Environmental Capacity in Industrial Clusters project - Phase 3

Technical Annex 2 – Tees Evidence baseline and analysis

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Acronyms

µg/m³	Micrograms (one-millionth of a gram) per cubic meter air
AFC	Allam-Fetvedt Cycle
ANC	Acid Neutralising Capacity
APIS	Air Pollution Information System
AQAP	Air Quality Action Plan
AQMA	Air Quality Management Area
AQS	UK National Air Quality Strategy
BP	British Petroleum
CAZs	Clean Air Zones
CC	Carbon Capture
CCGT	Combined Cycle Gas Turbine
CCUS	Carbon Capture Utilisation and Storage
CO	Carbon Monoxide
cSACs	Candidate SACs
Defra	Department for Environment, Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DLN	Dry Low NO_x
DR	Direct Reduction
EA	Environment Agency
EALs	Environmental Assessment Levels
EfW	Energy from Waste
EPR	European Pressurized Reactor
ERC	UK's Emission Reduction Commitment
EUNIS	European Union Nature Information System
GW	Gigawatt
HGVs	Heavy Goods Vehicles
IED	Industrial Emissions Directive
IOC	Instruments of Consent
JNCC	Joint Nature Conservation Committee
Kt	Knot
Ktpa	Thousand Tonnes Per Annum
LAQM	Local Air Quality Management

LAQM.TG	Local Air Quality Management Technical Guidance
LCP	Large Combustion Plant
LOI	Letter of Intent
MCP	Medium Combustion Plant
MCPD	Medium Combustion Plant Directive
MEA	Monoethanolamine
MW	Megawatt
MW_e	Megawatt Electric
MW_{th}	Megawatts Thermal
CCGT	Combined Cycle Gas Turbine
N	Nitrogen
N leaching	Nitrogen Leaching
NECR	National Emission Ceilings Regulations
NEP	Northern Endurance Partnership
NH_3	Ammonia
NMVOC's	Non-Methane Volatile Organic Molecules
NO_2	Nitrogen Dioxide
NO_x	Nitric oxide (NO) and Nitrogen Dioxide (NO2)
NZHF	Net Zero Hydrogen Fund
NZNS Storage	Net Zero North Sea Storage
NZT Power	Net Zero Teesside Power
NZT	Net Zero Teesside
OEMs	Original Equipment Manufacturer
OEP	Office for Environmental Protection
P	Phosphate
PCs	Process Contributions
pH	Potential of Hydrogen
PM_{10}	Particulate Matter With An Aerodynamic Diameter of Less Than 10 Micrometres (µm)
$PM_{2.5}$	Particulate Matter with a diameter of 2.5 µm or less ($PM_{2.5}$)
pSPAs	Proposed SPAs
RBT	Redcar Bulk Terminal
RDF	Refuse Derived Fuel
rDME	Renewable and Recycled Carbon Dimethyl Ether

REC	The Redcar Energy Centre
SACs	Special Areas of Conservation
SCR	Selective Catalytic Reducer
SO_2	Sulphur Dioxide
SPAs	Special Protection Areas
SAF	Sustainable Aviation fuels
Tpa incinerator	Tonnes per hour waste incineration
TV ERF	Tees Valley Energy Recovery Facility
VOC's	Volatile Organic Compounds

1.0 Report Structure

The structure of the following report gives a comprehensive and systematic exploration of the project, beginning with an introductory overview of the project to put the scope and significance in an environmental context. From there, it will expand upon general air quality and environmental considerations across the UK to give a more focused environmental baseline. Going further into this, the detailed study of the present air quality and ecology sites, down to the details of the Tees region, draws focus onto the localised context that is identified as crucial to understanding the relevance and impact of the project. The following sections outline in more detail Net Zero projects within the Tees Industrial Cluster and further support with the introduction of Teesside Workshops, showing what the project is about and how it aligns with regional sustainability objectives and processes of stakeholder engagement. This will provide means to strengthen the conclusion of the report with evidence and academic analysis, finally appendices bring forward the sources and hence further help in the exploration of the topic well in detail with support.

The following report is structured as follows:

- Air Quality and Ecological Considerations in the UK
- The Tees Industrial Cluster
- Existing Air Quality in the Tees Area
- Ecological Sites in the Tees Area
- Net Zero Projects in the Tees Industrial Cluster
- Analysis of Teesside Workshops

2.0 Air Quality and Ecological Considerations in the UK

2.1 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].

The UK is no longer a member of the European Union, however, some types of EU legislation such as Regulations and Decisions, are directly applicable as law in an EU Member State. This meant that, as a Member State, these types of legislation applied automatically in the UK, under section 2(1) of the European Communities Act 1972 (c.68), without any further action required by the UK. These types of legislation are published by the Publications Office of the European Union on the EUR-Lex website and are now published on legislation.gov.uk as 'legislation originating from the EU'.

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.

2.2 National Clean Air Strategy (2019)

In 2019, the UK government released its Clean Air Strategy 2019 [3], 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 been related to one pollutant, Nitrogen dioxide (NO_2), and its principal source in the UK, road traffic. However, the 2019 Strategy broadened the focus to other areas, including domestic emissions from wood-burning stoves and agriculture.

2.3 A Green Future: 25 Year Plan to Improve the Environment

The 25 Year Environment Plan, originally published in January 2018, sets out the actions the UK Government will take to help the natural world regain and retain good health [4]. The Environment Plan was updated in 2023 with the publication of the Environmental Improvement Plan 2023 [5]. The plan outlines several actions that are being taken to improve air quality, most notably the publication of the Clean Air Strategy [3] and the introduction of several Clean Air Zones (CAZs) across England. Emphasis is also placed on fine particulate matter $PM_{2.5}$ 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 to require 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."

2.4 Environment Act (2021)

The Environment Act 2021 [6] was approved on 9 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 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 will publish a report reviewing the AQS every five years (as a minimum and with yearly updates to Parliament), in the form of the Environmental Improvement Plan [5].

2.5 UK Air Quality Strategy

The UK National Air Quality Strategy (AQS) was initially published in 2000 [7], under the requirements of the Environment Act 1995 [8], as amended by the Environment Act 2021 [6]. The 2007 version of the AQS [9] 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 the environment.

A new AQS was published in April 2023 [10]. 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) [11].

Under the local air quality management (LAQM) regime, the local authority has a duty to carry out regular assessments of air quality against the objectives and if it is unlikely that they will be met in the given timescale, they must designate an Air Quality Management Area (AQMA) and prepare an Air Quality Action Plan (AQAP) with the aim of achieving the 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. Consequently, 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 Environment Agency (EA) has defined Environmental Assessment Levels (EALs) for the protection of human health for pollutant species without AQS objectives and are presented as part of the "Air emissions risk assessment for your environmental permit" guidance website [12]. The only EAL applicable to this assessment is the 1-hour assessment criterion for CO, also presented in Table 1, with all other applicable EALs being the same as the AQS objectives already presented.

Table 1 - UK Air Quality Strategy 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

2.6 Assessment Criteria for Sensitive Ecological Receptors

The UK is bound by the terms of the European Birds and Habitats Directives [13] and the Ramsar Convention [14]. The Conservation of Habitats and Species Regulations 2010 [15] provides for the protection of European sites created under these policies, i.e. Special Areas of Conservation (SACs) designated pursuant to 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 which is 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 [15], the Wildlife and Countryside Act 1981 (as amended) [16] and the Countryside and Rights of Way Act 2000 (as amended) [17].

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

- as direct impacts arising due to increases in atmospheric pollutant concentrations; assessed against Critical Levels; and
- indirect impacts arising through 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 Air Quality Strategy Objectives (for the Protection of Ecological Receptors)

Pollutant	Source	Concentration (µg/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.

Table 3. Air Pollution Information System Indicative Nitrogen Deposition Critical Load Values for Habitats Mapped Nationally in the UK [18]

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.

Habitat Type	Habitat Description	Critical Load Range (kgN/ha/yr)	UK Mapping Value (kgN/ha/yr)	Indication of Exceedance
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.
	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.

Habitat Type	Habitat Description	Critical Load Range (kgN/ha/yr)	UK Mapping Value (kgN/ha/yr)	Indication of Exceedance
	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.
	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. Air Pollution Information System 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

Habitat Type	Habitat Description	Critical Load Range (kgN/ha/yr)	Indication of Exceedance
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
	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. Air Pollution Information System 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.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
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 synthesize 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.
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 chalk, 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.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
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.
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.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
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.
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.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
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.
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 (upwellings 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.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
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.
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.

Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
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.
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.

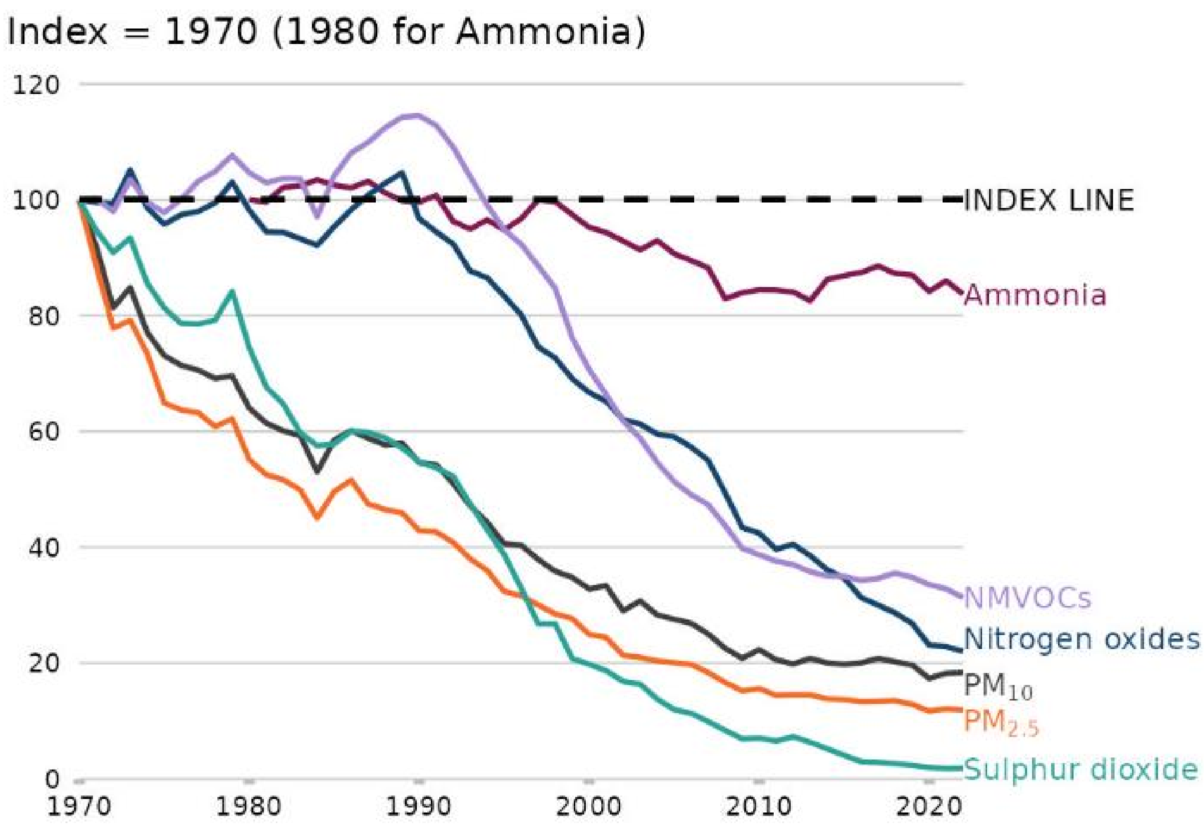
Habitat Type	Critical Load Range (keq/ha/yr)	Habitat Description	Effects and Implications
Standing Open Water and Canals	Value varies depending on species of interest and mineralogy, size & other characteristics of the waterbody and its catchment.	Acid deposition on acid-sensitive catchments (mostly 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 [19]

2.7 Summary of Primary Air Pollutants in the UK

As of July 2023, a total of 251 (71.7%) of Local Authorities across the UK had declared one or more AQMAs. Of these 628 were declared for NO_2, 83 for PM_{10} and 6 for sulphur dioxide (SO_2) [20]. 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 [21] 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 Molecules (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 [21]

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 several 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 sulfur 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) [22]. 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 ammonia (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
NMVOC	1123	624	32	44	Compliant
NO_x (as 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 [21]

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.

2.8 Emissions Data and Trends in the UK

The UK Informative Inventory Report (1990 to 2021) [23] 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 2021. Table 7 shows that there have been reductions in emissions of all six pollutants between 1990 and 2021.

Table 7 – UK Emissions Reductions between 1990 to 2021, and 2005 to 2021

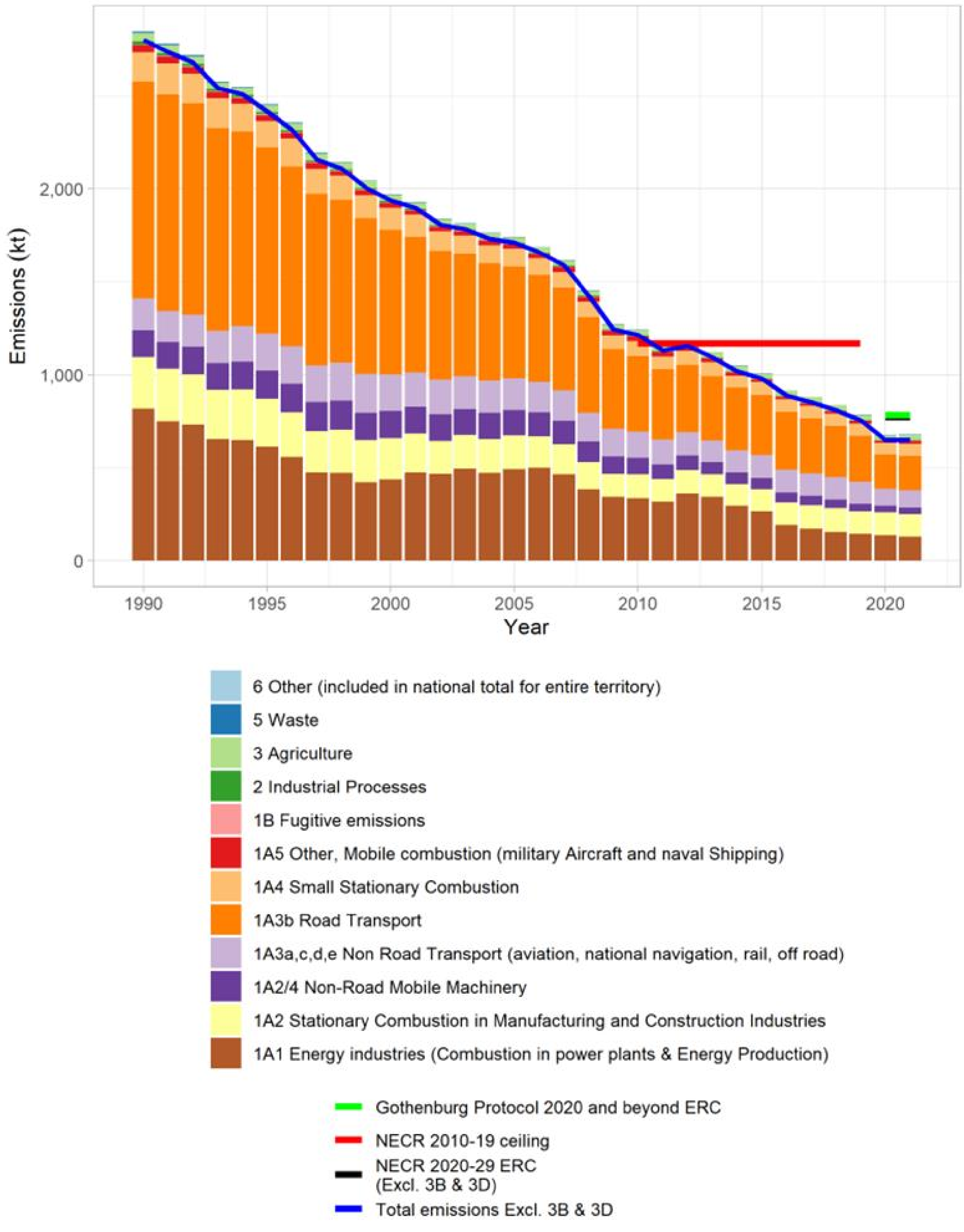
Pollutant	% Change from 1990 to 2021	% Change from 2005 to 2021
NO_x (as NO_2)	-70	-55
SO_x (as SO_2)	-96	-84
NH_3	-13	-5
NMVOC	-69	-34
CO	-83	-59
PM_{10}	-62	-29
$PM_{2.5}$	-67	-34

Source: Emissions of air pollutants in the UK Summary [21]

2.8.1 Nitrogen Oxides (NO_x)

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 therefore 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 1990-2021



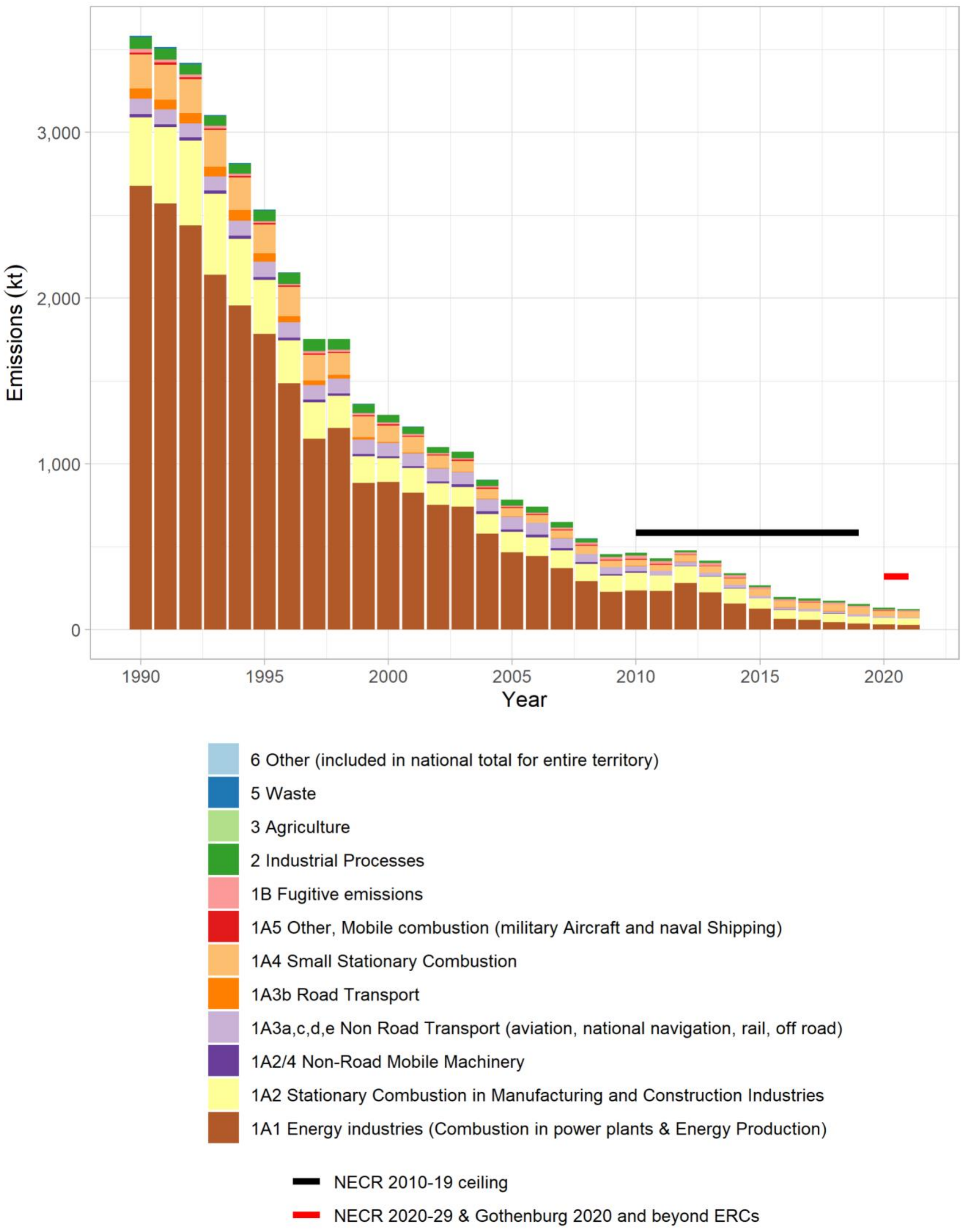
Source: Emissions of air pollutants in the UK Summary [21]

2.8.2 Sulphur Dioxide (SO2)

Emissions of SO_2 in the UK have fallen 96% between 1990 and 2021. This is the biggest decline of all the air quality pollutants controlled by the NECR and Gothenburg Protocols. Emissions of SO_2 measured approximately 3,580kt 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 126kt, with 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 time 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) [24] and the Industrial Emissions Directive (2010) [25], which implemented stricter regulations and mitigations on SO_2 emissions from energy and industrial sources.

