Appendix 1e: Air Quality

A1e.1 Introduction

Whilst air quality is not monitored routinely at offshore sites, estimated emissions are reported though the BEIS EEMS process[1] which provide some indication of inputs of air pollutants, and regular air quality monitoring is carried out by local authorities in coastal areas adjacent to each Regional Sea. The air quality of all local authority areas has generally been within national standards set by the UK government's air quality strategy (Defra 2007), though Air Quality Management Areas (AQMAs) have been declared to deal with problem areas. Generally, emissions from all pollutants have decreased since the earliest year the data is available from (1970, 1980, 1990 and 2000, depending on pollutant) partly as a result of policies put in place to control certain emissions (Carnell *et al.* 2019) and a decline in the use of solid and liquid fuels in the domestic and power generation sectors (NAEI website).

A1e.2 UK context

The Air Quality Strategy for England, Scotland, Wales and Northern Ireland of 2007 set national air quality standards with the objective of protecting human health. In the longer term, these standards along with other strategies connected with climate change could significantly improve air quality and achieve reductions in carbon dioxide (CO_2) by 2050 (Defra 2007). Many of the standards set in the strategy are derived from EU obligations for the reduction or non-exceedance of a particular pollutant[2]. The pollutant concentration levels have their origin in the 1996 Air Quality Framework Directive (1996/62/EC) and subsequent 'daughter' directives.

The most recent version of this directive, the 2008 ambient air quality directive (2008/50/EC) replaced nearly all the previous EU air quality legislation and was transposed into law in England through the *Air Quality Standards Regulations 2010*, which also incorporated the 4th air quality daughter directive (2004/107/EC) that set targets for levels in outdoor air of certain toxic heavy metals and polycyclic aromatic hydrocarbons (PAHs). These Regulations set:

- Legally binding limits for concentrations in outdoor air of major air pollutants that impact public health: sulphur dioxide, nitrogen oxides, particulate matter (as PM_{10} and $PM_{2.5}$), lead, benzene, carbon monoxide and ozone.

- Targets for levels in outdoor air for four elements; cadmium, arsenic, nickel and mercury, together with polycyclic aromatic hydrocarbons (PAH).

Equivalent regulations exist in Scotland, Wales and Northern Ireland. These were amended by the *Air Quality (Amendment of Domestic Regulations) (EU Exit) Regulations 2019*, which also amended the *National Emission Ceilings Regulations 2018* (see below).

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[1] https://www.gov.uk/guidance/oil-and-gas-eems-database
[2] See http://uk-air.defra.gov.uk/assets/documents/National_air_quality_objectives.pdf

The revised National Emission Ceilings Directive (Directive 2016/2284/EU) came into force on 31st December 2016. The Directive was transposed into UK legislation in February 2018, and the new legislation came into force on 1st July 2018[3]. Under the new Directive and the amended Gothenburg Protocol[4], the UK has targets in place to reduce emissions of five damaging air pollutants (ammonia, nitrogen oxides, non-methane volatile organic compounds, fine particulate matter and sulphur dioxide) by 2020 and 2030. In January 2019, the UK Government published its Clean Air Strategy, which set out how it will work towards these new emission reduction commitments (Defra 2019a). Similar strategies have been produced or are in preparation for Scotland[5], Wales[6] and Northern Ireland[7]. As required by the NECD, the National Air Pollution Control Programme (NAPCP)[8] was published in April 2019 and sets out how the actions in the Clean Air Strategy will enable the UK to meet its legally binding 2020 and 2030 emission reduction commitments (see Section A1e.5).

The UK has statutory monitoring networks in place to meet the requirements of the EU Directives, with air quality modelling used to supplement monitored data. The UK is divided into 43 zones for air quality assessment – 28 agglomeration zones (large urban areas) and 15 non-agglomeration zones. The recent compliance report (Defra 2019b) indicated that for 2018:

- The UK met the limit value for hourly mean nitrogen dioxide (NO_2) in 41 out of 43 zones.
- Seven zones were compliant with the limit value for annual mean NO_2. The remaining 36 zones exceeded this limit value. In 25 of these 36 zones the exceedance of the limit value has decreased compared to 2017. Implementation of measures as a result of the 2017 UK plan for tackling roadside nitrogen dioxide concentration has now started, with the effect on compliance expected to be demonstrated in subsequent years.
- All non-agglomeration zones complied with the critical level for annual mean NO_X concentration, set for protection of vegetation.
- Three zones exceeded the target value for benzo[a]pyrene.
- Four zones exceeded the target value for nickel.
- All zones met the target values for arsenic and cadmium.
- All zones met both the target values for ozone; the target value based on the maximum daily eight-hour mean, and the target value based on the AOT40 statistic.
- No zones were compliant with the long-term objective for ozone, set for the protection of human health and based on the maximum daily eight-hour mean.
- Five zones met the long-term objective for ozone, set for the protection of vegetation and based on the AOT40 statistic.

[3] http://www.legislation.gov.uk/uksi/2018/129/made
[4] 1999 Protocol to abate acidification, eutrophication and ground-level ozone (Gothenburg Protocol) to the Convention on Long-range Transboundary Air Pollution (CLRTAP).
[5] https://www.gov.scot/publications/cleaner-air-scotland-strategy-independent-review/
[6] https://gov.wales/sites/default/files/consultations/2019-12/consultation-a-clean-air-plan-for-wales.pdf
[7] https://www.airqualityni.co.uk/air-quality/policy
[8] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/791025/air-quality-napcp-march2019.pdf

- All zones met the limit value for daily and annual mean concentration of PM_{10} particulate matter, without the need for subtraction of the contribution from natural sources.
- All zones met both limit values for annual mean concentration of $PM_{2.5}$ particulate matter: the Stage 1 limit value, which came into force on 1st January 2015, and the indicative Stage 2 limit value which must be met by 2020.
- All zones met the EU limit values for sulphur dioxide, carbon monoxide, lead and benzene.

