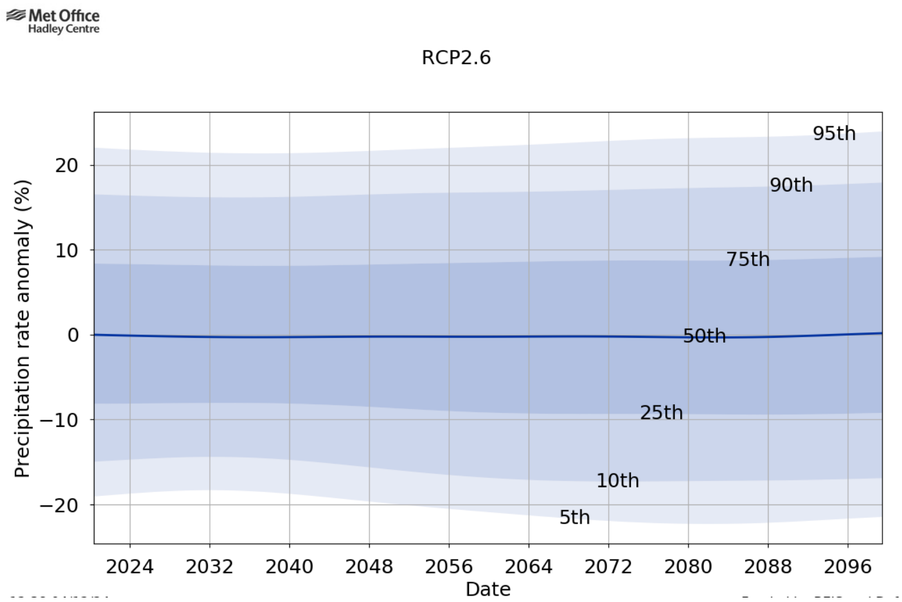


Figure 43 – Precipitation Projections of Air Pollutants in the UK – Low Emission Scenario



Overall, an increase in average temperatures is expected for all emission scenarios, this increase is similar across all scenarios between 2020-2039 with RCP2-4.5 predicting the smallest temperature increases in the short-term, but larger temperature increases can be expected with larger emission rates if projected further in time as evident from 2040-2059 annual mean temperature values. Precipitation rates are more unpredictable with a larger degree of uncertainty as to how they will change, but it can generally be expected that the annual precipitation rate will roughly stay the same with some variation in the pattern throughout the year.

Conclusions

As we look to the future, the advancement of low and zero-carbon technologies, including hydrogen production and carbon capture, signals a significant transformation towards a sustainable industrial framework (Schröder et al., 2024, Dutka et al., 2016 [81] [82]). The implementation of these technologies, while essential for carbon emission reduction, introduces potential environmental challenges that must be carefully managed. Notably, the combustion of hydrogen could result in elevated NO_x emissions, necessitating the adoption of comprehensive environmental management strategies to minimise any adverse impacts (Spietz et al., 2017 [83]). It is crucial to ensure that the local ecosystems' environmental capacity, especially regarding nitrogen deposition, is taken into account when introducing new technologies or emission sources which could increase emissions to air so as to prevent ecological harm.

To ensure the sustainability of the HyNet Cluster's evolution towards a hydrogen economy and a carbon-neutral future, further research is vital [84]. Key focus areas should include evaluating the environmental impacts of hydrogen production and the long-term effectiveness of carbon capture technologies. Establishing a robust environmental monitoring framework is imperative to assess how the cluster's development influences air quality and ecological health comprehensively (UKHSA, 2023 [85] [86] [87]).

In light of this transition, the HyNet Industrial Cluster's journey exemplifies the balance between industrial innovation and environmental sustainability. To safeguard this balance addressing known unknowns, incorporating adaptive management strategies, and ongoing policy review are crucial. Integrating insights from stakeholder discussions and regularly assessing emission limit values (ELVs) will be essential to protect the future air quality and ecological well-being of the area (UKHSA, 2023; AQEG, 2021 [85] [86] [88]).