Figure 3 - Total UK SO_X emissions for 1990-2021



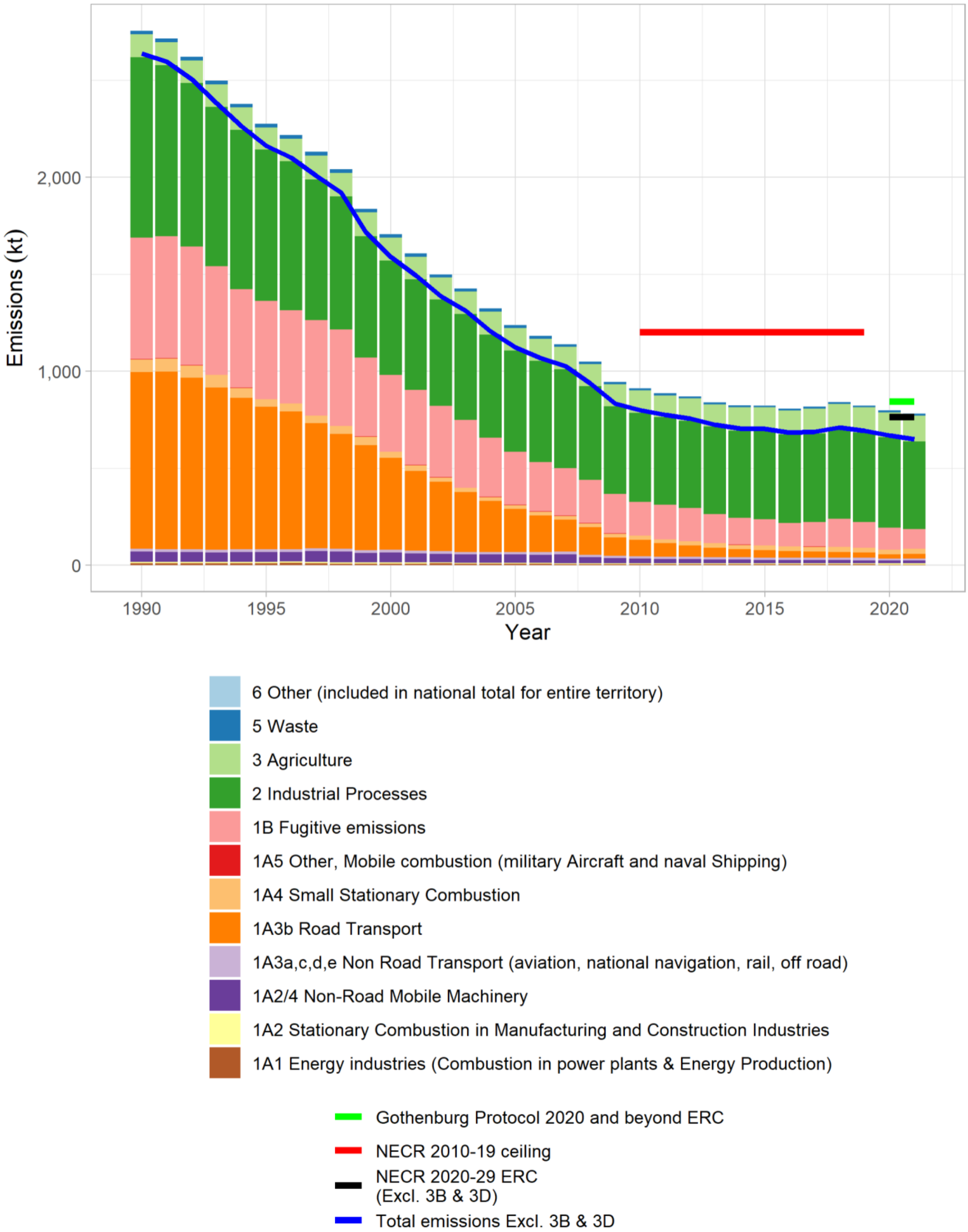
Source: Emissions of air pollutants in the UK Summary [21]

2.8.3 Non-Methane Volatile Organic Molecules (NMVOC's)

In 1990, NMVOC's emissions measured approximately 2,754 kt, with the largest source being from industrial processes accounting for 34% of total emissions. Emissions of NMVOC's in the UK have fallen 72% between 1990 and 2021 to approximately 781 kt with industrial processes accounting for 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 [26]). Coal mining was a relatively high emitter of NMVOC's in 1990 but was practically zero in 2021, largely due to coal being phased out for energy generation.

Figure 4 - Total UK NMVOC's emissions for 1990-2021 [23]



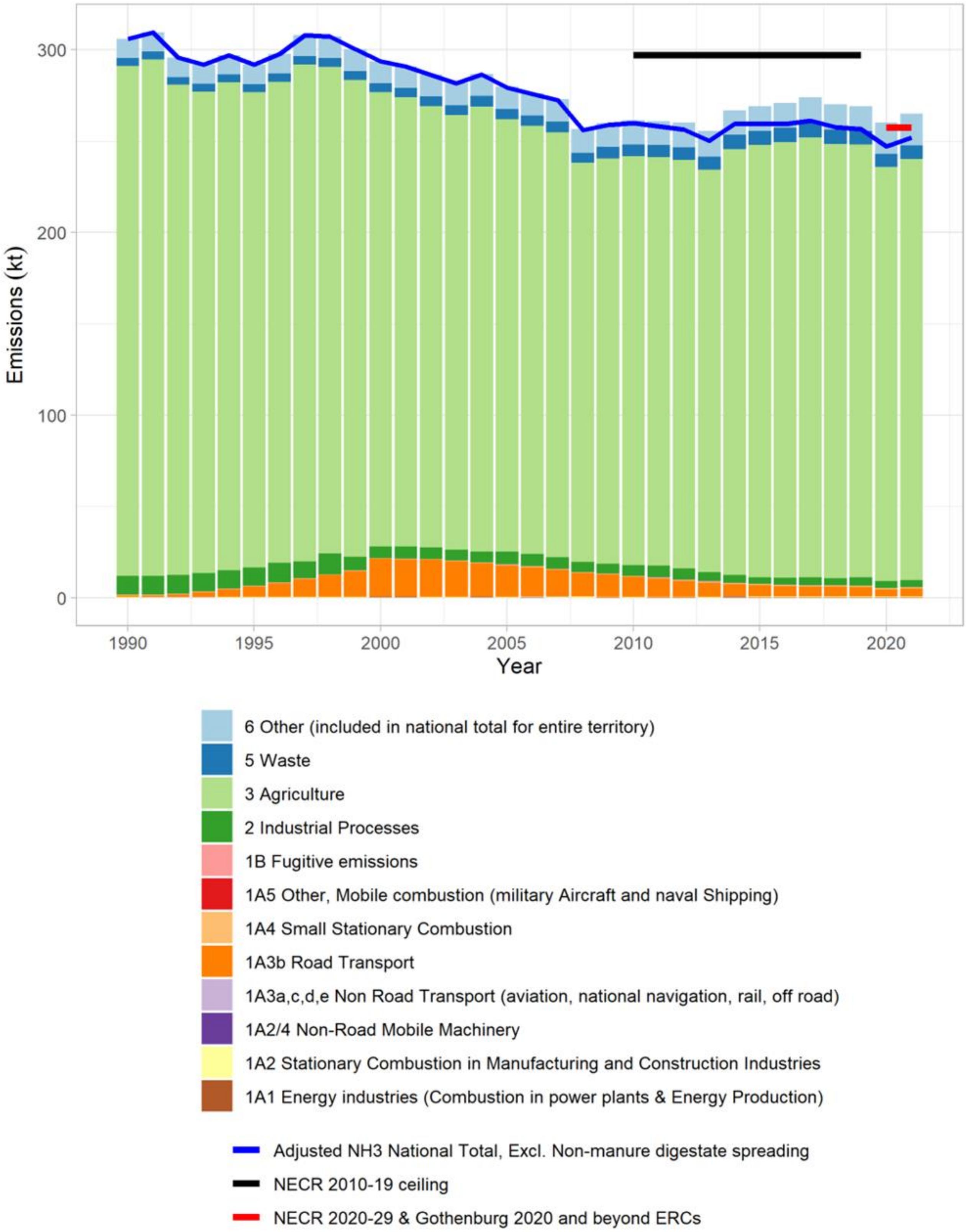
Source: Emissions of air pollutants in the UK Summary [21]

2.8.4 Ammonia (NH_3)

Emissions of NH_3 reduced by 13% between 1990 (306 kt) and 2021 (256 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) [27] 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 1990-2021 [23]



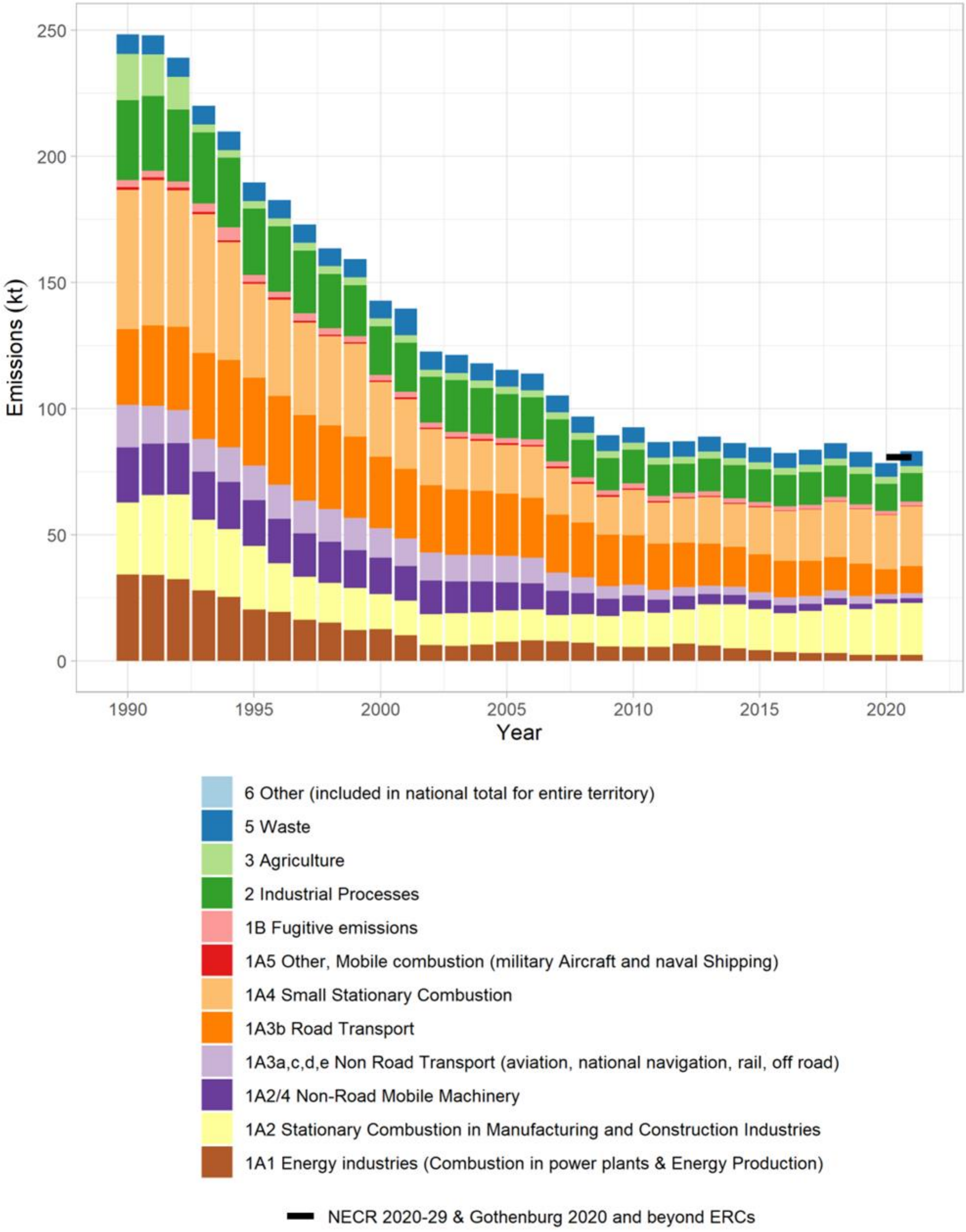
Source: Emissions of air pollutants in the UK Summary [21]

2.8.5 $PM_{2.5}$

Between 1990 and 2021, there has been a 66% reduction in total $PM_{2.5}$ emissions. However, since 2002 the rate of the continued decrease has slowed. Small stationary combustion represents the largest source of $PM_{2.5}$ emissions in the UK, which includes residential wood combustion primarily used for heating or cooking and has seen an increase in popularity since the mid-2000's, partially as a solution to reduce personal heating costs amid rising gas prices.

Stringent legislation has been put into place since the 1990's to control and regulate $PM_{2.5}$ emissions. The European 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 1990-2021 [23]



Source: Emissions of air pollutants in the UK Summary [21]

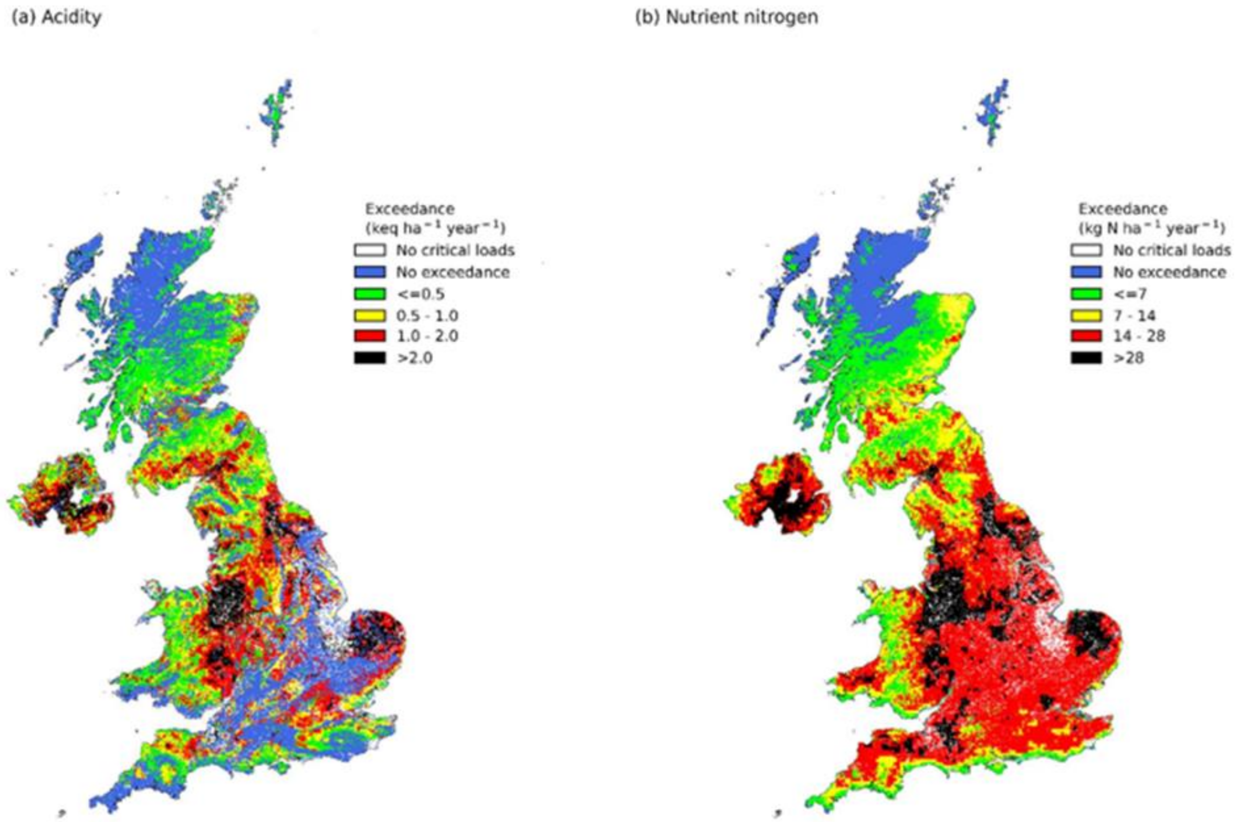
2.9 Ecology in the UK

The Joint Nature Conservation Committee (JNCC) [22] 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) sensitive to both. In 2020, acid deposition exceeded critical loads in 45% of sensitive terrestrial habitats, which is a 32% decrease since 2003 [28]. Nutrient nitrogen exceeds the critical loads in 86% of SSSI designated 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.