The air quality statistics for the UK, 1987 to 2019[9] indicate that:

- Urban background and roadside nitrogen dioxide (NO_2) pollution has shown long-term improvement. In 2019 the lowest average annual mean concentrations since the start of the time series for both roadside and urban background monitoring sites were recorded. There were on average fewer hours of moderate or higher levels of nitrogen dioxide pollution in 2019 compared with 2018 at roadside sites.
- Urban background and roadside particulate pollution (PM_{10}) has shown long-term improvement, with stable concentrations observed from 2015 to 2019 for both roadside and urban background sites. Fine particulate matter ($PM_{2.5}$) shows a similar trend. The number of hours of moderate or higher levels of particulate matter pollution reduced in the long term, but there was an increase in the number of hours of moderate or higher $PM_{2.5}$ pollution recorded in 2019 compared with 2018 at both roadside and urban background sites. Burning of wood and coal by households in stoves and open fires is a large contributor to emissions of particulate matter both in the UK and across Europe, most common in winter months and during the evenings.
- Urban background ozone pollution has remained fairly stable between 2003 and 2019, although daily maximum eight-hour mean concentrations have shown a long-term increase since monitoring began. Rural background ozone pollution has shown no clear long-term trend. At both site types, the number of hours of moderate or higher ozone pollution in 2018 was the highest in the last ten years, with 2019 having the second highest number. Ozone pollution is linked to hot, sunny conditions and prolonged instances of such conditions during the summer in 2018 and 2019 likely contributed to the higher incidences of moderate or higher ozone pollution.
- There was on average a greater number of days of moderate or higher pollution at urban pollution monitoring sites in 2019 compared with 2018 which goes against the established trend of an ongoing decline in days of moderate or higher pollution at urban sites. In 2019, as in 2018, ozone was responsible for a large proportion of the moderate or higher pollution days due to prolonged hot and sunny conditions experienced in the UK in the summers of 2018 and 2019.

[9] https://www.gov.uk/government/statistics/air-quality-statistics It is noted that updated air quality statistics are avaialbe covering 2020, however the data to 2019 is used here to reflect the trajectory prior to Government responses to COVID-19 pandemic.

The *Environment Act 1995* requires the Government to produce a national Air Quality Strategy (AQS) for the UK setting out air quality standards, objectives, and measures for improving ambient air quality. Under the *Environment Act 2021*, the Secretary of State must review the Strategy for England at least every five years, with a commitment for an initial review within 12 months of the measures coming into force. The first review will be published in 2023. The *Environment Act 2021* also establishes a legally binding duty on government to bring forward at least two new air quality targets in secondary legislation by 31 October 2022; those under consideration include reducing the annual mean level of fine particulate matter ($PM_{2.5}$) in ambient air (as required by Clause 2 of the Environment Act), and reducing population exposure to $PM_{2.5}$[10].

Part 4 of the *Environment Act 1995* requires local authorities to review and assess the air quality in their areas and its probable future trajectory. Since 1997 each local authority in the UK has been assessing their air quality and making projections on how it might change in years to come, with the aim of meeting the national air quality objectives by the relevant deadlines. An Air Quality Management Area (AQMA) must be declared where the local authority finds that it is unlikely to meet the objective of reducing pollution by the specified amount, and in accordance with the Air Quality Directive, a Local Air Quality Action Plan must be used to coordinate and improve air quality. There are a number of AQMAs in the UK for NO_2, SO_2 and PM_{10} and these are indicated in Figure A1e.1. Most AQMAs in the UK are in urban areas and result from traffic emissions of NO_2 or PM_{10}. Road transport is the main source in 97% of the AQMAs declared for NO_2 and in 79% of the AQMAs declared for PM_{10}. A further 2.8% of NO_2 and 10% of PM_{10} AQMAs result from transport mixed with either domestic or industrial sources (Defra 2019b). Section A1e.6 further describes environmental issues associated with exceedances of air quality limit values.

A1e.3 Atmospheric emissions of pollutants

The National Atmospheric Emissions Inventory (NAEI) contains a database listing the emissions of a range of pollutants across the UK. Emission inventories are estimates of the amount and type of pollutants that are emitted to the air each year from all sources (e.g. industrial point sources, shipping, rail, road traffic). The details of a number of pollutants are described below and their emissions are graphically represented in Figures A1e.2-9.

A1e.3.1 Gaseous and particulate matter emissions

1.3.1.1 Offshore emissions

Offshore oil and gas installation emissions (see Figures A1e.2-9) are reported annually to OSPAR. The latest OSPAR report for 2018 emissions indicates: UKCS SO_2 emissions decreased about 8% (to 2,877 tonnes) between 2017 and 2018, though was higher than 2016 emissions by several hundred tonnes; emissions of CO_2 decreased by approximately 7% (to *ca*. 13.2 million tonnes); emissions of NO_X decreased by approximately 14% (*ca*. 49,522 tonnes), emissions of non-methane volatile organic compounds (NMVOC) increased by approximately 24% (to 50,097 tonnes). However, in general emissions over the last decade have been relatively stable (OSPAR 2019, 2020, 2021). SO_2 emissions vary greatly year on year, as they are largely dependent on consumption of diesel for power generation which is determined by periods of shut down and as fields deplete there is a greater reliance on diesel to replace fuel gas. CO_2 accounts for the greatest proportion of emissions to air from UKCS