Regarding hydrogen combustion, the Environment Agency has outlined specific NO_x ELVs for both existing and new plants using hydrogen as a single fuel or in blends with natural gas [56]. These values are based on a correction factor applied to the NO_x ELVs established for natural gas to account for the changes in flue gas volume when using hydrogen. For example, at 100% hydrogen substitution a correction factor of 1.37 is applied to ELVs for natural gas combustion as specified in the guidelines for combustion plants covered by the Medium Combustion Plant Directive (MCPD) and the IED for Large Combustion Plant (LCP).

The HyNet Industrial Cluster aims to integrate pioneering low and zero-carbon technologies, including hydrogen production and carbon capture, the cluster faces a complex matrix of opportunity and challenge. The future air quality and ecological health of the cluster are hinged on the cluster’s ability to not only navigate but also to harness these complexities for environmental and economic benefit [89].

Carbon capture, utilisation, and storage (CCUS) technologies, diligent environmental management, technological optimisation, and adherence to evolving emission standards are indispensable for initiating a hydrogen economy. The risks of climate overshoot and significant carbon budget consumption, highlighted by Dillman and Heinonen (2023) [90], underscore the urgency of advancing clean hydrogen technologies. Meanwhile, the Global Warming Potential of hydrogen, articulated by Sand et al. (2023) [91], reinforces the need for a comprehensive approach to minimise hydrogen leakage and refine greenhouse gas impact estimates.

A comprehensive environmental monitoring framework becomes pivotal in this context. Such a framework should not facilitate the strategic assessment and management of cumulative air quality impacts and support the cluster's ambitious industrial development while preserving ecological integrity. This includes:

- Detailed studies on the lifecycle environmental impacts of hydrogen production and use, particularly for water usage, NO_x emissions and potential leakage.
- Long-term assessments of the effectiveness and environmental impacts of carbon capture technologies, focusing on amine emissions and their degradation products.
- Continuous monitoring and modelling to refine projections of air quality and ecological health within the cluster, informed by real-time data and technological advancements.

Rigorous research into the known unknowns of carbon capture technologies and the environmental impacts of different hydrogen production methods to inform adaptive policy-making and stakeholder engagement.

References

[1] HM Government, “The Air Quality Standards (Amendment) Regulations (2016). SI 2016 No. 1184,” Her Majesty’s Stationery Office, 2016.

[2] U. S. Instruments, “The Environment (Miscellaneous Amendments) (EU Exit) Regulations 2020,” 2020.

[3] European Commision, “Industrial Emission Directive (IED),” 2024.

[4] UK Public General Acts, “Clean Air Act,” 1993. [Online].

[5] HM Government, “Environment Act 1995, Part IV Air Quality,” Her Majesty’s Stationery Office, 1995.

[6] HM Government, “Environment Act 2021,” 2021.

[7] HM Government, “Climate Change Act,” 2008. [Online].

[8] UK Statutory Instruments, “The Environmental Permitting (England and Wales) Regulations,” 2016. [Online].

[9] Environment Agency, “Environmental Constraints in Industrial Clusters - Phase 3 Technical Annex 2,” 2024. [Online].

[10] Department for Environment, Food and Rural Affairs (Defra), “Clean Air Strategy 2019,” 2019.

[11] Department for Environment, Food and Rural Affairs (Defra), “A Green Future: Our 25 Year Plan to Improve the Environment,” 2018.

[12] Department for Environment, Food & Rural Affairs (Defra), “Environmental Improvement Plan 2023,” 2023.

[13] Department for Environment, Food and Rural Affairs (Defra), “The Air Quality Strategy for England, Scotland, Wales and Northern Ireland 2000,” 2000.

[14] Department for Environment, Food and Rural Affairs (Defra), “The Air Quality Strategy for England, Scotland, Wales and Northern Ireland 2007,” Her Majesty’s Stationery Office, 2007.

[15] Department for Environment, Food and Rural Affairs (Defra), “Air quality strategy: framework for local authority delivery,” Her Majesty’s Stationery Office, 2023.