Figure 7 displays UK spatial coverage information for acidity and nutrient nitrogen critical load exceedances in the UK for 2022. As illustrated, most 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 [29]



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.

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) [22]

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) [30]

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) [30]

3.0 The Tees Industrial Cluster

The Tees industrial cluster is a tightly packed area with a radius of 7 km. It is an energy hub with access to gas and oil from the North Sea and an extensive industrial history alongside planned hydrogen and carbon capture projects. The geographically compact nature of the cluster, its proximity to ideal offshore CO_2 storage sites, together with strong public and political support for these industries, makes Teesside an important location to decarbonise industry [31], power and to kick start the hydrogen economy using CCUS (Net Zero Teesside or NZT). NZT is a cluster of industrial, power and hydrogen businesses which aim to decarbonise their operations through the deployment of carbon capture utilisation and storage (CCUS).

The NZT project forms part of the wider Northern Endurance Partnership (NEP) initiative which aims to repurpose offshore oil and gas sites for long-term geological storage of CO_2. NEP was formed in 2020 as the CO_2 transportation and storage company which will deliver the onshore and offshore infrastructure needed to capture carbon from a range of emitters across Tees and Humber Industrial Cluster (Zero Carbon Humber), which is located further south, are collaborating within the NEP East Coast Cluster, to transport captured CO_2 to offshore storage in the Endurance store. Hydrogen production, hydrogen use and carbon capture in the Tees Industrial Cluster is the primary focus of this review.

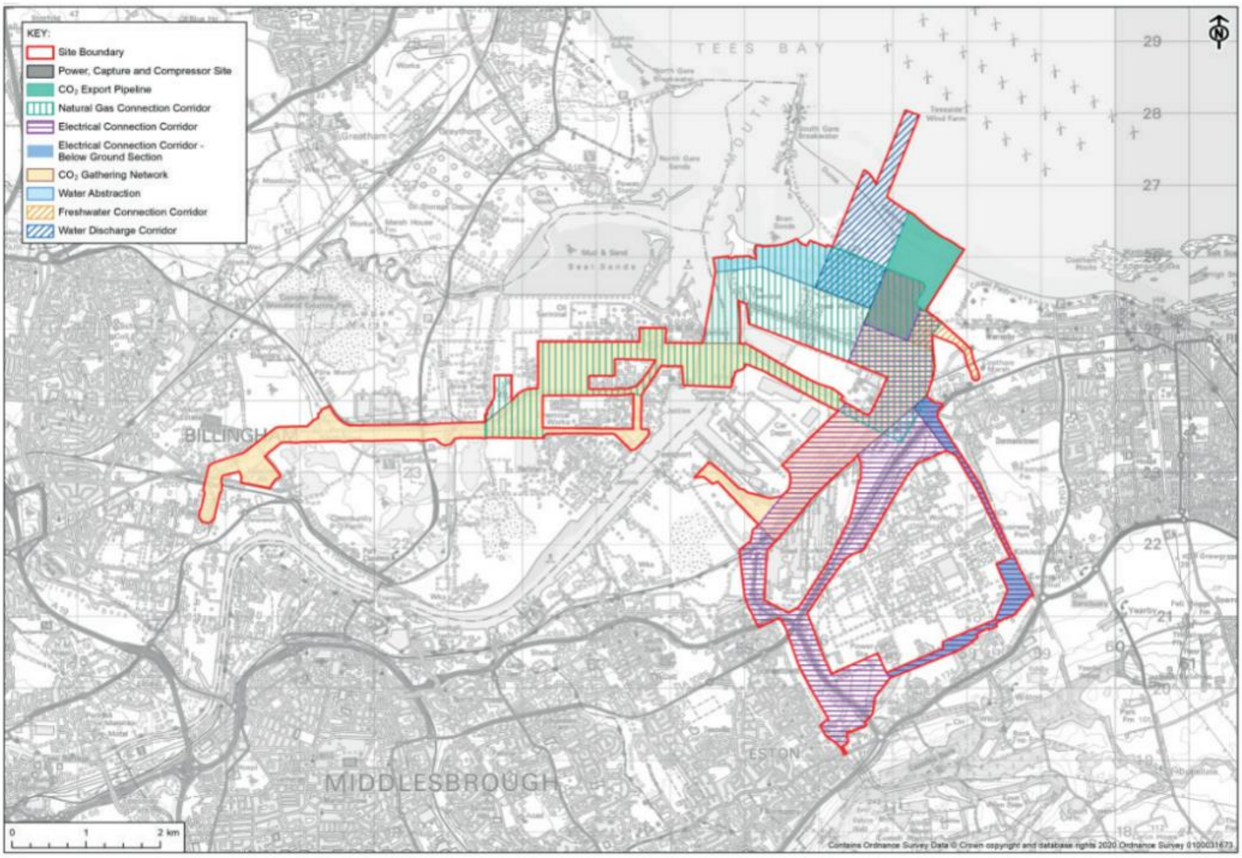
Teesside already includes a large chemicals industry that produces and uses half the UK's industrial hydrogen. Teesside and Humberside together represent half of the CO_2 emissions produced by six primary industrial clusters in the UK. In October 2021, The NEP East Coast Cluster (Net Zero Teesside and Zero Carbon Humber) project was selected as a priority cluster in Phase 1 of the UK Government's CCUS cluster sequencing process [32].

The NZT initiative comprises two principal partnerships. The first, NZT Power, focuses on electricity generation through an 850 MW Combined Cycle Gas Turbine (CCGT) plant paired with a post-combustion carbon capture facility. It has now been updated to a CCGT with a thermal input capacity of approximately 1,400 Megawatts thermal (MW_{th}), reflecting the latest information from the draft NZT permit. This endeavour is led by BP and includes partnerships with Eni, Equinor, and Total. Notably, the NZT Power project aligns itself with the set of strategic directives by the UK Government to the new gas-fired power stations. Its design is such that it works under demand with a target operational year of 65% for the first ten years, hence permissive to allow reduced operating rate years of 33% in the subsequent fifteen years. This demonstrates how this project aligns and is adjustable within the changing energy landscape, therefore assuring that the project developed will be in balance with responsible environmental stewardship.

The second, Net Zero North Sea Storage (NZNS Storage), is dedicated to creating a CO_2 'gathering network' that includes pipelines connecting other industrial sites in Teesside to a compression plant adjacent to the NZT Power station. This will facilitate the onshore and offshore transport and sequestration of CO_2. Alongside BP, the NZNS Storage consortium features Eni, Equinor, National Grid, Shell, and Total.

Additionally, the NZT installation will include auxiliary boilers and emergency diesel generators to support commissioning, start-up, shutdown, and maintenance activities ensuring the carbon capture equipment remains operational even when the main CCGT plant is offline.

Figure 8 - Current Extent of the NZT Project



3.1 Existing Air Quality in the Tees Area

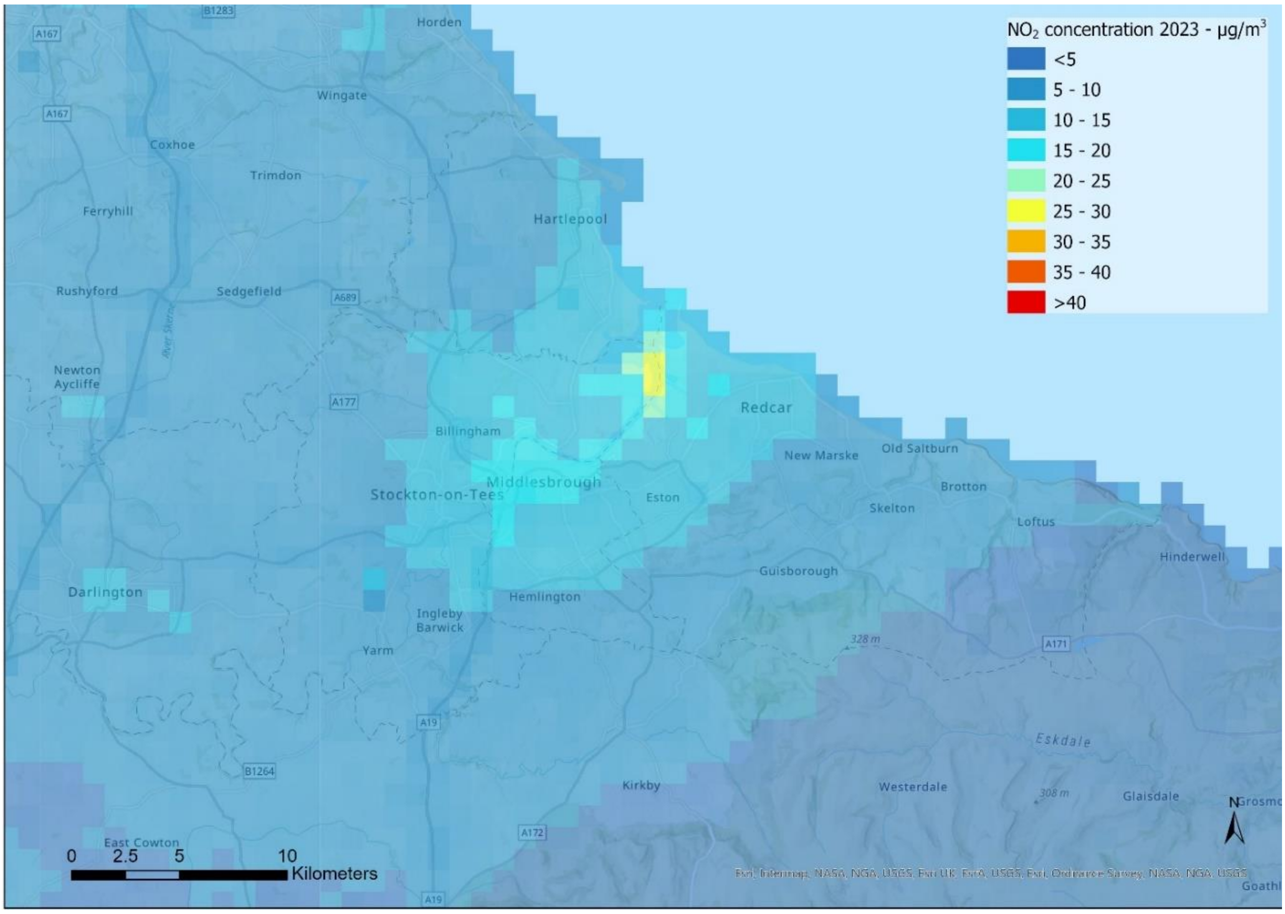
In the UK, the responsibility for meeting air quality limits is assigned by the UK Government to the national administrations in England, Wales, and Northern Ireland. The Department for Environment, Food and Rural Affairs (Defra) coordinates the assessment and development of air quality plans for the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

Under the Environment Act 1995, the UK is required to establish a national Air Quality Strategy (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 Air Quality Management Areas (AQMAs). Following this, 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. Local authorities are also obligated to continuously monitor air quality and assess whether any breaches of AQS objectives occur. If a breach is detected, an AQMA is declared. There are no AQMAs declared by any of the councils included within the Tees Industrial cluster. The nearest AQMA, the Scarborough AQMA, is approximately 21 km away from the closest council areas that make up the Tees Industrial Cluster.

Teesside is a built-up area around the River Tees in Northeast England, located between County Durham and North Yorkshire. The area is governed by the jurisdictions of five local councils: Redcar and Cleveland, Middlesbrough, Darlington, Stockton-on-Tees, and Hartlepool.

Figure 9 to Figure 14 display a series of maps generated using ArcGIS Pro, which illustrates the background concentrations of key pollutants associated with industrial activities in the Tees area. The maps represent annual mean concentrations of these pollutants. The spatial resolution of the data is 1km x 1km, providing a detailed geographic assessment of the pollution levels. The data to generate Figure 9 to Figure 12 was obtained from the Defra background maps using data for 2023 predicted based on a base year of 2018 [33]. These maps utilise data for 2023, which are projected based on actual emissions data and environmental conditions from a base year of 2018. Defra updates these background maps periodically to reflect changes in underlying data, including emission factors and environmental policies. The projections for years beyond the base year, including 2023, are constructed using a set of assumptions that were current before the Covid-19 outbreak, which means they do not account for any short or long-term impacts on emissions resulting from behavioural changes during national or local lockdowns. The primary purpose of these background maps is to provide estimates of background concentrations for specific pollutants, such as NO_x, NO_2, PM_{10}, and $PM_{2.5}$. These estimates are critical for air quality assessments, allowing for a better understanding of the contribution of local sources to total pollutant concentrations across a wide area. Figure 13 and Figure 14 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 2019 to 2021[1]. These pollutants are critically important to evaluate due to their potential impact on human health and sensitive ecological habitats.

Figure 9 - Background NO_2 Concentrations (annual mean)



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[1] The selection of the years 2019 to 2021 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 10 - Background NO_X Concentrations (annual mean)