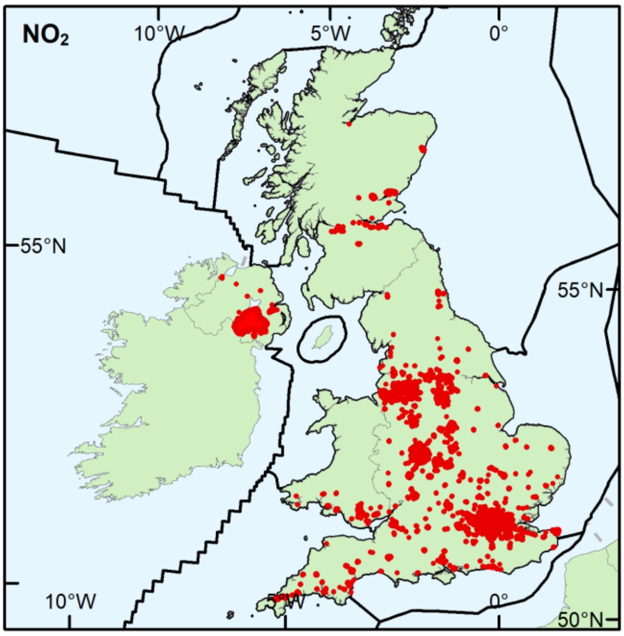
[10] https://uk-air.defra.gov.uk/library/air-quality-targets

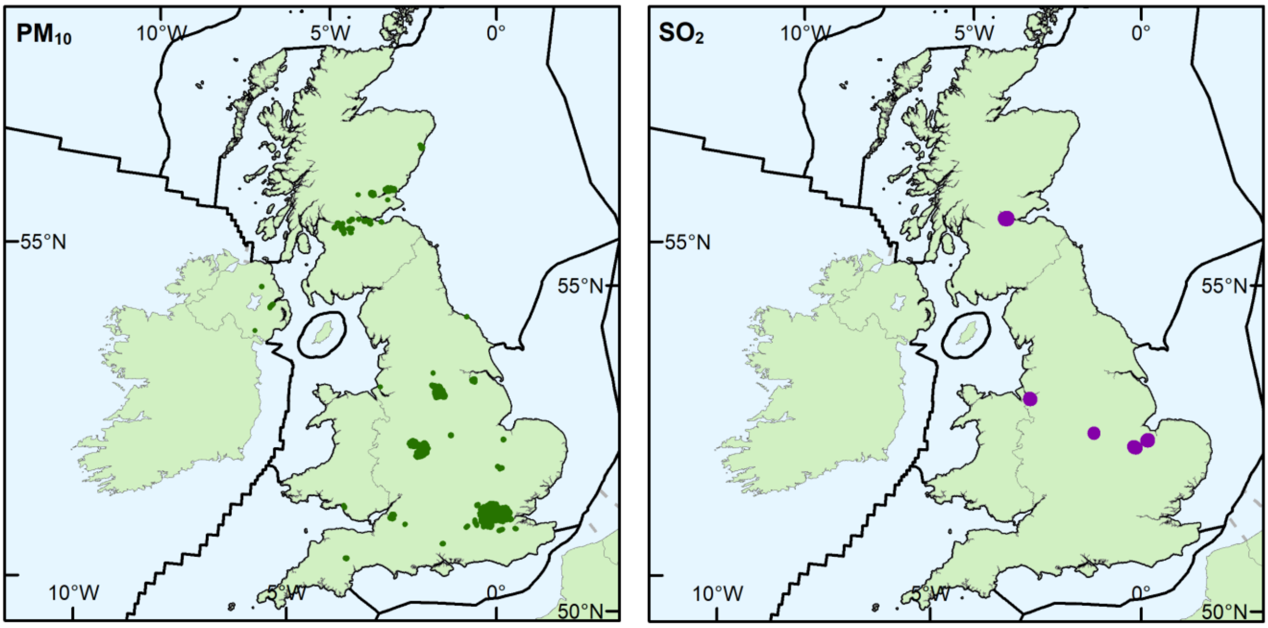
offshore installations, primarily generated from fuel consumed by combustion equipment to provide electrical power and drive compressors for oil and gas export (Oil & Gas UK 2018). In general, those installations with higher emissions are the larger operators with greater production levels and predominantly oil-producing platforms in the central and northern North Sea regions (Oil & Gas UK 2018).

Figure A1e.1: AQMAs in the UK

Pollutant	England	Wales	Scotland	N. Ireland	London
Nitrogen dioxide NO_2	505	43	29	16	33
Particulate Matter PM_{10}	38	1	19	3	28
Sulphur dioxide SO_2	5		1		

Note this table does not provide a total count for the number of AQMAs declared. It is a count of the number of AQMAs declared for each pollutant. For example where an AQMA has been declared for both NO2 and PM10 it will have two entries in the above table.





Legend

AQMAs

- NO_2
- PM_{10}
- SO_2

Data source: OGA, DEFRA.

0 75 150 300 450 Km

ED1950 TM 0 N

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Emissions from shipping, due to the combustion of marine fuels with high sulphur content, contribute significantly to air pollution in the form of sulphur dioxide and particulate matter. The *Merchant Shipping (Prevention of Air Pollution from Ships) and Motor Fuel (Composition and Content) (Amendment) Regulations 2014* which came into force in December 2014, partly implements EU Directive 2012/33/EU on the sulphur content of marine fuel. The Regulations include limits to the sulphur content of fuel oil used or intended to be used in sulphur oxide emission control areas (defined by Annex VI of the MARPOL Convention and including the North Sea and English Channel), to not more than 0.1% by mass from January 2015. The EU Sulphur Directive came into force in January 2015 and mandated cuts in the maximum sulphur content in marine fuels from 3.5% to 0.5% from January 2020 for ships operating outside designated emission control areas (ECA) in line with Annex VI of MARPOL Annex VI.