[16] Department for Environment, Food and Rural Affairs (Defra), “Local Air Quality Management. Technical Guidance 2022 (LAQM.TG22),” 2022.

[17] Environment Agency (EA), “Air emissions risk assessment for your environmental permit,” [Online]. Available: https://www.gov.uk/government/collections/risk-assessments-for-specific-activities-environmental-permits#air-emissions. [Accessed February 2024].

[18] H. Government., “Air emissions risk assessment for your environmental permit,” 2016. [Online].

[19] HM Government, “Appendix C: summary of toxicological evidence for MEA and NDMA,” 2021. [Online]. Available: https://www.gov.uk/government/consultations/environmental-assessment-levels-eals-used-in-air-emissions-risk-assessments/public-feedback/appendix-c-summary-of-toxicological-evidence-for-mea-and-ndma.

[20] European Commission (EC), “The Habitats Directive EC 92/43/EEC,” European Economic Community, 1992.

[21] United Nations Educational, Scientific and Cultural Organization (UNESCO), “Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat,” 1971.

[22] H.M. Government, “The Conversion of Habitats and Species Regulations, SI1490,” Her Majesty’s Stationery Office, 2010.

[23] H.M. Government, “Wildlife and Countryside Act (as amended),” 1981.

[24] H.M. Government, “Countryside and Rights of Way Act (as amended),” 2000.

[25] Jane Hall et al., “Methods for the calculation of critical loads and their exceedances in the UK. Report to Defra, prepared under Contract AQ0826,” 2015.

[26] Air Pollution Information System (APIS), “Air Pollution Information System,” 2024. [Online]. Available: https://www.apis.ac.uk/.

[27] Department for Enviornment Food & Rural Affairs, “Air Pollution in the UK 2023,” 2024.

[28] Department for Environment Food & Rural Affairs (Defra), “Air Pollution in the UK 2022,” 2023.

[29] Natural England, “Nutrient Mitigation Scheme,” 2023. [Online].

[30] Department for Environment Food & Rural Affairs (DEFRA), “Emissions of air pollutants in the UK - Summary,” 19 February 2024. [Online]. Available: https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-summary. [Accessed February 2024].

[31] HM Government, “The National Emission Ceilings Regulations,” 2018. [Online]. Available: https://www.legislation.gov.uk/uksi/2018/129/contents/made. [Accessed February 2024].

[32] Ingledew D et al., “UK Informative Inventory Report (1990 to 2021),” Department for Environment, Food and Rural Affairs (Defra), 2023.

[33] The Stationery Office (TSO) , “Environmental Protection Act,” 1990. [Online]. Available: https://www.legislation.gov.uk/ukpga/1990/43/pdfs/ukpga_19900043_en.pdf.

[34] European Commission, “Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control),” January 2011. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02010L0075-20110106.

[35] European Commision, “Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC,” 20 November 2023. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31998L0070.

[36] Statutory Instuments 1990 No. 1013, “The Nitrate Sensitive Areas (Designation) Order 1990,” 1990. [Online]. Available: https://www.legislation.gov.uk/uksi/1990/1013/pdfs/uksi_19901013_en.pdf.

[37] Joint Nature Conservation Committee (JNCC), “UKBI - B5a. Air pollution,” 2023. [Online]. Available: https://jncc.gov.uk/our-work/ukbi-b5a-air-pollution#key-results. [Accessed February 2024].

[38] Natural England, “Guidance on Nutrient Pollution and Sensitive Ecosystems,” 2023. [Online].

[39] Ed Rowe et al., “Trends Report 2022: Trends in critical load and critical level exceedances in the UK,” Department for Environment, Food and Rural Affairs (Defra), 2023.

[40] Join Nature Conservation Committee (JNCC), “Nitrogen Futures, JNCC Report No. 665,” October 2020. [Online]. Available: https://data.jncc.gov.uk/data/04f4896c-7391-47c3-ba02-8278925a99c5/JNCC-Report-665-FINAL-WEB.pdf.

[41] Science and Industry Museum, “Manchester’s smoke nuisance: air pollution in the industrial city,” 2021. [Online]. Available: https://www.scienceandindustrymuseum.org.uk/objects-and-stories/air-pollution.