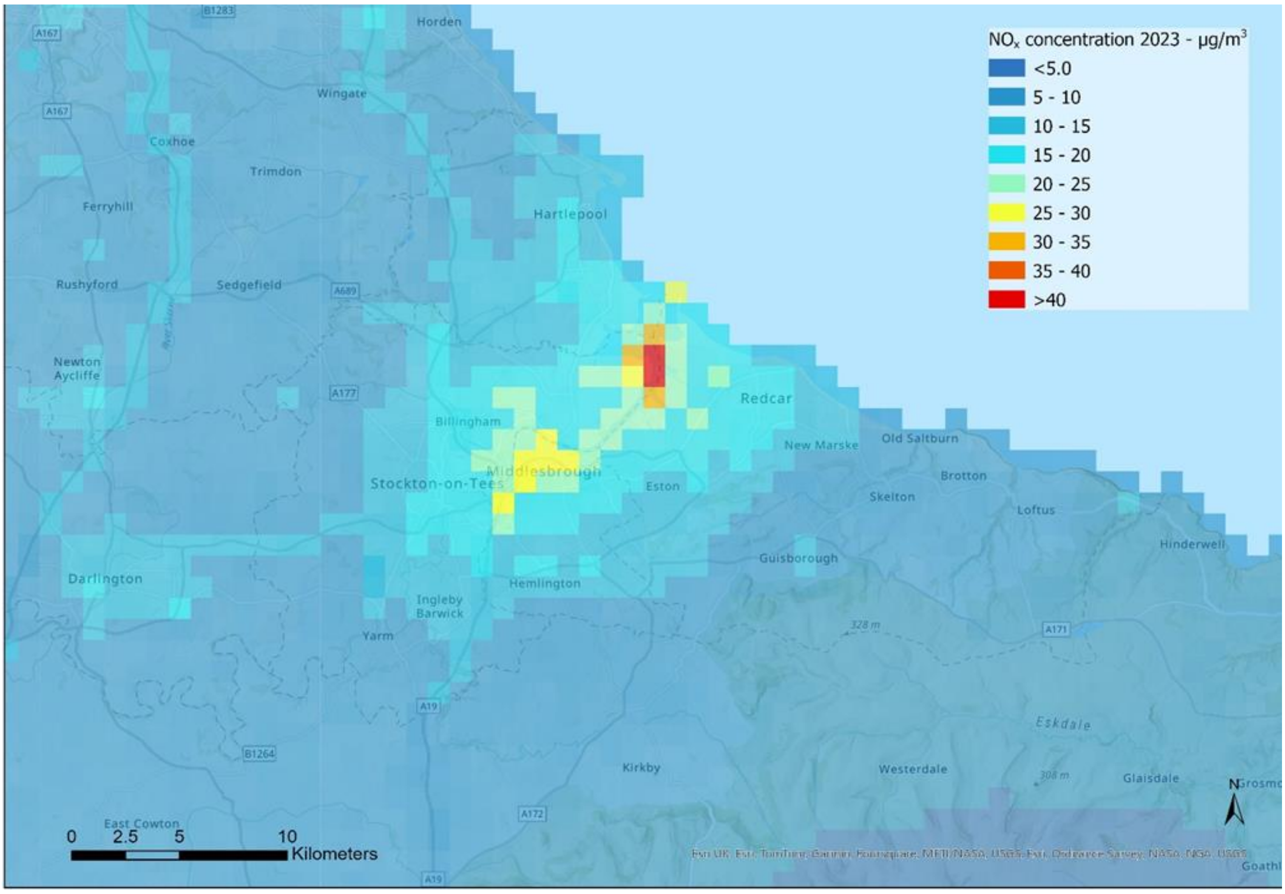


Figure 11 - Background PM_{10} Concentrations

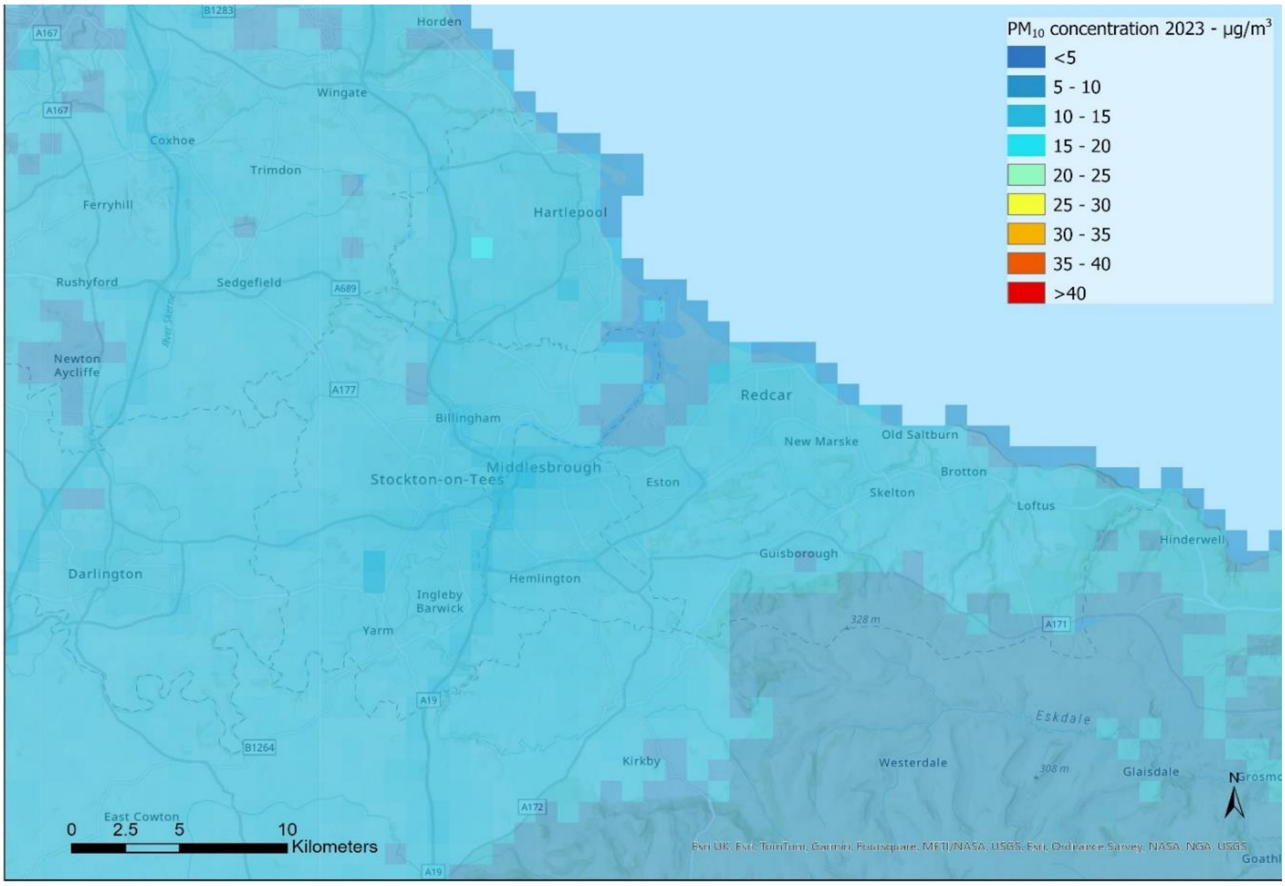


Figure 12 - Background $PM_{2.5}$ Concentrations

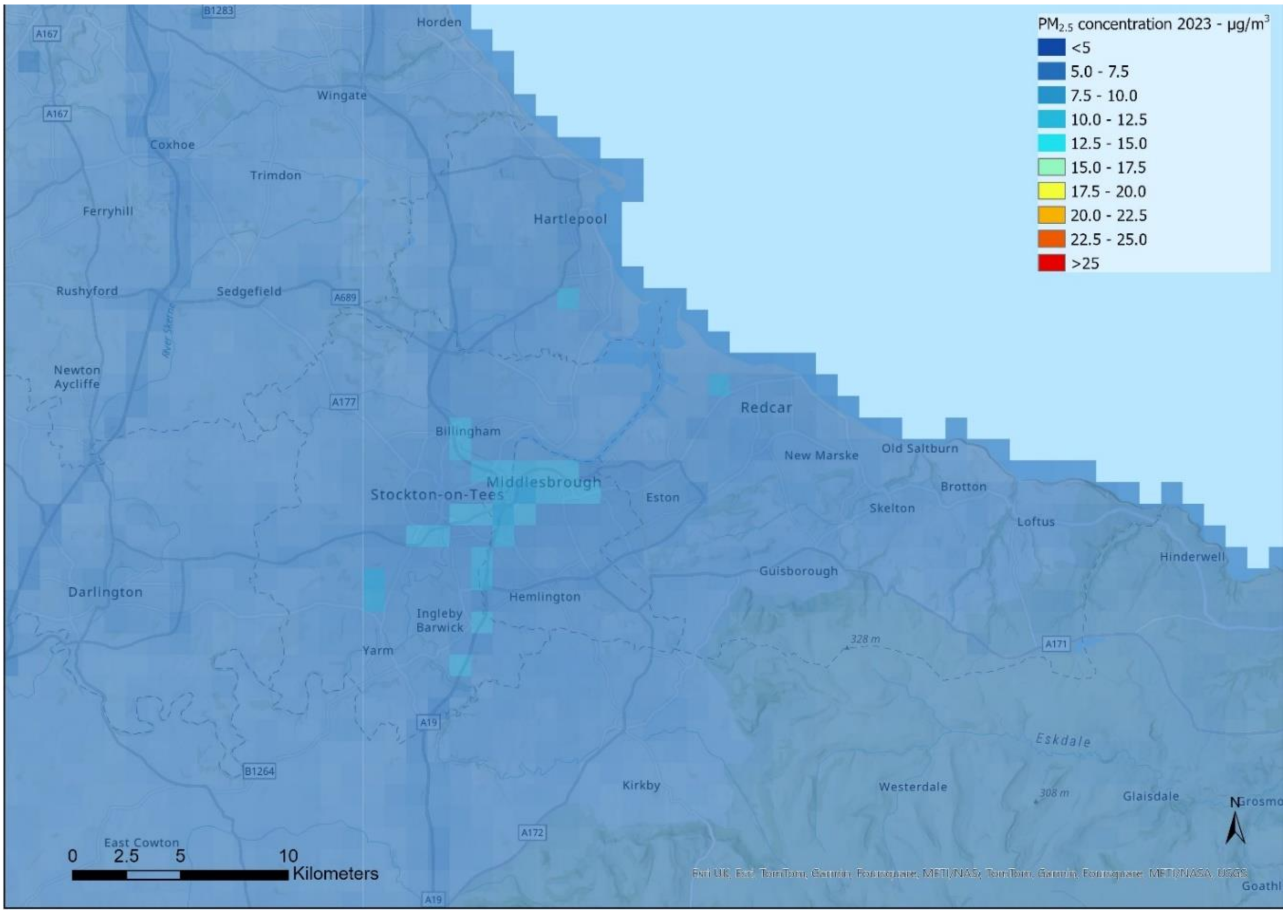


Figure 13 - Background SO_2 Concentrations

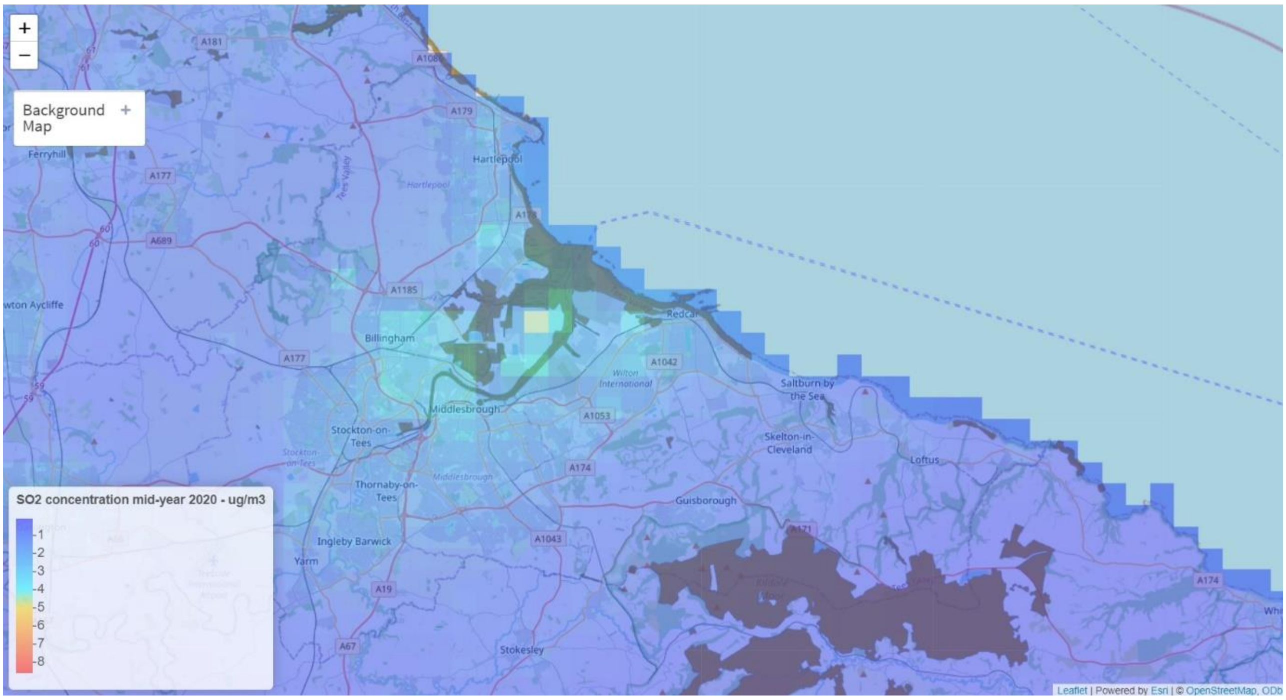
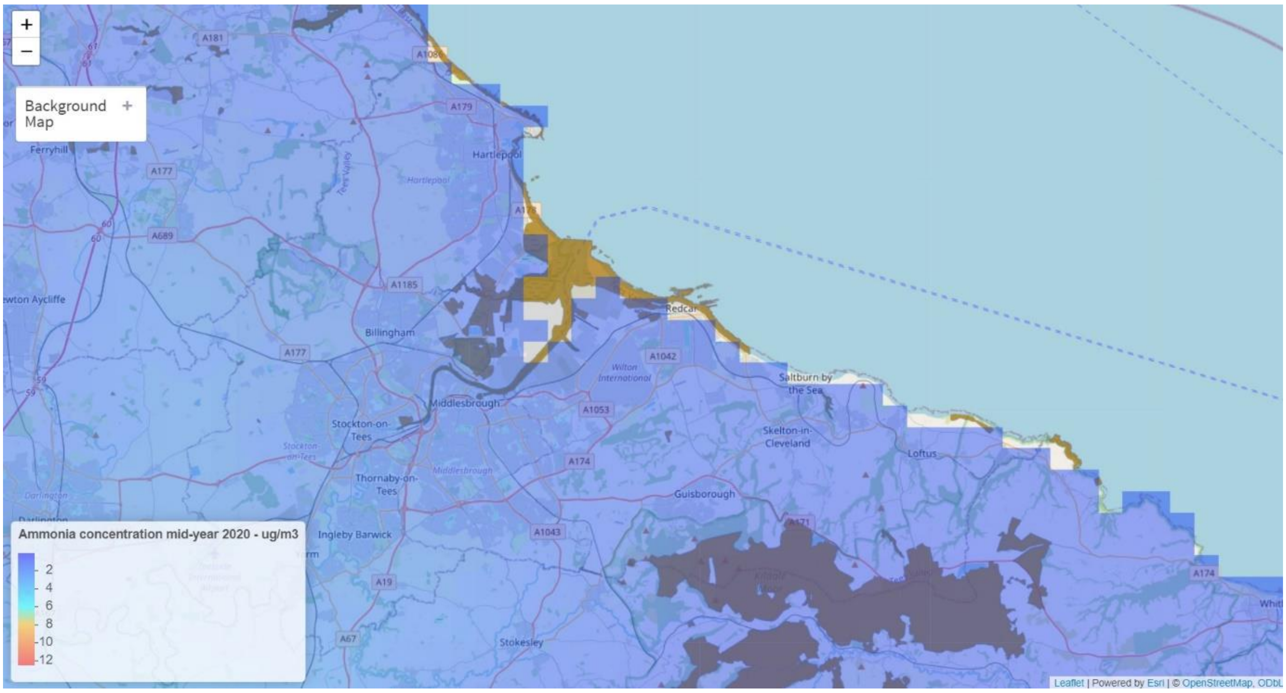


Figure 14 - Background NH_3 Concentrations



The provided figures reflect the air quality within the proposed NZT project area and its vicinity. Specifically, there is a distinct zone where NO_2 levels reach between 25 µg/m³ and 30 µg/m³, with a peak where NO_x concentrations exceed 40 µg/m³. Despite this, maximum concentrations of NO_2 levels remain below the relevant AQS objectives, indicating compliance with regulatory standards. Surrounding areas show notably lower concentrations, generally falling below 15 µg/m³ and 20 µg/m³ for NO_2 and NO_x, respectively.

SO_2 concentrations within the same area are observed to range between 3 µg/m³ and 5 µg/m³, which, while elevated relative to adjacent regions, also stay within acceptable AQS objectives. The distribution pattern for PM_{10} and $PM_{2.5}$, however, differs as the highest concentrations are not observed within the NZT project boundaries. 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 Tees 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 Teesside, historical air quality issues have largely stemmed from rapid industrial expansion, 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.

3.2 Local Air Quality Management in the Tees Area

The local authorities within the Tees Area conduct air quality monitoring using automatic and non-automatic techniques. Table 11 presents a summary of the air quality monitoring undertaken in the Tees area.

Table 11 - Air Quality Monitoring across Local Authorities in the Tees Area

Council	Annual Status Report Year	Air Quality Management Areas (AQMAs)	Automatic monitors (pollutants)	Non-automatic monitors (pollutants)
Redcar and Cleveland Borough Council [34]	2022	N	Redcar Dormanstown (NO_2, PM_{10}, $PM_{2.5}$, O_3)	14 (NO_2)
Middlesborough Council [35]	2022	N	Breckon Hill (NO_2, PM_{10}, $PM_{2.5}$, O_3, SO_2, Benzene, PAH) Macmillan College (NO_2, PM_{10})	22 (NO_2)
Stockton on Tees Borough Council [36]	2022	N	Stockton-on-Tees Eaglescliffe (NO_2, PM_{10}, $PM_{2.5}$) Stockton-on-Tees A1305 (NO_2, $PM_{2.5}$) Billingham (NO_2)	13 (NO_2)
Hartlepool Borough Council [37]	2021	N	A1 Stockton Road (NO_2, PM_{10}) A2 Headland (PM_{10}) A3 St Abbs Walk (NO_2)	3 (NO_2)
Darlington Borough Council [38]	2022	N	N/A	15 (NO_2)

As shown in Table 11, there are several automatic monitors in operation within the Tees area. The annual mean NO_2, PM_{10} and $PM_{2.5}$ concentrations as measured by these monitors for 2018 to 2022 are presented in Figure 15 to Figure 16. Annual mean NO_2 concentrations associated with the non-automatic monitors (diffusion tubes) from 2018 to 2022 are shown in Table 12.

Figure 15 - Annual Mean NO_2 Concentrations at Automatic Monitoring Sites in the Tees Area (2018 - 2022)

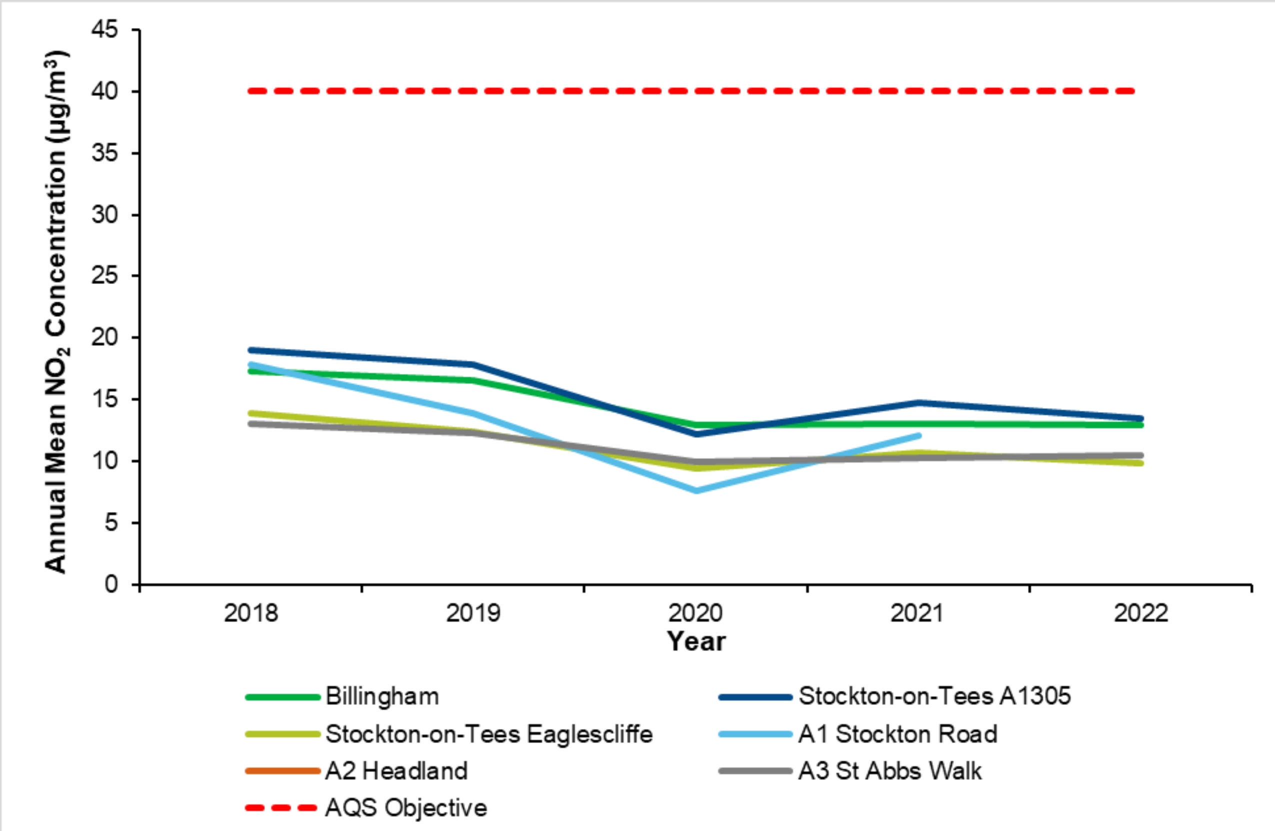


Figure 16 - Annual Mean $PM_{2.5}$ Concentrations at Automatic Monitoring Sites in the Tees Area (2018 - 2022)