Shipping emissions have previously been estimated by modelling fuel consumption from a database of shipping activities around UK waters for different vessel, fuel and journey types (Entec 2010). This approach provided the best available solution at that time but had some recognised issues such as the age of the dataset (dating from 2007), estimated location of vessels rather than actual locations, low spatial resolution and insufficient representation of shipping types other than internationally trading vessels (Richmond *et al.* 2020). Improvements made to the shipping emissions modelling for the National Inventory, first reported in Scarbrough *et al.* (2017), give a higher resolution and greater accuracy to emissions estimates (through improved coverage of various vessel types), as well as enabling a deeper understanding of the spatial pattern of emissions compared with the previous approach (Richmond *et al.* 2020).

The revised method has been developed using Automatic Identification System (AIS) data supplied by the Maritime and Coastguard Agency. A complete set of one year's worth of AIS data received by terrestrial UK receivers was obtained and processed to give a dataset that records shipping activity at five-minute intervals for the whole of the year 2014. This was then used to calculate fuel consumption and emissions for each vessel for the year 2014 in conjunction with a second dataset of technical characteristics of individual vessels. The estimates for year 2014 were then forecast to the current NAEI year accounting for activity changes over time, the 2015 sulphur emission control area change in sulphur content limit, fleet-wide efficiency gains and additional NO_X emission factor changes to account for fleet turnover (Richmond *et al.* 2020).

The boundary of the sulphur oxide ECA around the UK is clearly visible in maps of SO_2 from shipping emissions (see Figure A1e.2). Along the length of the SECA boundary present off the coast of south-west England, a pronounced linear drop in emissions can be seen from west to east. This reflects the fuel switching process, as vessels burn cleaner gas oil when within the SECA (to the east of the boundary) but burn fuel oil when outside its limits, emitting greater amounts of SO_2 (Richmond *et al.* 2020).

In 2016, the IMO Marine Environment Protection Committee (MEPC) approved the designation of the North Sea and the Baltic Sea as emission control areas (ECA) for nitrogen oxides (NO_X) under Regulation 13 of MARPOL Annex VI. Draft amendments to MARPOL Annex VI would see both ECAs enter into effect on 1 January 2021[11].

In 2018, emissions of SO_2 and NO_x from domestic shipping (NFR 1A3dii national navigation) represented 7 and 11% respectively of UK total emissions with international maritime

[11] http://www.imo.org/en/MediaCentre/MeetingSummaries/MEPC/Pages/MEPC-70th-session.aspx

navigation (1A3di(i)) representing 36 and 30% (National emission inventories, EIONET central data repository[12]). The estimation of domestic shipping emissions is included in national inventory totals reported to the United Nations Framework Convention on Climate Change (UNFCCC) and EU for greenhouse gases and the UN Economic Commission for Europe (UNECE) and EU for air pollutant emissions, whereas emissions from international shipping emissions are not, being reported as a memo item in official inventories (Scarborough *et al.* 2017).

The Clean Maritime Plan (Department for Transport 2019a) is the environment route map of Maritime 2050 (Department for Transport 2019b), setting out how Government sees the UK's transition to a future of zero emission shipping. It encompasses the maritime commitments within the Clean Air Strategy to ensure that the maritime sector takes the steps necessary to protect human health and the environment from air quality pollutants.

1.3.1.2 Onshore emissions

Sulphur dioxide (SO_2)

The largest source of SO_2 emissions is the energy industries (primarily power stations), which accounted for 31% of total UK emissions in 2018 (total of 160 kilotonnes, Figure A1e.2 shows NAEI mapped data for 2017). Since 1990 SO_2 emissions have declined by 96%, directly linked to an economy-wide shift away from sulphur-containing fuels, as natural gas has largely replaced coal as the main fuel for electricity producers, industry and for residential heating (Richmond *et al.* 2020). Annual sulphur emissions have remained stable since 2009 and in some years have increased slightly, mostly due to the recent economic downturn which has caused an increase in the use of relatively cheap solid fuels (NAEI website). However, the downward trend returned in subsequent years (Richmond *et al.* 2020).

Nitrogen oxides (NO_X)

All combustion processes in air produce NO_X. Nitrogen dioxide (NO_2) and nitric oxide (NO) are both oxides of nitrogen and together are referred to as NO_X. Road transport is the largest source of NO_X in the UK (31% in 2018), with industrial combustion and power generation also accounting for a large fraction of the emission total (823 kilotonnes in 2018, Richmond *et al.* 2020). Since 1990 there has been a steady decline in road transport emissions due to the introduction of catalytic converters on cars and stricter regulations on truck emissions (Figure A1e.3). In addition, significant decreases from the 1990s onwards have been due to factors such as the fitting of low NO_x burners and other NO_x reduction technology to power stations along with a phasing out of coal-fired power stations and a general decline in coal consumption in other sectors in favour of natural gas (Richmond *et al.* 2020).

Carbon monoxide (CO)

CO arises from incomplete fuel-combustion and is of concern mainly because of its effect on human health and its role in tropospheric ozone formation. The decline in UK CO emissions since 1990 from 9,081 kilotonnes to 1,525 kilotonnes in 2018 has been driven by reductions in

[12] http://cdr.eionet.europa.eu/gb/eu/nec_revised/inventories/envxmo47g/Annex_I_Emissions_reporting_2020_GB_v2.0.xls/manage_document

emissions from sources including road transport, agricultural field burning and the domestic sector (Figure A1e.4).

Non-Methane Volatile Organic Compounds (NMVOCs)

NMVOCs are emitted to air as combustion products, as vapour arising from handling or use of petroleum distillates, solvents or chemicals, and from numerous other sources. There is a wide diversity of processes which emit NMVOCs covering not only industry, but also transport, agriculture and domestic sources. In 1990, the largest contributions to the total emissions of 2,825 kilotonnes were from road transport, fugitive emissions and industrial processes. Since 1990, emissions from all sources have decreased to a 2018 total of 804 kilotonnes, which is generally attributed to the introduction of wide-ranging legislative controls, and changes in industrial activity in the UK. The fugitive emissions source category includes emission sources associated with the extraction, refining and distribution of fossil fuels which accounted for 17% of the total emissions in 2017 (Figure A1e.5, NAEI website). More stringent controls on emissions from extraction and refining operations, programmes to replace older gas main pipes, and improved emission controls at petrol stations have all contributed to the reduction in emissions from this source sector across the timeseries (Richmond *et al.* 2020).