[42] Runcorn Historical Society, “Runcorn : A Historical Sketch,” [Online]. [Accessed 2025].

[43] Cheshire West and Chester Council, “Pollution and air quality,” 2024. [Online].

[44] Redcar and Cleveland Borough Council, “Air Quality Annual Status Report 2022,” 2023.

[45] Middlesbrough Council, “Air Quality Annual Status Report 2022,” 2023.

[46] Hartlepool Borough Council , “Air Quality Annual Status Report 2021,” 2022.

[47] Darlington Borough Council, “Air Quality Annual Status Report 2022,” 2023.

[48] Stockton on Tees Borough Council , “Air Quality Annual Status Report 2022,” 2023.

[49] Department for Environment Food and Rural Affairs (Defra), “Defra data services platform,” [Online]. Available: https://environment.data.gov.uk/. [Accessed February 2024].

[50] J. a. G. P. Nilsson, “Critical Loads for Sulphur and Nitrogen,” Report from Skokloster Workshop, 1988.

[51] M. C. Council, “Holcroft Moss Supplementary Planning Document,” 2024.

[52] Environment Agency (EA), “Environmental Constraints in Industrial Clusters - Phase 3 Technical Annex 1,” 2024.

[53] Zhou Y. et al., “Potential and critical pathways of CO 2 emissions reduction: A city-based study,” *Carbon Capture Science & Technology,* 2024.

[54] Chen S. et al., “A critical review on deployment planning and risk analysis of carbon capture, utilization, and storage (CCUS) toward carbon neutrality,” *Renewable and Sustainable Energy Reviews,* 2022.

[55] Gur T. M., “Carbon Dioxide Emissions, Capture, Storage and Utilization: Review of Materials, Processes and Technologies,” *Progress in Energy and Combustion Science,* 2022.

[56] Lin Q. et al., “Technical Perspective of Carbon Capture, Utilization, and Storage,” *Engineering,* 2022.

[57] Reuters Events, “LESSONS FROM PEERS: DECARBONISING INDUSTRY THROUGH INDUSTRIAL CLUSTERS,” 2023. [Online].

[58] Tham R. et al., “Scoping review to understand the potential for public health impacts of transitioning to lower carbon emission technologies and policies,” *Environmental Research Communications,* 2020.

[59] Nitrogen Futures, “UNDERSTANDING IMPACTS OF NITROGEN ON NATURE,” JNCC, 2020.

[60] Dragosits U. et al., “Nitrogen Futures,” JNCC, 2020.

[61] Zheng F. et al., “Controlled CO2 Injection into Storage Reservoirs to Minimize Geomechanical Risks Under Geologic Uncertainty,” *SPE Annual Technical Conference and Exhibition,* 2023.

[62] Roy P. et al., “Effect of thermal stress on wellbore integrity during CO2 injection,” *International Journal of Greenhouse Gas Control,* vol. 77, pp. 14-26, 2018.

[63] Wolterbeek T. K. T. et al., “Effect of CO2-induced reactions on the mechanical behaviour of fractured wellbore cement,” *Geomechanics for Energy and the Environment,* vol. 7, pp. 26-46, 2016.

[64] S. L. Roberts J. J., “What have we learnt about CO2 leakage from CO2 release field experiments, and what are the gaps for the future?,” *Earth-Science Reviews,* 2020.

[65] NRAP, “Integrated Assessment Model for CO_2 Storage. National Risk Assessment Partnership Technical Report.,” 2024.

[66] HSE, “Major Hazard Potential of Carbon Dioxide,” Health and Safety Executive, 2024.

[67] Turnbull J. C. et al., “Atmospheric Monitoring of Carbon Capture and Storage Leakage Using Radiocarbon,” *Environmental Monitoring Journal,* 2017.

[68] Doherty B. et al., “Estimating the Leakage Along Wells During Geologic CO_2 Storage: Application of the Well Leakage Assessment Tool to a Hypothetical Storage Scenario in Natrona County, Wyoming,” *Energy Procedia,* 2017.