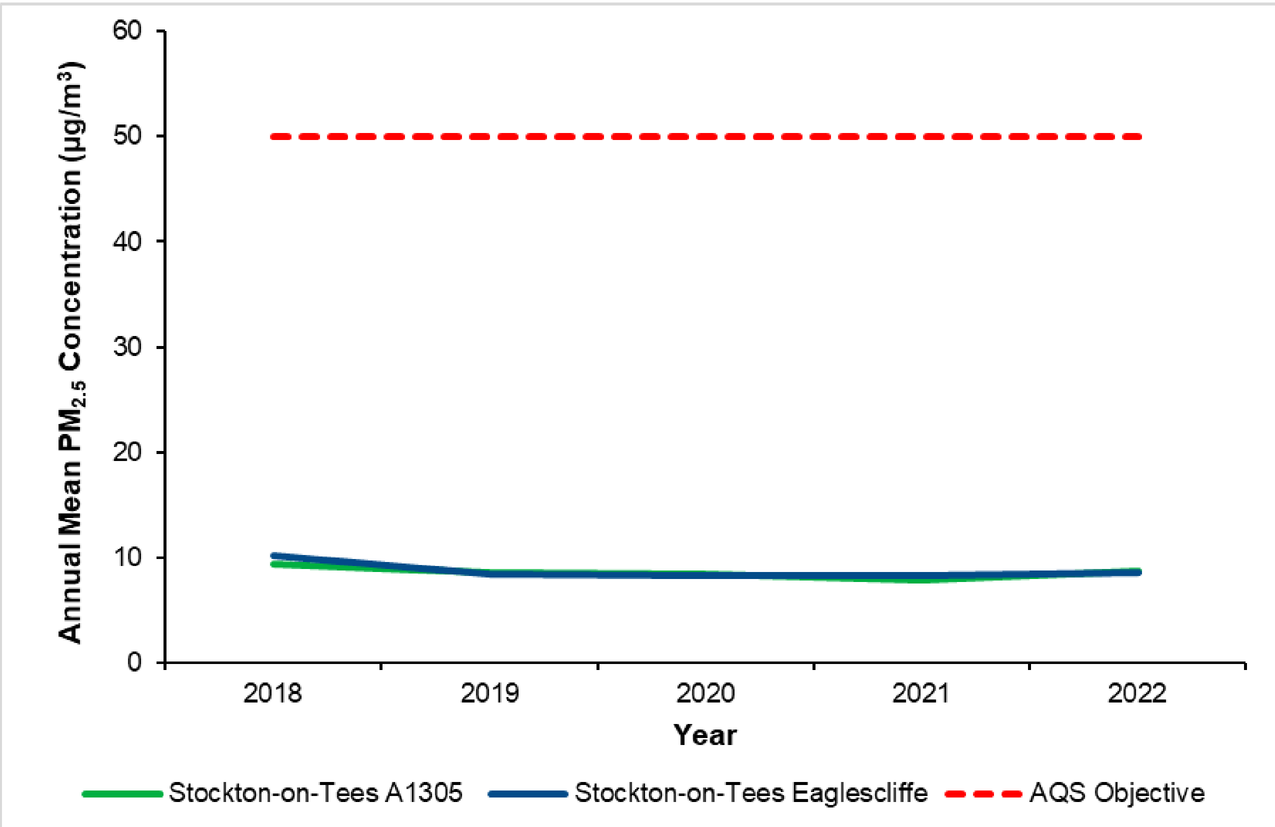


Table 12 – Annual Mean NO_2 Concentrations across the Non-Automatic (Diffusion Tube) Monitoring Network in the Tees Area (2018 – 2022)

Council	Annual Mean NO_2 Concentration (µg/m^3)				
	2018	2019	2020	2021	2022
Redcar and Cleveland	24.0	19.8	17.6	17.5	13.9
Middlesborough	25.1	21.4	15.1	17.7	17.6
Hartlepool	7.4	13.6	9.7	10.9	-
Darlington	30.9	27.7	21.8	22.4	21.4
Stockton-on-Tees	28.7	25.9	18.8	21.6	19.5

Source: Redcar and Cleveland Borough Council 2023 Air Quality ASR [34]; Middlesbrough Council 2023 Air Quality ASR [35], Hartlepool Borough Council 2022 Air Quality ASR [37]; Darlington Borough Council 2023 Air Quality ASR [38] and Stockton on Tees Borough Council 2023 Air Quality Annual Status Report [36]

Annual mean NO_2 concentrations in the Tees area have exhibited a steady downward trend in the Tees area (see Figure 15 and Table 12) between 2018 and 2022. Concentrations have been well below the annual mean AQS objective for NO_2 (40 µg/m^3). This is also the case for PM_{10} and $PM_{2.5}$ annual mean concentrations, with Figure 15 and Figure 16 illustrating levels well below the AQS objectives for both pollutants. 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.

To demonstrate long-term changes in air quality in the Tees area, Figure 17 to Figure 23 present the NO_2 and PM_{10} monitoring data from Redcar and Cleveland Borough Council (1998 to 2022) and NO_2, PM_{10} and $PM_{2.5}$ data from Middlesbrough Council (1997 to 2021) as presented in each council's most recent Annual Status Report (ASR).

Figure 17 - Annual Mean NO_2 Concentrations at Redcar Dormanstown Automatic Monitor

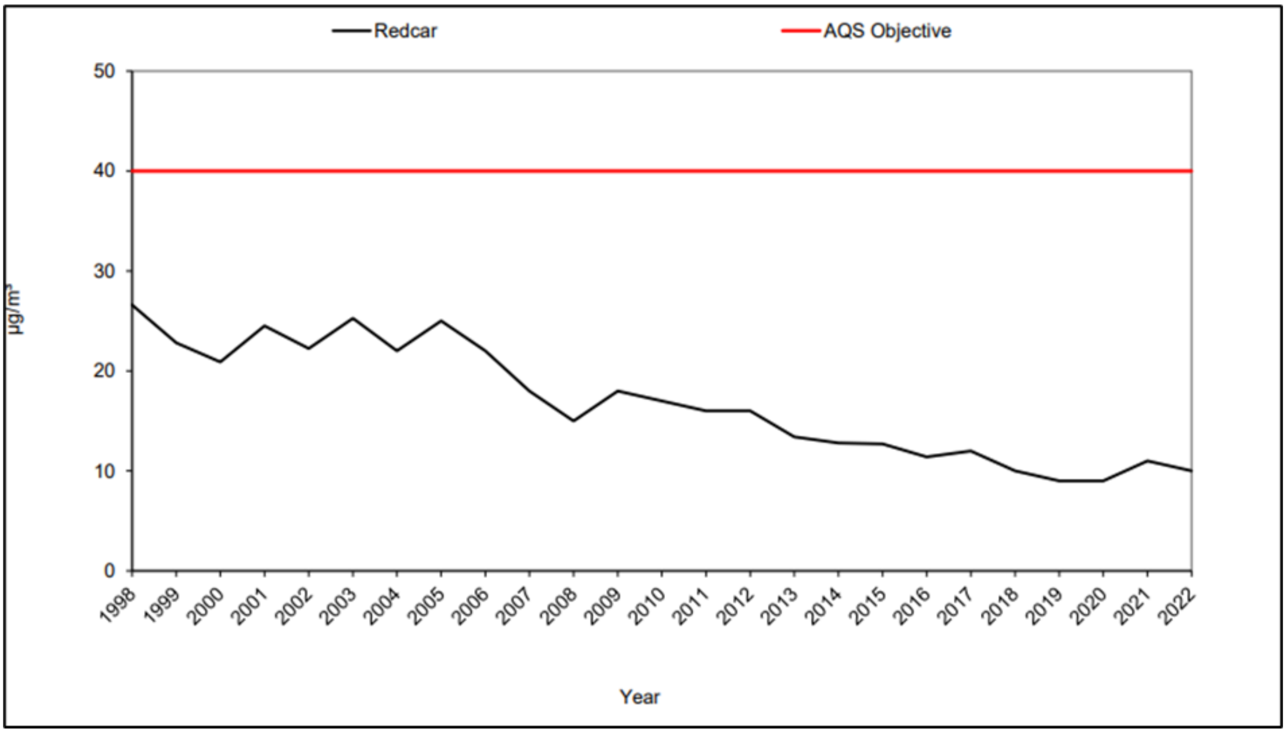


Figure 18 - Annual Mean PM_{10} Concentrations at Redcar Dormanstown Automatic Monitor

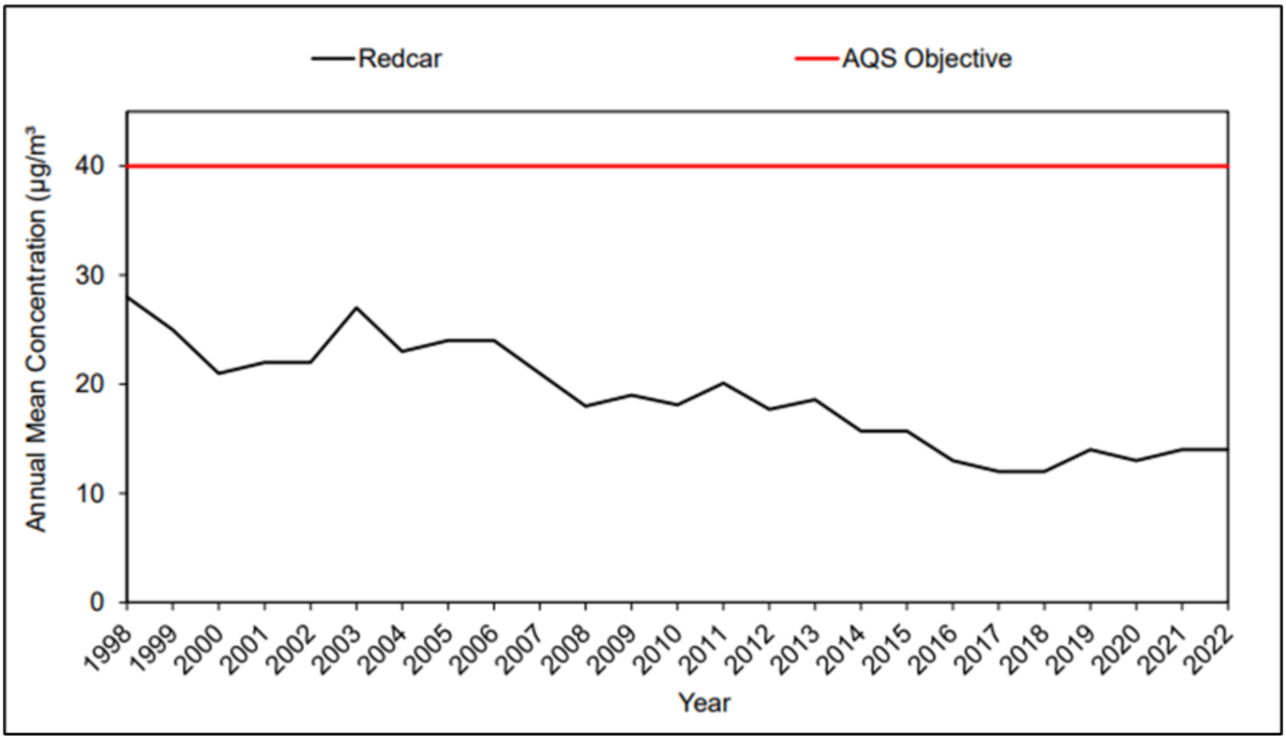


Figure 19 - Annual Mean NO_2 Concentrations at the Middlesbrough (Breckon Hill) AURN Station

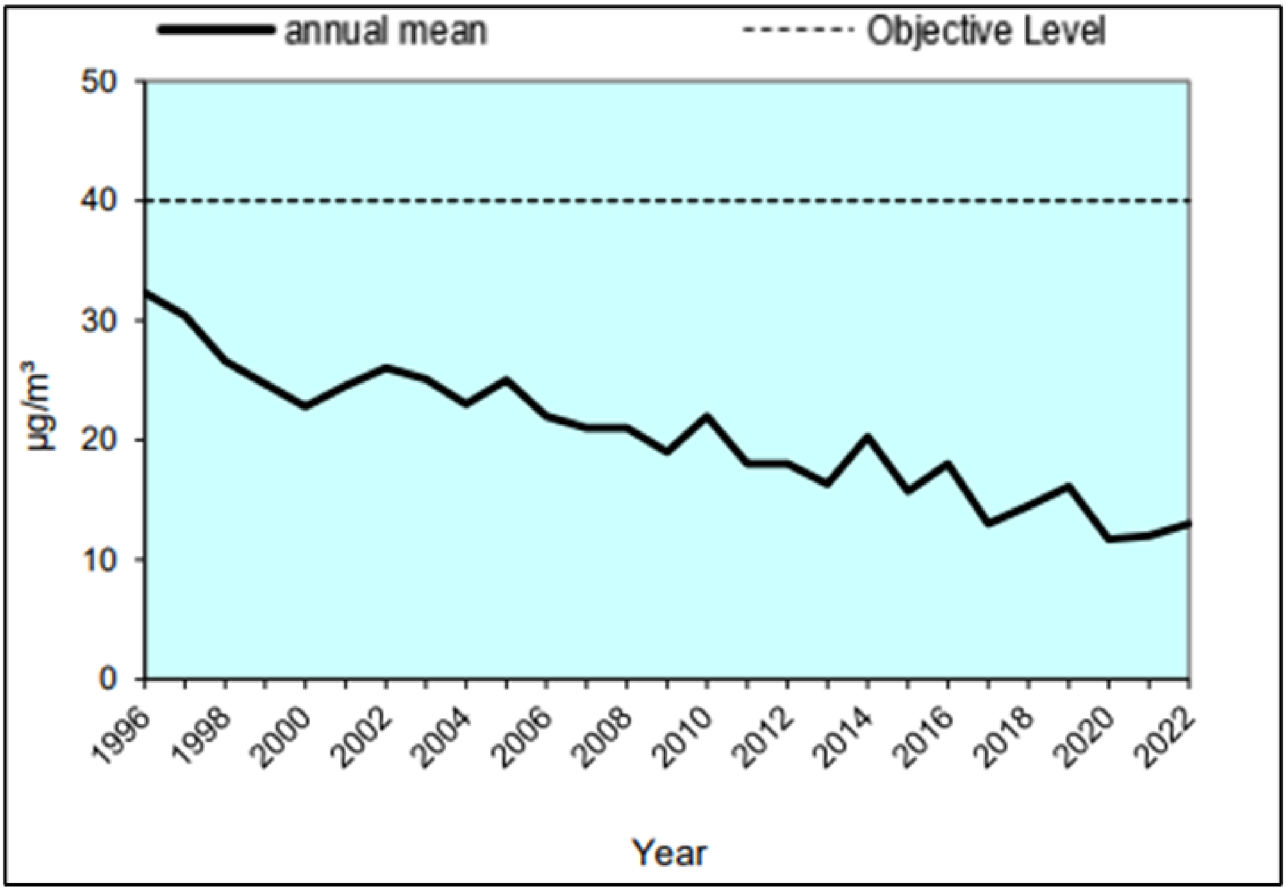


Figure 20 - Annual Mean NO_2 Concentrations at the Middlesbrough (MacMillan College) AURN Station

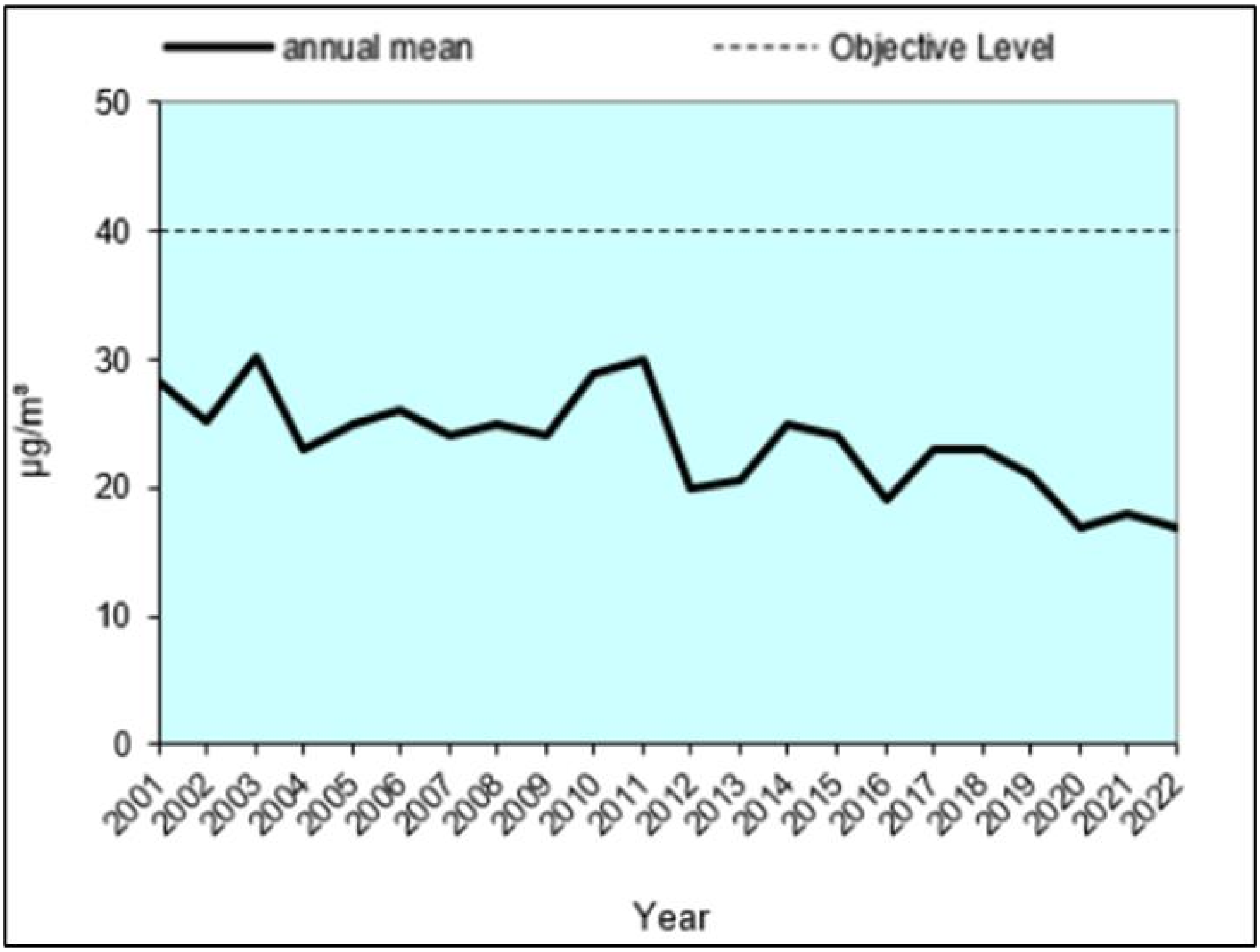


Figure 21 - Annual Mean PM_{10} Concentrations at the Middlesbrough (Breckon Hill) AURN Station