Particulate matter (PM_{10} & $PM_{2.5}$)

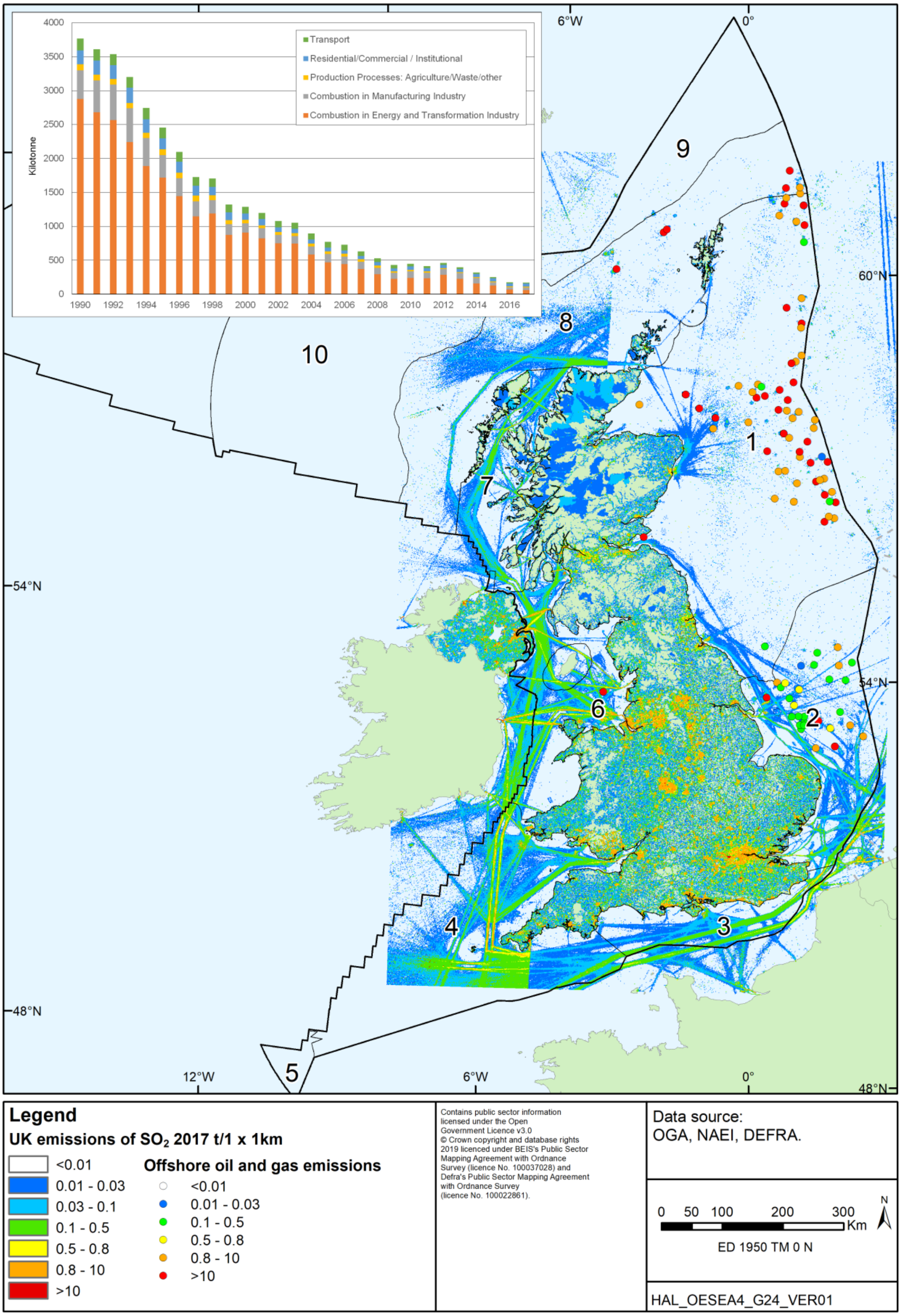
Particulate matter is generally categorised on the basis of the size of the particles (for example PM_{10} consists of particles measuring 10µm or less). Concentrations of PM comprise primary particles emitted directly into the atmosphere from combustion sources and secondary particles formed by chemical reactions in the air. UK emissions of PM_{10} have decreased by 53% since 1990 to 175 kilotonnes in 2018. The contribution of large industrial sources such as power stations and other large combustion plant burning coal and fuel oil has declined from about a quarter of the UK total in 1990 to about 4% in 2017. The mass emitted from road transport has also fallen since 1990, but the contribution in percentage terms has increased: from 9% in 1990 to 12% in 2017. Similarly, emissions from industrial processes have almost halved since 1990, yet the contribution that the sector makes to the UK total has increased, from 27% in 1990 to 30% in 2017 (Figure A1e.6, NAEI website). All road transport modes emit PM_{10}, but diesel vehicles emit a greater mass of particulates per vehicle kilometre, and the proportion of road transport activity by diesel-engined vehicles has increased over time. More than 50% of the emissions within the industrial processes group are from construction and quarrying.