[69] Ko Y. et al., “Highly Efficient Colorimetric CO_2 Sensors for Monitoring CO_2 Leakage from carbon capture and storage sites,” *Sensors and Actuators.,* 2020.

[70] Roberts J. R. et al., “Assessing the health risks of natural CO_2 seeps in Italy,” *National Academy of Sciences,* 2011.

[71] Ma J. et al., “Short-term effects of CO2 leakage on the soil bacterial community in a simulated gas leakage scenario,” 2017.

[72] Blackford J. et al., “Environmental risks and performance assessment of carbon dioxide (CO2) leakage in marine ecosystems,” *Developments and Innovation in Carbon Dioxide (CO2) Capture and Storage Technology,* 2010.

[73] Environment Agency, “Environmental Capacity in Industrial Clusters - Phase 4 Technical Annex 1,” 2025.

[74] Risktec, “Carbon Dioxide Containment Risk Assessment: The Current State-of-the-Art,” 2024.

[75] Environmental Protection Agency (EPA), “Climate Change Impacts.,” 2024. [Online]. Available: https://www.epa.gov/climateimpacts.

[76] Environmental Protection Agency (EPA), “Climate Change Impacts on Air Quality.,” 2024. [Online]. Available: https://www.epa.gov/climateimpacts/climate-change-impacts-air-quality.

[77] Intergovernmental Panel on Climate Change (IPCC), “Climate Change 2022: Impacts, Adaptation and Vulnerability.,” 2022. [Online]. Available: https://www.ipcc.ch/report/ar6/wg2/.

[78] The Meteorological Office, “Historic Station Data,” 2024. [Online]. Available: https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data. [Accessed 2024].

[79] The Meteorological Office, “UK Climate Projections (UKCP),” 2024. [Online]. Available: https://ukclimateprojections-ui.metoffice.gov.uk/ui/home. [Accessed 2024].

[80] Intergovernmental Panel on Climate Change (IPCC), “AR6 Summary for Policymakers,” 2024. [Online]. Available: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf. [Accessed 2024].

[81] Schröder et al., “Experimental mild conversion of a lean burn natural gas engine with SCR to a hydrogen engine: NOx and GWP potential for marine applications.,” *International Journal of Engine Research, 24(6).,* pp. 2369-2387, 2022.

[82] Dutka et al., “NOx emissions and turbulent flow field in a partially premixed bluff body burner with CH4 and H2 fuels.,” *International Journal of Hydrogen Energy, 41(28),,* pp. 12397-12410, 2016.

[83] Spietz et al., “Ammonia emission from CO2 capture pilot plant using aminoethylethanolamine.,” *International Journal of Environmental Science and Technology, 15(5).,* pp. 1085-1092, 2017.

[84] Derwent et al., “Global environmental impacts of the hydrogen economy.,” 2006.

[85] UK Health Security Agency (UKHSA), “Chapter 4: Impacts of climate change and policy on air pollution and human health.,” 2023. [Online]. Available: https://www.gov.uk/government/publications/climate-change-health-effects-in-the-uk.

[86] UK Health Security Agency (UKHSA), “Chapter 14. Net zero: health impacts of policies to reduce greenhouse gas emissions.,” 2023. [Online]. Available: https://www.gov.uk/government/publications/climate-change-health-effects-in-the-uk.

[87] Lag et al., “Health effects of amines and derivatives.,” 2011.

[88] Air Quality Expert Group (AQEG), “Optimising air quality co benefits in a hydrogen economy: a case for hydrogen specific standards for NOx emissions.,” 2021.

[89] London School of Economics , “Decarbonisation of the UK economy and green finance.,” 2019.

[90] K. &. H. J. Dillman, “Towards a Safe Hydrogen Economy: An Absolute Climate Sustainability Assessment of Hydrogen Production,” *Climate, 11(1),* 2023.

[91] Sand et al., “A multi-model assessment of the Global Warming Potential of hydrogen,” 2023.

[92] HM Government , “Industrial Decarbonisation Strategy.,” HM Government , 2021.