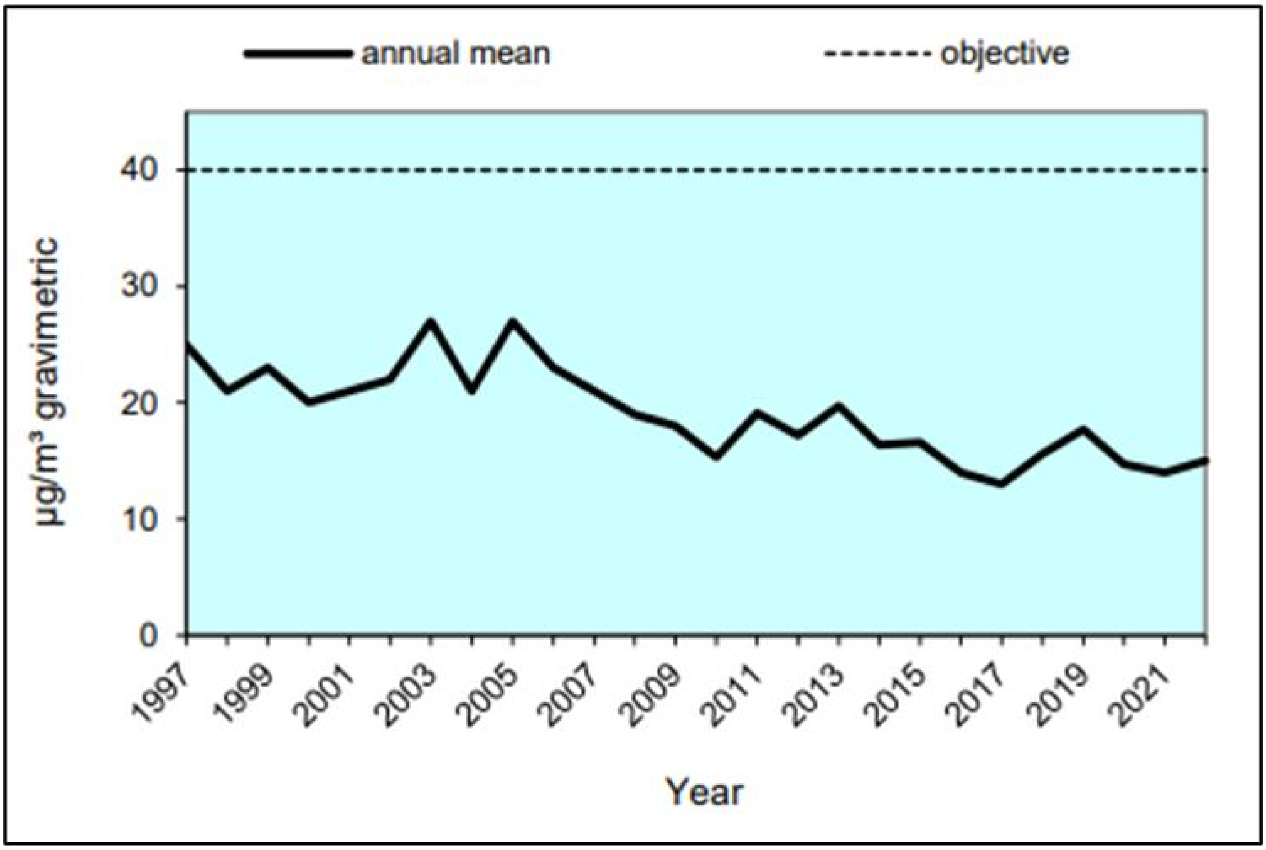


Figure 22 - Annual Mean PM_{10} Concentrations at the Middlesbrough (MacMillan College) AURN Station

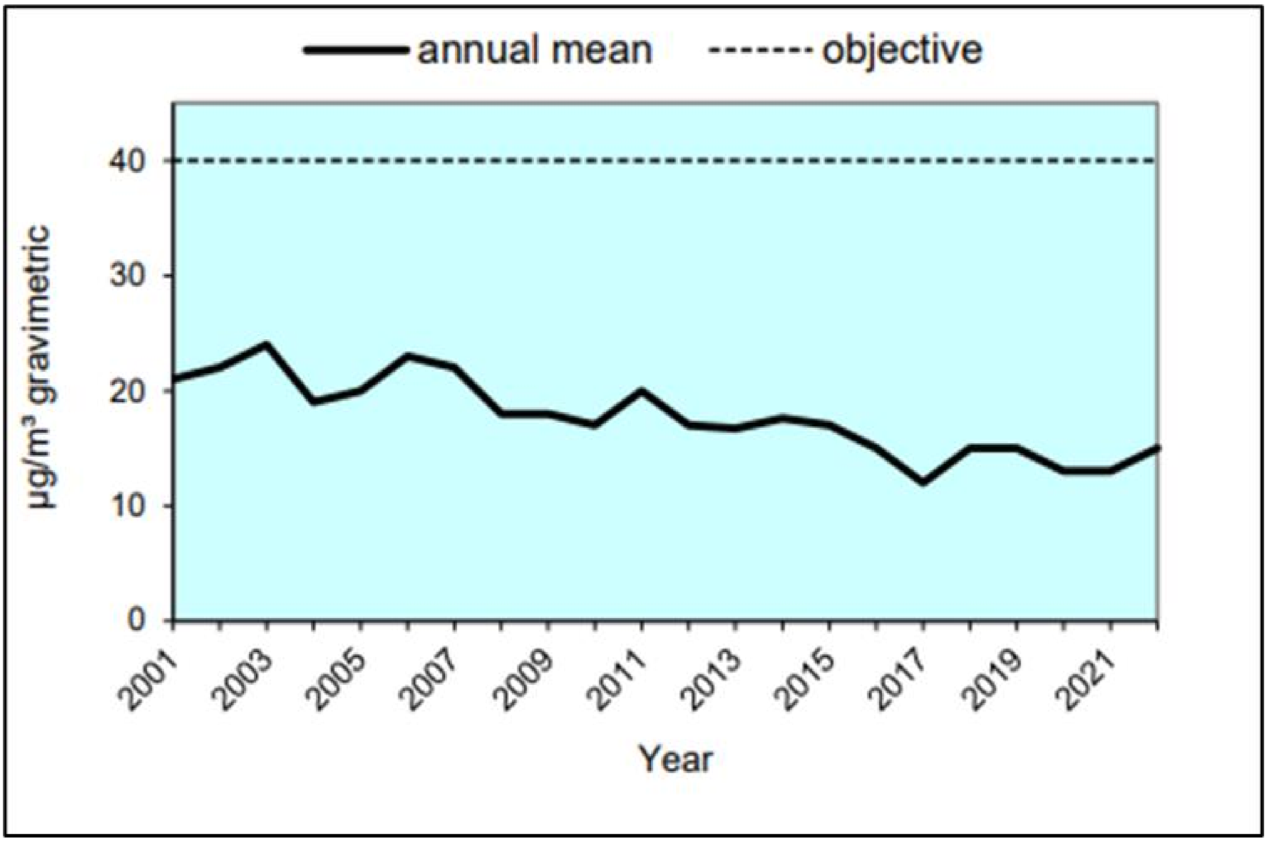


Figure 23 - Annual Mean $PM_{2.5}$ Concentrations at the Middlesbrough (Breckon Hill) AURN Station

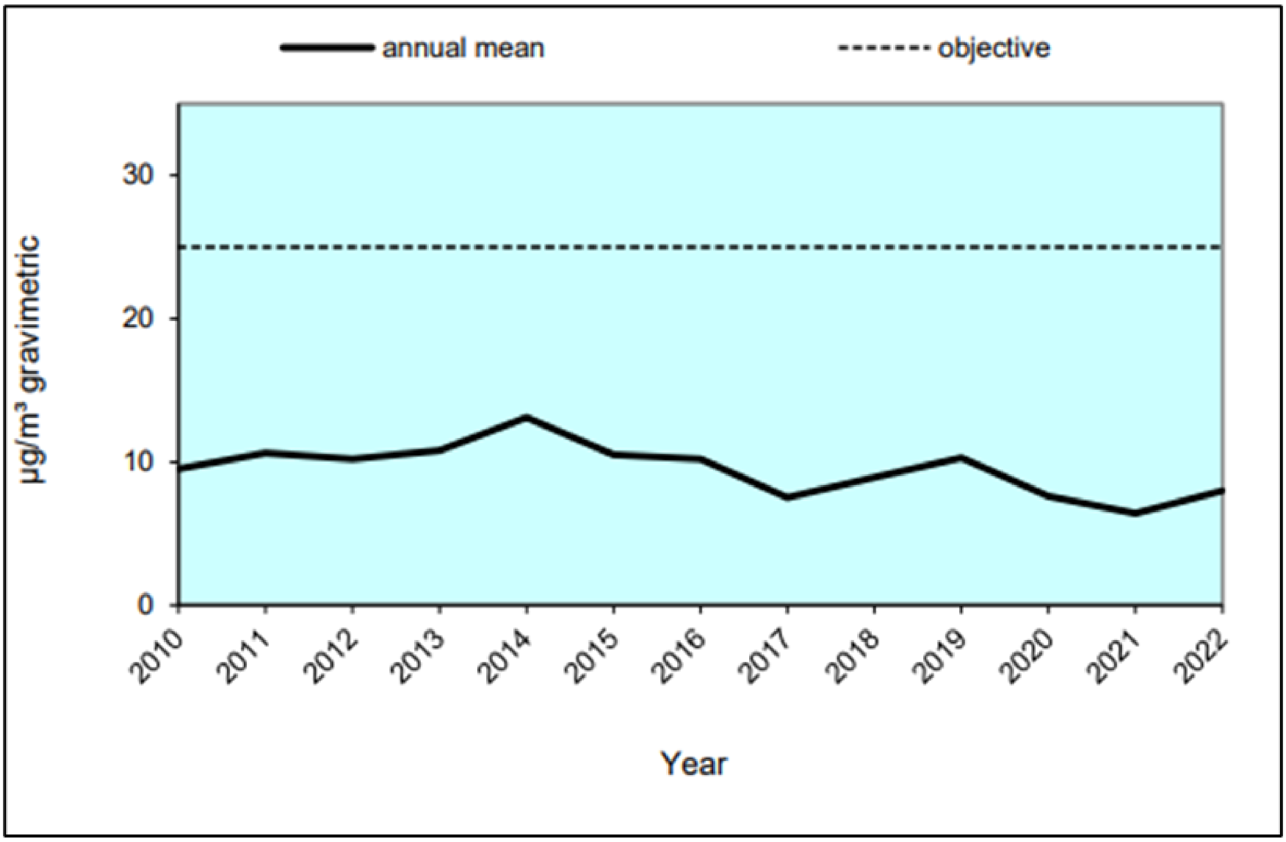


Figure 17 to Figure 23 show that there has been a reduction in NO_x, PM_{10} and $PM_{2.5}$ concentrations at the automatic continuous monitors operated by both Middlesbrough and Redcar and Cleveland councils. The applicable AQS objective for each pollutant monitored is predicted to be achieved at all presented monitoring stations. NO_2 concentrations generally show a more rapid reduction than those seen in PM_{10}/$PM_{2.5}$ which is consistent with national rates of pollutant emissions. It is also worth noting that $PM_{2.5}$ concentrations at the Middlesbrough (Breckon Hill) AURN station only started recording measurements in 2009 and is a likely contribution to its flatter gradient.

3.3 Ecological Sites in the Tees Area

A significant area of the Tees Estuary is designated for conservation purposes. An extension to the existing Teesmouth and Cleveland Coast SPA and Ramsar site was classified on 16 January 2020. All the UK protected area datasets were downloaded from Defra's Data Services Platform [39]. Table 13 outlines all the protected areas located within 15 km from the cluster (i.e., site boundaries), which are illustrated in Figure 24.

Figure 24 - Protected habitats near Teesside Industrial Cluster

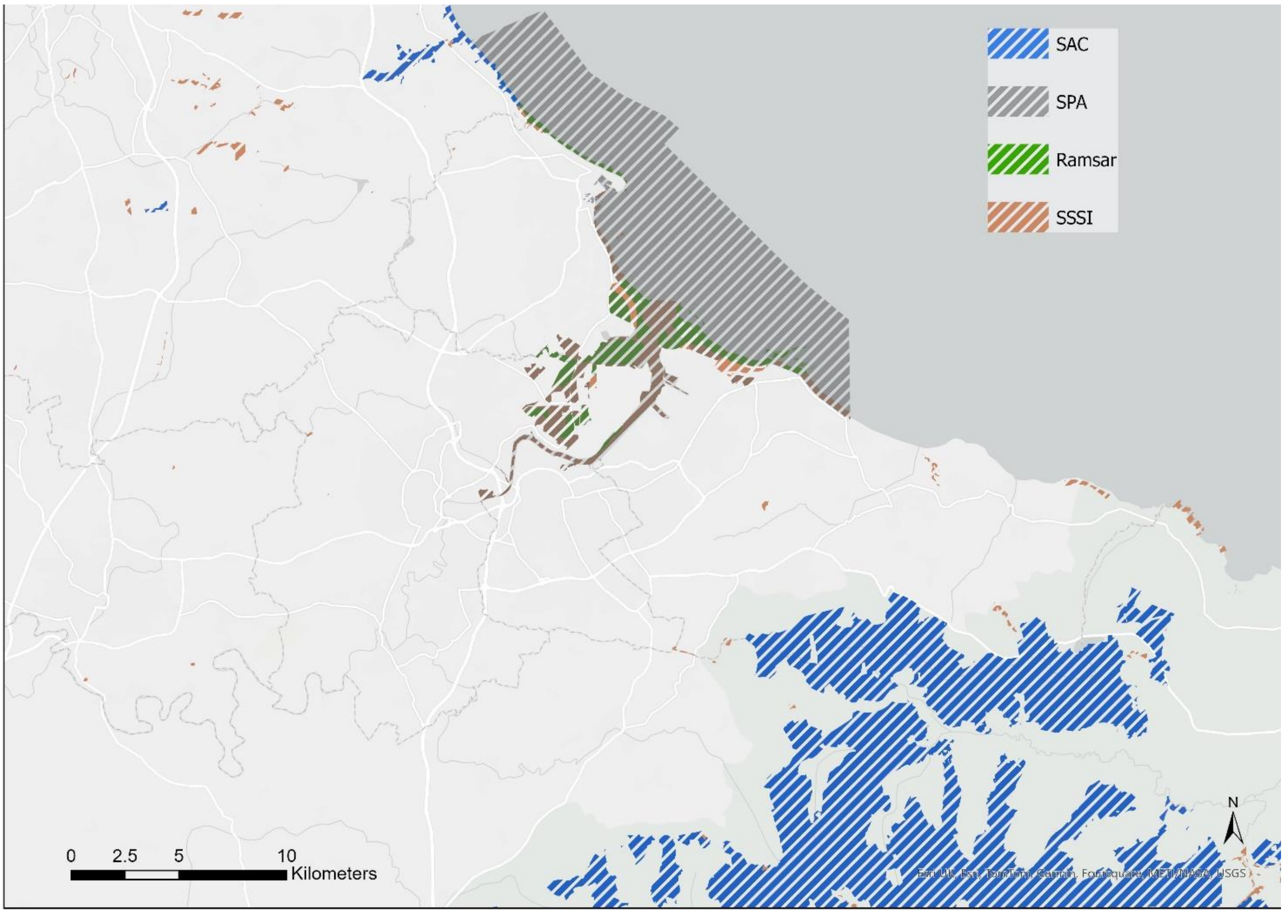


Table 13 - Ecological sites within 15 km of the Teesside Industrial Cluster

Name	Designation	Location relative to the cluster (approximate distance)	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)
Teesmouth and Cleveland Coast	SPA, SSSI & Ramsar site	Within the Teesside area (N/A)	Coastal dune grassland (calcareous type)	10 - 15	Min 6.825 Max 10.861 Ave 8.452	Min 85% Max 56%	Calcareous grassland	Min N 0.856/1.071 Max N 4.856/5.071 Max S 4/4	Min 0.617 Max 1.049 Ave 0.785	4.5% / 4.5%
North York Moors	SPA, SAC & SSSI	South of the cluster (7 km)	Dry Heath	5 - 15	Min 9.773 Max 20.093 Ave 15.495	Min 310% Max 103%	Calcareous grassland	Min N 0.856/1.214 Max N 4.856/5.214 Max S 4/4	Min 0.754 Max 1.545 Ave 1.186	24.4% / 2.0%
Northumbria Coast	SPA & Ramsar site	North of the cluster (13 km)	Coastal dune grassland (acid type)	5 - 10	Min 5.57 Max 9.484 Ave 7.5	Min 150% Max 75%	Calcareous grassland	Min N 0.856/1.071 Max N 4.856/5.071 Max S 4/4	Min 0.403 Max 0.778 Ave 0.572	5.1% / 5.1%
Durham Coast	SAC	North of the cluster (13 km)	Coastal dune grassland (calcareous type)	10 - 15	Min 7.268 Max 8.592 Ave 8.052	Min 81% Max 54%	Acid grassland	Min N 0.856/1.071 Max N 4.856/5.071 Max S 4/4	Min 0.583 Max 0.72 Ave 0.668	2.3% / 2.3%
Castle Eden Dene	SAC	North of the cluster (15 km)	Broad-leaved deciduous woodland	10 - 15	Min 7.98 Max 8.868 Ave 8.379	Min 84% Max 56%	Unmanaged Broadleafed/ Coniferous Woodland	Min N 0.147/0.357 Max N 1.626/2.519 Max S 1.269/2.377	Min 0.665 Max 0.711 Ave 0.684	42.7% / 27.2%

			Nitrogen Deposition (kgN/ha/yr)				Acid deposition (keq/ha/yr)			
Name	**Designation**	**Location relative to the cluster (approximate distance)**	**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)**
Durham Coast, Hart Bog, and Pike Whin Bog	SSSI	North of the cluster (12 km)	Coastal dune grasslands (grey dunes)	5 - 15	Min 7.266 Max 8.82 Ave 8.016	Min 160% Max 53%	Calcareous grassland (using base cation)	Min N 0.856/1.071 Max N 4.856/5.071 Max S 4/4	Min 0.583 Max 0.737 Ave 0.665	2.3% / 2.3%
Briarcroft Pasture and Whitton Bridge Pasture	SSSI	West of the cluster (10 km)	Low and medium altitude hay meadows	10 - 20	Min 6.397 Max 6.397 Ave 6.397	Min 64% Max 32%	Calcareous grassland (using base cation)	Min N 1.071/1.071 Max N 5.071/5.071 Max S 4/4	Min 0.57 Max 0.57 Ave 0.57	2.8% / 2.8%
Langbaurgh Ridge, North York Moors Cliff Ridge, and Roseberry Topping	SSSI	South of the cluster (6 km)	Geological	N/A	Min 10.636 Max 11.398 Ave 11.048	N/A	Geological	N/A	Min 0.85 Max 0.905 Ave 0.879	N/A
Saltburn Gill	SSSI	East of the cluster (8 km)	Broad-leaved, mixed and yew woodland	15 - 20	Min 8.299 Max 8.746 Ave 8.523	Min 57% Max 43%	Unmanaged Broad-leafed/ Coniferous Woodland	Min N 0.142/0.357 Max N 2.639/2.813 Max S 2.448/2.497	Min 0.676 Max 0.706 Ave 0.961	36.4% / 34.2%
Lovell Hill Pools	SSSI	Southeast of the cluster (2 km)	No comparable habitat with established critical load for estimate available.		Min 9.336 Max 10.138 Ave 9.737	N/A	No comparable habitat with established critical load for estimate available.		Min 0.781 Max 0.837 Ave 0.809	N/A
Boulby Quarries	SSSI	East of the cluster (15 km)	Geological	N/A	Min 8.677 Max 9.034 Ave 8.856	N/A	Geological	N/A	Min 0.683 Max 0.711 Ave 0.697	N/A

Note: APIS Mid-year Selection 2020 (2019 to 2021)

The information displayed in Table 13 highlights designated habitats within the Tees industrial area showing the total nitrogen and sulphur deposition, and ranges of nutrient nitrogen and acid critical loads of the most sensitive habitat features. [40].