In general, emissions of finer particulates follow similar trends as for PM_{10}. UK emissions of $PM_{2.5}$ (particles measuring <2.5µm) have declined by 54% since 1990 due mainly to a reduction in coal use, and the banning of crop residue burning in 1993. Emissions from coal-fired power stations have fallen by 99% since 1990. Residential sector emissions fell between 1990 (43kt) to 2002 (27kt), reflecting declining coal use. However, emissions from this source are now back at around 1990 levels due to increased use of wood as a fuel for homes (wood contributed 87% of domestic combustion emissions in 2018, compared with 13% in 1990). Industrial use of biomass fuels is also increasing and has, as a result, become a more significant contributor to UK emissions – 11% of UK emissions of $PM_{2.5}$ in 2018 (NAEI website).

Ammonia (NH_3)

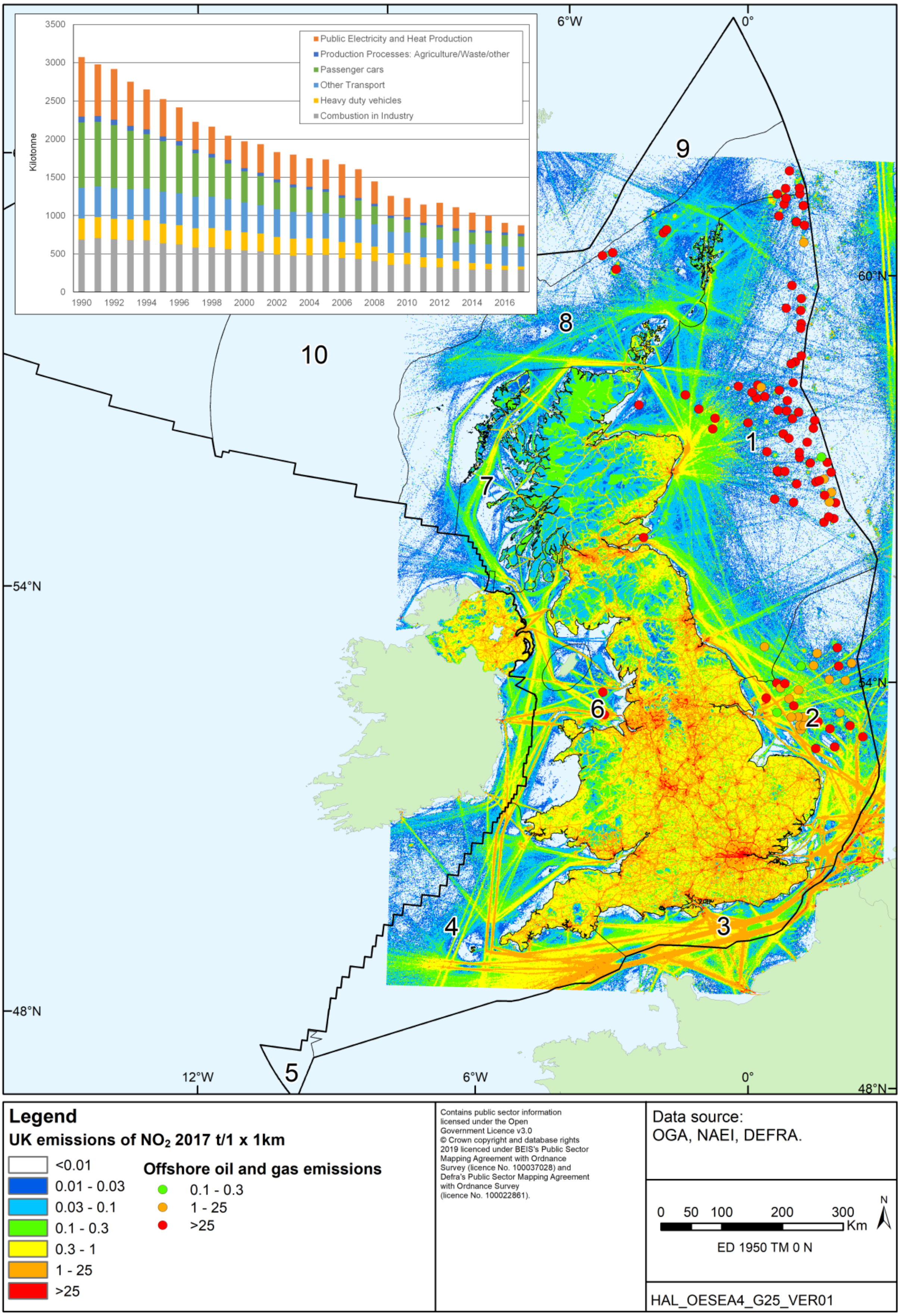
Ammonia (NH_3) plays an important role in a number of different environmental issues including acidification, nitrification, and eutrophication. It also acts as a precursor to secondary particulate matter, therefore contributing to the related health impacts (see Section A1e.6). The atmospheric chemistry of NH_3 means that it can react with other chemicals to produce particles, which can be removed from the atmosphere by rain, or to produce other ammonia compounds, which can be transported long distances. As a result, NH_3 emissions can impact on a highly localised level, as well as contributing to effects from long-range pollutant transport. Agriculture is the dominant source of emissions, with the sector accounting for 84% of total emissions in 2018. The lack of a reduction in overall NH_3 emissions since 2005 (Figure A1e.7) is largely because of a reversal in the previous downward trend in emissions from fertiliser use, increasing emissions from dairy cattle, and growth in the spreading on agricultural land of digestates from anaerobic digestion of non-manure wastes (NAEI website).