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 Tees area's ecosystems, Table 14 and Table 15 presents total nitrogen and sulphur deposition in the Tees industrial 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. Those categorised as “other” imports, etc. represent the largest source in terms of both nitrogen and sulphur deposition.

Transport is the next most significant, of which road traffic forms a relatively small component. Industrial activities have a variable impact on different habitats, contributing more to sulphur deposition than to nitrogen, with the Teesmouth and Cleveland Coast SPA seeing an 8.0% industrial contribution to sulphur deposition. 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, suggesting room for optimization and control in these sectors.

Table 14 - 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.)
Teesmouth and Cleveland Coast SPA	1.3	7.4	20.7	2.1	68.5
Teesmouth and Cleveland Coast SSSI	1.3	7.7	22.7	2.3	66
North York Moors SPA, SAC, SSSI	1.2	6.3	2.6	1.2	88.7
Northumbria Coast SPA	1.2	8.5	5.8	1.0	83.5
Durham Coast SAC	1.6	9.3	6.5	1.1	81.5
Durham Coast SSSI	1.7	9.6	6.4	1.1	81.2
Saltburn Gill SSSI	1.4	7.8	3.7	1.3	83.8
Hart Bog SSSI	1.5	10.1	4.9	1.0	82.5
Pike Whin Bog SSSI	0.8	6.3	2.7	0.7	89.5
Lovell Hill Pools SSSI	0.8	6.3	2.6	0.9	89.4
Castle Eden Dene	1.5	8.7	6.4	1.1	82.3
Boulby Quarries	1.3	6.7	3.3	1.2	87.5

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 15 - 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.)
Teesmouth and Cleveland Coast SPA	8.0	0.3	23.1	6.2	63.4
Teesmouth and Cleveland Coast SSSI	8.3	0.4	24.7	6.6	60
North York Moors SPA, SAC, SSSI1	6.8	0.5	2.6	3.0	87.1
Northumbria Coast SPA	5.6	0.4	3.3	8.5	82.2
Durham Coast SAC	7.0	0.3	5.0	4.0	83.7
Durham Coast SSSI	7.1	0.4	4.9	3.9	83.7
Saltburn Gill SSSI1	7.6	0.4	1.4	4.8	86.2
Hart Bog SSSI2	8.1	0.4	1.3	3.5	86.7
Pike Whin Bog SSSI	8.7	0.5	1.1	4.3	85.4
Lovell Hill Pools SSSI	7.9	0.2	1.3	7.7	82.9
Castle Eden Dene SSSI	8.8	0.5	0.7	2.6	87.4
Boulby Quarries SSSI	6.7	0.3	1.2	3.3	87.5

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.

3.4 Net Zero Projects in the Tees Industrial Cluster

Table 16 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.

Table 16 - Existing and New Industrial Projects within the Teesside Industrial Cluster

Site name	Status of the project	Project information	Technology/Approach
SABIC, Cracker	Existing	£200m spent at the Olefins 6 plant at Wilton International site, Teesside, as part of a broader £1 billion-plus strategy to transform its UK operations towards carbon neutrality by 2030. The Olefins plant is crucial for producing ethylene, propylene, and butadiene - key components for a wide range of products. The investment highlights SABIC's commitment to reducing its carbon footprint by up to 60% and exploring hydrogen as a potential fuel source for future operations.	Hydrogen, Carbon Neutrality by 2030
Sembcorp GT1	Existing	An existing 183 MW_{th} CCGT at the Wilton International site, Teesside, providing steam and power to the wide range of industrial customers. Featuring the latest 'Dry Low NO_x' (DLN) technology, GT1 operates under stringent environmental permitting regulations, ensuring compliance with local and national emission standards. Sembcorp's initiative to reduce CO_2 emissions and contribute to the UK's Net Zero by 2050 climate change target may involve fuel switching to H_2-fuel once a robust supply can be demonstrated.	H_2-fuel, Dry Low NO_x Technology
Sembcorp GT2	Existing	An existing 133 MW_{th} CCGT at the Wilton International site, Teesside, providing steam and power to the wide range of industrial customers. Featuring the latest 'Dry Low NO_x' (DLN) technology, GT2 operates under stringent environmental permitting regulations, ensuring compliance with local and national emission standards. Sembcorp's initiative to reduce CO_2 emissions and contribute to the UK's Net Zero by 2050 climate change target may involve fuel switching to H_2 fuel once a robust supply can be demonstrated.	H_2-fuel, Dry Low NO_x Technology
BOC Seal Sands	Existing	The BOC North Tees Hydrogen Plant, operational since 2002, produces approximately half of the UK's industrial hydrogen. Production utilises natural gas through the Steam Methane Reforming (SMR) process. This method inherently produces CO_2 as a byproduct, which, until now, has been released into the atmosphere. BOC's recent initiative to capture and liquefy a portion of this CO_2 for various food and drink sector industries marks a pivotal move towards environmental sustainability. BOC's Teesside Hydrogen CO_2 Capture project has been selected by the UK Government to progress to the next phase of the DESNZ Track-1 cluster sequencing process to deliver low-carbon hydrogen and will retrofit post combustion carbon capture technology designed by Linde Engineering. The captured CO_2 will be fed into the decarbonising infrastructure developed by the East Coast Cluster and transported 145 km offshore to the Endurance geological storage facility. This project is one of the eight Primary Emitters associated with the East Coast Cluster bid, in the Tees Industrial Cluster.	SMR, CO_2 Capture & Liquefaction

Site name	Status of the project	Project information	Technology/Approach
Ensus	Existing	Ensus operates one of Europe's largest production plants for renewable ethanol at Wilton International, Teesside. The raw materials used by Ensus absorb CO_2 from the atmosphere during growth. When converted into usable products such as ethanol and animal feed, biogenic CO_2 is produced during sugar fermentation. This pure CO_2 is captured, transferred and liquified by the Wilton-based company Nippon Gases, one of the leading producers of industrial and medical gases in Europe.	Renewable Ethanol, Biogenic CO_2 Capture
Statera Energy Saltholmes North	Existing	Newly built 4 x 26 MW_{th} spark ignition fast start reciprocating gas engines, operating to provide energy to the grid during peak periods. Operating under Section 1.1 Part A(1)(a) of the Environmental Permitting Regulations (EPR) for the burning of fuel in an appliance with a rated thermal input of 50 MW_{th}. The individual engines are also Medium Combustion Plant (MCP) under Schedule 25A of the Environmental Permitting Regulations. Currently limited to operating 3,500 hr pa maximum with NO_x emissions abated with SCR. Statera Energy have signed a Heads of Terms agreement with Kellas Midstream for the provision of low carbon hydrogen from Kellas' H_2NorthEast project, Teesside enabling the Saltholmes flexible energy generation plants to fuel switch.	Low Carbon Hydrogen from H_2NorthEast
Statera Energy Saltholmes South	Existing	Newly built 4 x 26 MW_{th} spark ignition fast start reciprocating gas engines, operating to provide energy to the grid during peak periods. Operating under Section 1.1 Part A(1)(a) of the Environmental Permitting Regulations (EPR) for the burning of fuel in an appliance with a rated thermal input of 50 MW_{th}. The individual engines are also Medium Combustion Plant (MCP) under Schedule 25A of the Environmental Permitting Regulations. Currently limited to operating 3,500 hr pa maximum with NO_x emissions abated with SCR. Statera Energy have signed a Heads of Terms agreement with Kellas Midstream for the provision of low carbon hydrogen from Kellas' H_2NorthEast project, Teesside enabling the Saltholmes flexible energy generation plants to fuel switch.	Low Carbon Hydrogen from H2NorthEast

Site name	Status of the project	Project information	Technology/Approach
Hydrogen Transport Hub	Existing	An initiative aimed at creating the country's first multi-modal hydrogen transport hub. The project is set to be fully operational by 2025 and includes facilities for green hydrogen production, storage, distribution, and refuelling stations, which will serve existing and evolving transport networks and services. By acting as a test bed, the hub will help to understand the role of hydrogen in the energy transition within the transport sector. Ten Toyota Mirai hydrogen fuel cell electric cars and a Toyota fuel cell forklift truck were handed over to the Tees Valley Hydrogen Transport Hub, at the opening of the new Element 2 hydrogen fuelling station at Teesside International Airport. Toyota have also provided hydrogen fuel cell electric vehicles for use by the region's rapid response services, including Cleveland Police, NHS patient support as well as the Combined Authority, Anglo American and Stagecoach. Utilisation of hydrogen fuel results in significant environmental savings with each kilogram of hydrogen fuel used offsetting 3.7 litres of diesel and 10 kg of CO_2 emissions, however they also emit warm air which may contribute to global warming.	Green Hydrogen Production & Distribution
Seal Sands	Existing	Brine caverns for storage.	Storage
Wilton	Existing	Brine caverns for storage.	Storage
CF Fertilisers UK	Existing	CF Fertilisers UK is undergoing a significant transformation to enhance its sustainability and competitiveness in the global market. Recognising the challenges posed by high natural gas prices and carbon costs, the company has decided to concentrate its operations at the Billingham facility, noted for its efficiency and lower production costs. This facility will continue to produce Ammonium Nitrate (AN) fertiliser and nitric acid using imported ammonia. CF Fertilisers is a key participant in the HyNet North West project, a pioneering carbon capture and storage (CCS) initiative aimed at reducing the UK's industrial carbon emissions. This project, which involves a £510,000 government grant matched by CF Fertilisers, is expected to capture 330,000 tonnes of CO_2 annually, significantly contributing to the decarbonisation of the UK agriculture industry and supporting the UK's 2050 Net Zero carbon target. This project is one of the eight Primary Emitters associated with the East Coast Cluster bid, in the Tees Industrial Cluster.	CCS in Agriculture, HyNet north west

Site name	Status of the project	Project information	Technology/Approach
Suez Recycling and Recovery UK	Existing	Suez propose to retrofit two commercial scale carbon capture (CC) plants onto their existing Energy from Waste (EfW) plant at Haverton Hill, Billingham. The project will capture 240 ktpa of CO_2 from the flue gas to be fed into the decarbonising infrastructure developed by the East Coast Cluster and transported 145 km offshore to the Endurance geological storage facility. Suez operates 5 separate EfW lines at Haverton Hill. The initial planning application relates to two CC plants removing carbon from Lines 1 & 2 and Line 3. It is envisaged that when the project is fully operational, further applications for a carbon capture plant for lines 4 and 5 will be proposed in a second phase. The first phase of the project (Lines 1 – 3) would not only avoid the emission of CO_2 from the EfW, but also result in more than 70 ktpa CO_2 being removed from the atmosphere. This is because the biogenic carbon within the waste is captured, such as paper and wood, which is already in the carbon cycle in addition to the fossil carbon (e.g. plastic). This project is one of the eight Primary Emitters associated with the East Coast Cluster bid, in the Tees Industrial Cluster.	CC on EfW, CO2 Capture & Storage
Marlow Foods	Existing	The plant-based food brand Quorn is working towards net-zero operational emissions by 2030 and has announced a partnership with UK-based hydrogen production and services company Protium, to investigate how using dual-fuel boilers for heating processes at Quorn's factory in Billingham could cut emissions and energy costs. The boilers will be capable of running on natural gas, currently used at the factory, as well as pure hydrogen and hydrogen blends. Under the partnership, Protium will supply the hydrogen to Quorn's factory, generated at their proposed facility located approximately one mile away.	Hydrogen Dual-Fuel Boilers
NZT Power	New	A pioneering initiative by Net Zero Teesside Power, NZT Power and the anchor project for decarbonising the Tees Industrial Cluster. This is a new build, 860 MW_e gas-fired power station equipped with carbon capture technology operating in dispatchable mode. It is capable of powering up to 1.3 million homes, annually. By integrating carbon capture, the project aims to capture up to two million tonnes of CO_2 each year, contributing significantly to reducing industrial emissions. This venture is a collaboration between BP and Equinor, with BP serving as the operator. This project is one of the eight Primary Emitters associated with the East Coast Cluster bid, in the Tees Industrial Cluster. Project selected by the UK Government to progress to the next phase of the DESNZ Track-1 cluster sequencing process to deliver low-carbon hydrogen	Gas-fired Power with Carbon Capture

Site name	Status of the project	Project information	Technology/Approach
NEP	New	NEP, Northern Endurance Partnership, is the CO_2 transportation and storage provider for the East Coast Cluster. The Teesside onshore NEP infrastructure will serve the Teesside-based carbon capture projects – NZT Power, H_2Teesside and Teesside Hydrogen CO_2 Capture – that were selected for first connection to the ECC by DESNZ in March 2023 as part of the UK's cluster sequencing process for carbon capture usage and storage. Around 4m tonnes of CO_2 per year from these projects could be transported and stored from 2027.	CO2 Transportation & Storage
BP H_2Teesside	New	H_2Teesside aims to become one of the UK's largest facilities of its kind, producing 1.2 GW of blue hydrogen production by 2030. This accounts for over 10% of the UK government's hydrogen target for the same year. The project plans to produce hydrogen from natural gas, capturing and permanently storing up to two million tonnes of CO_2 annually at the Northern Endurance Partnership (NEP) facility for geological storage, at Endurance. This project is one of the eight Primary Emitters associated with the East Coast Cluster bid, in the Tees Industrial Cluster. Project selected by the UK Government to progress to the next phase of the DESNZ Track-1 cluster sequencing process to deliver low-carbon hydrogen	Blue Hydrogen Production
H_2North East project, Kellas Midstream CATS	New	By 2027, H_2North East will deliver 355 MW of low-carbon hydrogen to local industry, upscaling to 1 GW by 2030 and contributing up to 10% of the UK's target hydrogen capacity. This project is one of the eight Primary Emitters associated with the East Coast Cluster bid, in the Tees Industrial Cluster.	Low-Carbon Hydrogen Delivery
8Rivers/Whitetail Energy	New	The Whitetail Energy project will harness the Allam-Fetvedt Cycle (AFC), pioneered by NET Power and 8 Rivers Capital. The process involves oxy-combustion of natural gas and uses the resulting supercritical CO_2 as the working fluid to generate power. As a result, nearly all air emissions, including traditional pollutants and CO_2, are captured. Pipeline-quality CO_2 can then be stored offshore, in the Endurance geological storage facility. This project is one of the eight Primary Emitters associated with the East Coast Cluster bid, in the Tees Industrial Cluster.	Allam-Fetvedt Cycle, CO_2 Capture
HyGreen Teesside	New	As one of the UK's prospective largest green hydrogen facilities, bp's HyGreen Teesside has initial phase plans for 80 MW of installed hydrogen production capacity, with ambitions to expand up to 500 MW by 2030. This green hydrogen production aligns with the UK's broader hydrogen strategy and aims to power the equivalent of over 10,000 Heavy Goods Vehicles, further establishing Teesside as a major hydrogen transport hub.	Green Hydrogen Production

Site name	Status of the project	Project information	Technology/Approach
Protium	New	This proposed 68.8 MW PEM electrolyser for green hydrogen production will help local manufacturers and logistics firms make the switch from natural gas and diesel. Two stages of construction are planned for the Teesside project. The first aims to take place in Q3 2025 and will involve 1 array of the PEM electrolyser, which will produce 17.2 MW. The second stage in 2026, will scale this to 4 arrays in total, reaching a maximum of 68.8 MW capacity.	Green Hydrogen via PEM Electrolysis
EDF Renewables	New	EDF Renewables UK and Hynamics, a 100% subsidiary of EDF Group specialising in hydrogen, have been shortlisted for the government's Net Zero Hydrogen Fund (NZHF) for their Teesworks-based Tees Green Hydrogen project. Tees Green Hydrogen will be a pioneering project, using the green electricity from nearby Teesside Offshore Wind Farm and a planned new solar farm, which EDF Renewables UK has proposed near Redcar, to produce electrolytic renewable hydrogen. The project will supply local industry with hydrogen to support decarbonisation efforts and a significant reduction in industrial pollution. In its initial phase, the electrolyser will have a 730-50MW capacity, but is designed to be able to scale to over 500MW, in line with emerging demand. Subject to the NZHF and planning considerations, it was hoped that work could begin on site in 2024, with the facility operational by 2025. PD Ports will be one of the first customers for Hynamics and EDF Renewables UK's Teesside-produced green hydrogen as part of the initial phase of the project. PD Ports will deploy the gas to power its port operations. A Memorandum of Understanding was agreed with Northern Gas Network, to supply the Hydrogen Village project in Redcar, a trial replacing domestic and business natural gas appliances with hydrogen. This project has now been abandoned.	Electrolytic Renewable Hydrogen
Green Lithium	New	Proposed lithium refinery, manufacturing raw materials for battery production. Chinese lithium refineries are large emitters of CO_2, typically emitting 16.2 kg CO_2 for every kg of lithium chemicals produced. Green Lithium will create a supply of lithium which, under its decarbonised scenario, will emit 3.3 kg CO_2 emissions per kg lithium – 75% lower emissions than equivalent Chinese refineries. Green Lithium will achieve this by adopting and incorporating the latest clean-energy technology e.g. hydrogen gas fuel, carbon capture and storage, and waste-heat recycling.	Clean-Energy Tech in Lithium Refining