Figure A1e.2: Emissions of SO_2 in 2017 and as a timeseries, 1990-2017



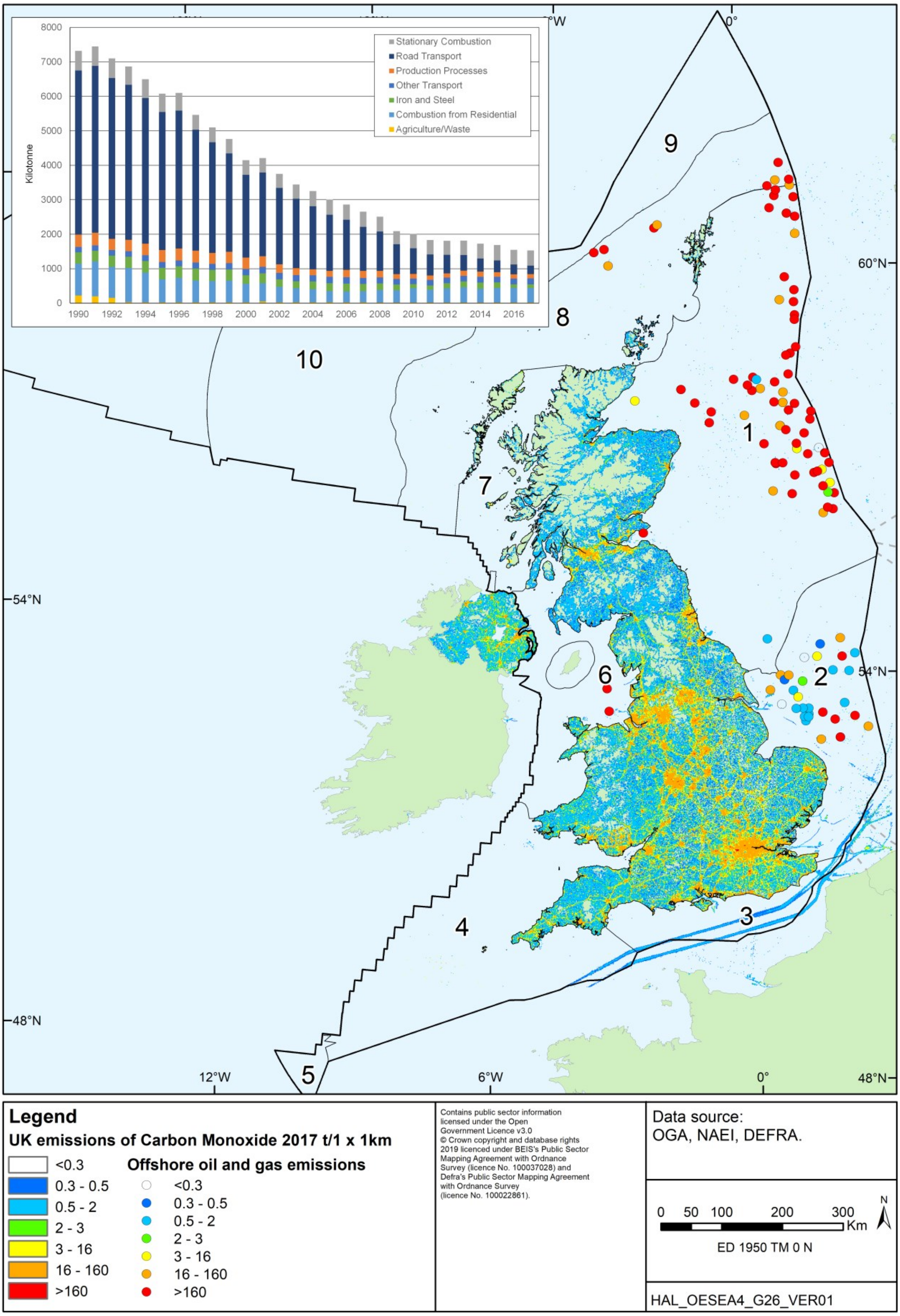
Note: Offshore emissions are presented as point sources, as the raster data cell size is too small to be visible at the scale used in the map.

Figure A1e.3: Emissions of NO_X in 2017 and as a timeseries, 1990-2017



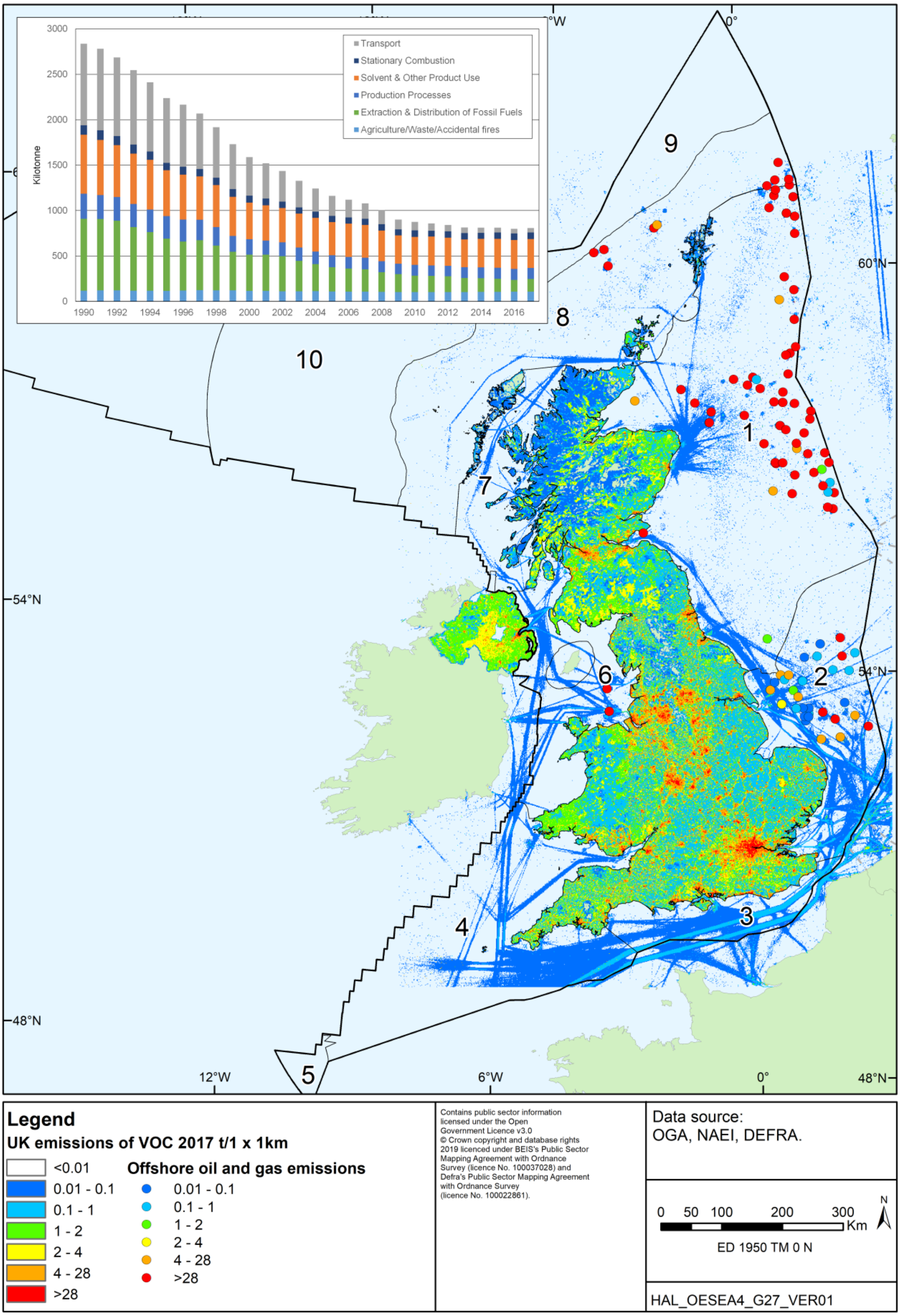
Note: See note for Figure A1e.2.