Site name	Status of the project	Project information	Technology/Approach
Circular Fuels Ltd	New	Proposed manufacturing of di methyl ether from non-recyclable resources and biomass, for use as a fuel substitute for LPG and diesel. When fully operational, the £150 million plant will be able to produce 50,000 tonnes of fuel per year from non-recyclable household and industry waste by converting it into a safe, cost-effective, and clean burning fuel. This plant will be carbon capture-ready, with the potential to connect into the NEP CO_2 pipeline for geological storage at Endurance. This renewable fuel, called renewable and recycled carbon dimethyl ether (rDME), has similar properties to LPG and can be stored in cylinders and tanks. This means it can serve properties not connected to the national gas grid, which are often some of the hardest to decarbonise.	Renewable Fuel, Carbon Capture-Ready
Tees Valley Lithium Ltd	New	Proposed lithium chemical processing for battery production. Tees Valley Lithium's £200 million refinery could produce up to 96,000 tonnes per year, representing 15% of European electric vehicle makers' required lithium hydroxide once it reaches capacity in 2030. Located at the Wilton International Plug & Play Chemicals Park, Teesside, Tees Valley Lithium will be the first major ultra-low carbon Lithium Hydroxide plant to be established in Europe. The project has received full planning permission from Redcar & Cleveland Borough Council as Wilton International benefits from Instruments of Consent (IOC) granted by Redcar, Eston and Guisborough Borough Councils in 1946 and effectively confers deemed planning consent for heavy and light industrial development.	Ultra-Low Carbon Lithium Hydroxide
Nova Pangaea Technologies	New	Nova Pangaea Technologies (NPT) converts biomass such as forestry and agricultural residues into sustainable sugars and biochar using proprietary technology. The sugars can be fermented into bioethanol that is used as a drop in for sustainable aviation fuels, and the biochar replaces coke within sectors such as the steel industry to create green steel and is considered carbon neutral. When the biochar is used as a soil enhancer for agricultural purposes, it is also considered a carbon capture and delivers carbon negative. Construction of NPTs first waste-to-fuel commercial-scale production facility, and the UK's first of its kind, has commenced, with the facility producing biofuels by 2025. Investment into NPT, announced by International Airlines Group, is in addition to its \$865 million commitment to SAF.	Biomass to Sustainable Sugars & Biochar

Site name	Status of the project	Project information	Technology/Approach
alfana	New	The Lighthouse plant at Seal Sands is one of the first projects underway in the UK aiming to convert biogenic and non-biogenic solid wastes and residues into sustainable aviation fuels (SAF) on a large scale. The new plant with its innovative syngas cleaning, hydrogen purification & carbon capture technologies, will process around one million tonnes of wastes and residues into SAF each year. The plant is expected to enter commercial operation in 2028 and to fuel the equivalent of more than 25,000 short-haul or 2,500 long-haul flights a year.	SAF from Biogenic and Non-Biogenic Waste
Tees Valley Energy Recovery Facility	New	A proposed 49.9 MW_e Tees Valley Energy Recovery Facility (TV ERF) will allow the seven participating councils (Darlington, Durham, Hartlepool, Middlesbrough, Newcastle, Redcar & Cleveland and Stockton) to have full control over the management of waste from across the region, that is left over after recycling (known as “residual waste”) - ensuring it is managed locally, sustainably and safely, over the long term. The facility will be located at the Teesworks site, on the former British Steel works at Grangetown, and will support the regeneration of the local area. This location also offers the potential for the TV ERF to export heat, as well as electricity, to future nearby users and, in the longer term, the possibility of connecting to the Northern Endurance Partnership (NEP) CCS infrastructure as part of the East Coast Cluster. This project is one of the eight Primary Emitters associated with the East Coast Cluster bid, in the Tees Industrial Cluster. Whilst this project was not selected for Track 1 funding, the plant will be designed to be carbon capture ready in the event that future CCUS funding rounds occur.	EfW with Potential for CCS
Redcar Energy Centre	New	Proposed 49.9 MW_e EfW plant with carbon capture. The Redcar Energy Centre (REC) will be a state-of-the-art materials and energy recovery facility generating baseload power to more than 100,000 homes. The REC is a joint venture between PMAC Energy and Low Carbon Limited. The project secured planning permission in January 2021 from Redcar & Cleveland Borough Council. The project will be located on a 25-acre site at Redcar Bulk Terminal, the former British Steel works.	EfW with Carbon Capture
Wentworth Clean Power Limited	New	A proposed for a 30 MW_e Waste to Energy plant at the TeesPort Commerce Park, producing sufficient power for up to 27,000 homes with the potential to provide decentralise energy to existing and planned industrial users via combined heat and power. Wentworth state "WCP does not consider there to be any valid reasons for implementing any plant without carbon capture and utilisation capability today."	Waste to Energy with CCU

Site name	Status of the project	Project information	Technology/Approach
Teesside Green Energy Park Ltd	New	Solar 21 have submitted a proposal for a 240,000Tpa incinerator to treat refuse derived fuel (RDF) and generate 30 MW_e of power, at Seal Sands. The plant would be supported by low carbon technologies including hydrogen production. Carbon capture utilisation and storage plant would be installed to capture a proportion of the carbon associated with the preparation of the facility.	Incineration with Low Carbon Technologies
Blastr	New	In July 2023 Blastr Green Steel (Blastr) signed a letter of intent (LOI) with Redcar Bulk Terminal (RBT), located in Teesside, UK, to explore its potential as a future location for a pellet plant. The plant would be used to supply feedstock to Blastr's steel plant, currently being developed in Inkoo, Finland. Blastr plans may involve the use of a H_2 atmosphere to produce 6 Mt of high-quality direct reduction (DR) pellets as feedstock for its ultra-low CO_2 Inkoo steel plant. Approximately half of the pellet volumes will go to Blastr's steel plant at Inkoo, while the rest will be sold by Cargill Metals for distribution to the growing world market for DR pellets.	H_2 Atmosphere for Pellet Production
British Steel	New	A proposed, new £1.25 billion electric arc furnace project, producing "green steel" at Lackenby, Redcar. British Steel is investigating the use of green hydrogen produced by EDF Renewables and the new furnaces could be operational by late 2025. Planning permission was granted on 3 April 2024.	"Green Steel" with Green Hydrogen
Exolum	New	The Government has awarded £7 million to a project which will see fuel distributer Exolum build the new publicly accessible hydrogen filling station near Middlesbrough at the intersection of the A19 and A66. Initially serving at least 25 new, zero-emission HGVs making deliveries from supermarket groceries to new clothes, it will be capable of dispensing up to 1.5 tonnes of hydrogen per day.	Publicly Accessible Hydrogen Filling Station
Arcadia e-Fuels	New	Waste industrial CO_2 plus green H_2 to SAF. Capacity of 67kt/y by 2028. Received £12.3m Department for Transport Government funding in October 2023.	Waste CO_2 + Green H_2 to SAF
Willis Lease Finance Corporation	New	A proposed plant at Dorman Point, Teesworks utilising industrially captured CO2 and green H2 to manufacture sustainable aviation fuel (SAF). Aiming to produce 14 kt/y by 2028, Willis received £4.7m Department for Transport Government funding in October 2023.	SAF from Captured CO_2 and Green H_2
Enfinium's Ferrybridge	New	Enfinium, in collaboration with Navigator Terminals, aims to develop the UK's first 'Rail to Zero' carbon capture rail corridor to transport CO2 from the Ferrybridge energy from waste facilities in Yorkshire to Teesside for offshore storage. This project is part of a groundbreaking initiative to decarbonise the Ferrybridge site, the largest energy from waste site in the UK, potentially delivering 700,000 tonnes of negative emissions annually, aligning with the UK Government's negative emissions target for 2035. The Ferrybridge site, acting as an anchor project, could enable additional dispersed industrial sites in Northern England to access carbon capture storage solutions provided by Navigator Terminals.	Rail corridor for Carbon Capture

3.5 Analysis of Teesside Workshops

Discussion has arranged and taken place with various project stakeholders and environmental consultants regarding the potential emissions and air quality impacts from the developments within the Tees Industrial Cluster, including Carbon Capture and Storage (CCS) as well as Hydrogen production.

A significant point highlighted across workshops was that air quality standards are not a target and the lower the concentrations, the better. Concentrations downwind of sources should be below the air quality standards so there are no negative impacts on human health and the environment.

Current monitoring results within the area show there should not be any issues regarding NO_2, PM_{10} and $PM_{2.5}$ concentrations providing levels do not increase. However, there is uncertainty on the amount of NO_x emissions that Hydrogen combustion processes produce as they tend to produce higher levels of thermal NO_x which may increase further due to fuel recirculation processes. Hydrogen may also be mixed with other fuels for combustion which adds unknowns to the NO_x emission levels. The dispersion of emissions may also be impacted by low-efflux movement. Original Equipment Manufacturers (OEMs) have confirmed testing of burners that use a 30% Hydrogen fuel blend, which achieved a 20-25ppm NO_x release without a Selective Catalytic Reducer (SCR), but 100% hydrogen burners are still in development.

OEMs did note that the current startup of equipment is reliant on natural gas, partly due to regulations. In France, startup/shutdown must be on Natural Gas due to explosive risk, but in Japan, regulations allow startup/shutdown on pure hydrogen. Currently, there is no legislation either way in the UK. Ultimately the goal is to minimise natural gas combustion, as such work is in progress to achieve this.

There was discussion on blend progression versus the switch to 100% hydrogen. Manufacturers confirmed most current technology would be suitable for up to 30% hydrogen. From 30 - 100% hydrogen most manufacturers agree a change in technology is required which would be suitable for 100% hydrogen. Therefore, the switch to 100% hydrogen without blends will be limited by availability. It is anticipated that switching to 100% is more likely close to the cluster due to increased availability, but this could change with time. Hydrogen availability can be combated with hydrogen storage, salt caverns are in discussion where the geology is suitable.

The effects of increased water vapour in combustion product streams, NH_3 dilution and SCRs have also yet to be confirmed. The need for SCRs has been called into question by unknowns for NO_x emission levels, but discussion is currently underway with OEMs regarding the effects of water vapour. Currently, they have observed that increased water vapour has only been seen in the last stage of combustion and has only affected the decision-making for different coatings on turbine blades to reduce corrosion. There has been no effect on the downstream exhaust treatment. Changes to the selection and efficiency of the catalyst in SCRs have not been affected.

Use of NH_3 as a hydrogen carrier fuel was brought into consideration. Currently, only NH_3 use in small gas turbines with SCR systems and lower firing temperatures are being considered due to the inability to limit NO_x emissions in higher-class gas turbines. A full program is underway considering the safety requirements of NH_3 as a hydrogen carrier in handling, storage and management as well as the control and detection of leakages.

It was suggested that the Environment Agency provide Environmental Limit Values (ELVs) for each group of amines, primary, secondary and tertiary, after each group has a fully understood degradation rate and reaction pathway [41]. However, there is difficulty in knowing the specific effects of these amines as technology licensors are reluctant to disclose the specific amines present in solvents, they may also be mixed during the operation of the plant. As well as this, it is not always known what amine solvent will be used in the planning stages. Applicants will typically list monoethanolamine (MEA) and nitrosodimethylamine (NDMA) as the amine in the absence of an agreement with the proprietary solvent supplier to obtain permits by a specific date / for funding as it is considered the worst-case solvent and has an EAL. Once the solvent has been determined, applicants will then request a permit variation to reflect this change, which will require revisiting previous Air Quality Assessments (AQA). Some operators have chosen this approach which is not considered standard in environmental permitting. This change in substance could impact the plant size due to the difference in CO_2 removal efficiencies. Removal efficiencies would have to remain constant between solvents to avoid altering these plant parameters.

The stakeholders have stated an approach is in discussion for assessing these solvent changes at the permitting stage as well as potentially producing EALs for new solvents for planning stages. Currently, there are a lot of unknowns surrounding the chemistry of new amines, the calculations of EALs are based on the proxy system and chemical structure to determine toxicity. These unknowns also apply to nitrosamines and their breakdown products, which have been highlighted for concern due to difficulties in measuring them as they are typically below the limits of detection and have a fast breakdown. Nitrosamines can be directly emitted as a result of solvent degradation and can be formed from some amines in the atmosphere. Traces ng/m3 of nitrosamine in ambient air makes air quality monitoring challenging. The Environment Agency has begun to consider building a library of impacts from particular solvents and their effects on air quality. Potentially using historic data of amines in uses other than CCS, such as pH and corrosion control, for insight into present-day consents of CCS developments.

The impacts on sensitive ecological receptors were highlighted as a significant risk and a cause of concern for development progression. The sensitivity of these areas to nitrogen deposition, amines and nitrosamines was discussed at length highlighting the unknown current levels and potential emissions associated with carbon capture and NO_X reduction systems due to the technology being the first of its kind. Discussions included assessing the difference between previous background concentrations with historical industry in the area, current concentrations and predicted future concentration impacts on these sensitive areas, to confirm improvement. Ecological receptor sensitivity, particularly Coatham dunes, was discussed alongside the considered acceptable impact defined by Natural England and the risk this posed to continued development in the area.

The current lack of monitoring in cluster-specific industrial areas and the lack of ambient amine monitoring highlights potential information gaps on the current background concentrations of pollutants at the future source release points and downwind which will need to be addressed by applicants for permitting. Amine monitoring challenges include difficulties due to the chemistry and technology detection limit for amines and nitrosamines. Potential suggestions for monitoring amines included communications with laboratories and industries to understand developments in this area and potential suitable monitoring equipment to bridge this knowledge gap. Amine emissions are likely to be low [42] [43] but an understanding of industry levels is required for confirmation of ecological impacts such that Process Contributions (PCs) are lower than 1% as required by Natural England. A suggestion was made for the Environment Agency to provide an approach or consider the possibility of hosting data for numerous plant proposals and provide a goal for process contribution within a wider impact assessment. Suggestions for monitoring responsibility included the Environment Agency, a technical cluster working group made up of cluster companies and local authorities combining monitoring with current monitoring responsibilities.

It was noted that the perceived uncertainty of ELVs may be limiting development as they are typically used for permitting when the process contribution of new developments could potentially be negligible if NH_3 slip is managed, this falsely presents available headroom. There are currently plans to engage Natural England during the establishment of ELVs, specifically on nutrient nitrogen deposition, nutrient neutrality and the link from residual emissions deposition to ecological receptors.

Another topic of discussion was the potential to offset emissions as industrial farming is another potential source of ammonia emissions, their removal could reduce baseline concentrations and allow more room for industrial projects. However, there is no evidence to suggest that a decrease in agricultural ammonia emissions would provide enough headroom in deposition. There is a need to investigate the impacts on air quality with decreases in farming.

The discussion also included difficulties regarding the cumulative effects from all the industrial sites in the Tees cluster. Source data of neighbouring sites is publicly available from permitting applications and monitoring reports, though there was agreement that a central database would make information access easier. Currently cumulative assessments are done on a first come first serve model which has led to confusion regarding total pollutant concentrations to the environment from the Tees Cluster. Applicants have the responsibility to consider other, future plans and projects and sources that may affect the estimation of impacts from their installations and decreased headroom. A change of approach has been highlighted as a point for discussion, which has been ongoing between the Environment Agency and Natural England to understand the issues and enable progress. Potential contributed solutions include the development of area wide modelling or digital twin development based on the current known emissions in the area.

3.6 Future Air Quality in the Tees Industrial Cluster

The trajectory of air quality and ecological health within the Tees 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 [44]). These positive changes are echoed within the Tees area, where, for instance, the annual average NO_2 concentration in Redcar and Cleveland has decreased from 24 µg/m³ in 2018 to 13.9 µg/m³ in 2022, 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 [45] [46]. Specifically, the potential for exacerbated air quality issues due to rising temperatures and changing precipitation patterns threatens to disproportionately affect vulnerable populations and ecosystems [47]. 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 [48] [49]. 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 [50]. It is crucial to ensure that the local ecosystems' environmental capacity, especially regarding nitrogen deposition, aligns with the technological transition. Nitrogen deposition rates within the cluster must be managed to prevent ecological harm, maintaining them within the observed range of 9.7 kg N/ha/yr to 17.0 kg N/ha/yr for the protection of various habitats [19].

To ensure the sustainability of the Tees Industrial Cluster's evolution towards a hydrogen economy and a carbon-neutral future, further research is vital [51]. 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 [52] [53] [54].

In light of this transition, the Tees Industrial Cluster's journey exemplifies the intricate 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 for protecting the future air quality and ecological well-being of the area [52] [53] [55].

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 plant covered by the Medium Combustion Plant Directive (MCPD) and the Industrial Emissions Directive (IED) for Large Combustion Plant (LCP).

The Tees Industrial Cluster stands at a critical juncture, balancing industrial innovation with environmental stewardship. As it embarks on a transformative journey toward decarbonisation [31], integrating pioneering low and zero-carbon technologies, including hydrogen production and carbon capture, the cluster faces a complex matrix of promise 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 [57] .

To realise its potential as a pivotal area for initiating a hydrogen economy underpinned by carbon capture, utilisation, and storage (CCUS) technologies, diligent environmental management, technological optimisation, and adherence to evolving emission standards are indispensable. The risks of climate overshoot and significant carbon budget consumption, highlighted by Dillman and Heinonen (2023) [58], underscore the urgency of advancing clean hydrogen technologies. Meanwhile, the Global Warming Potential of hydrogen, articulated by Sand et al. (2023) [59], reinforces the need for a comprehensive approach to minimise hydrogen leakage, potential fugitive emissions and refine greenhouse gas impact estimates.

A comprehensive environmental monitoring framework becomes pivotal in this context. Such a framework should not only facilitate the strategic assessment and management of cumulative air quality impacts but also 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 regarding 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.

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