Figure A1e.4: Emissions of CO in 2017 and as a timeseries, 1990-2017



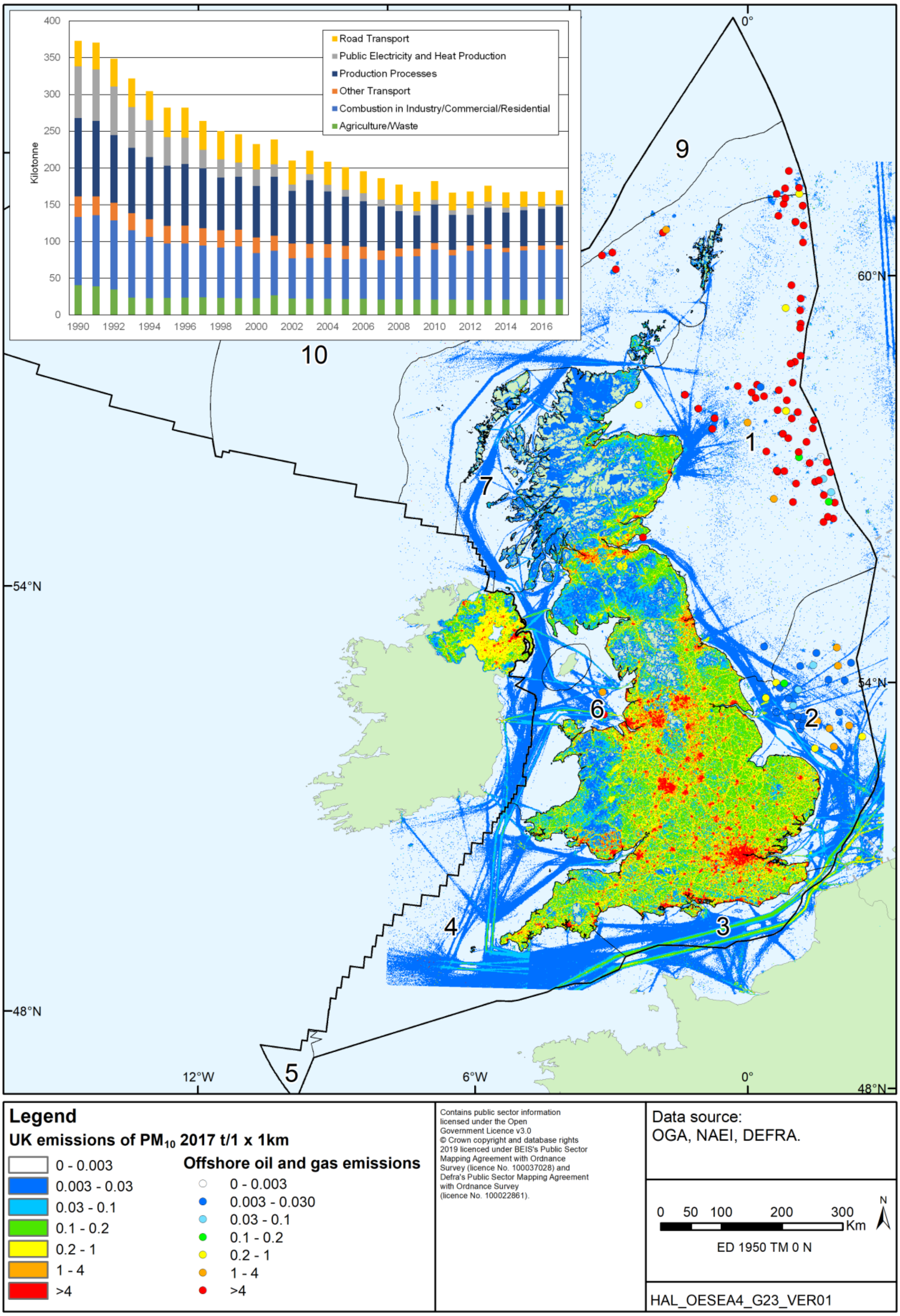
Note: See note for Figure A1e.2.

Figure A1e.5: Emissions of NMVOCs in 2017 and as a timeseries, 1990-2017



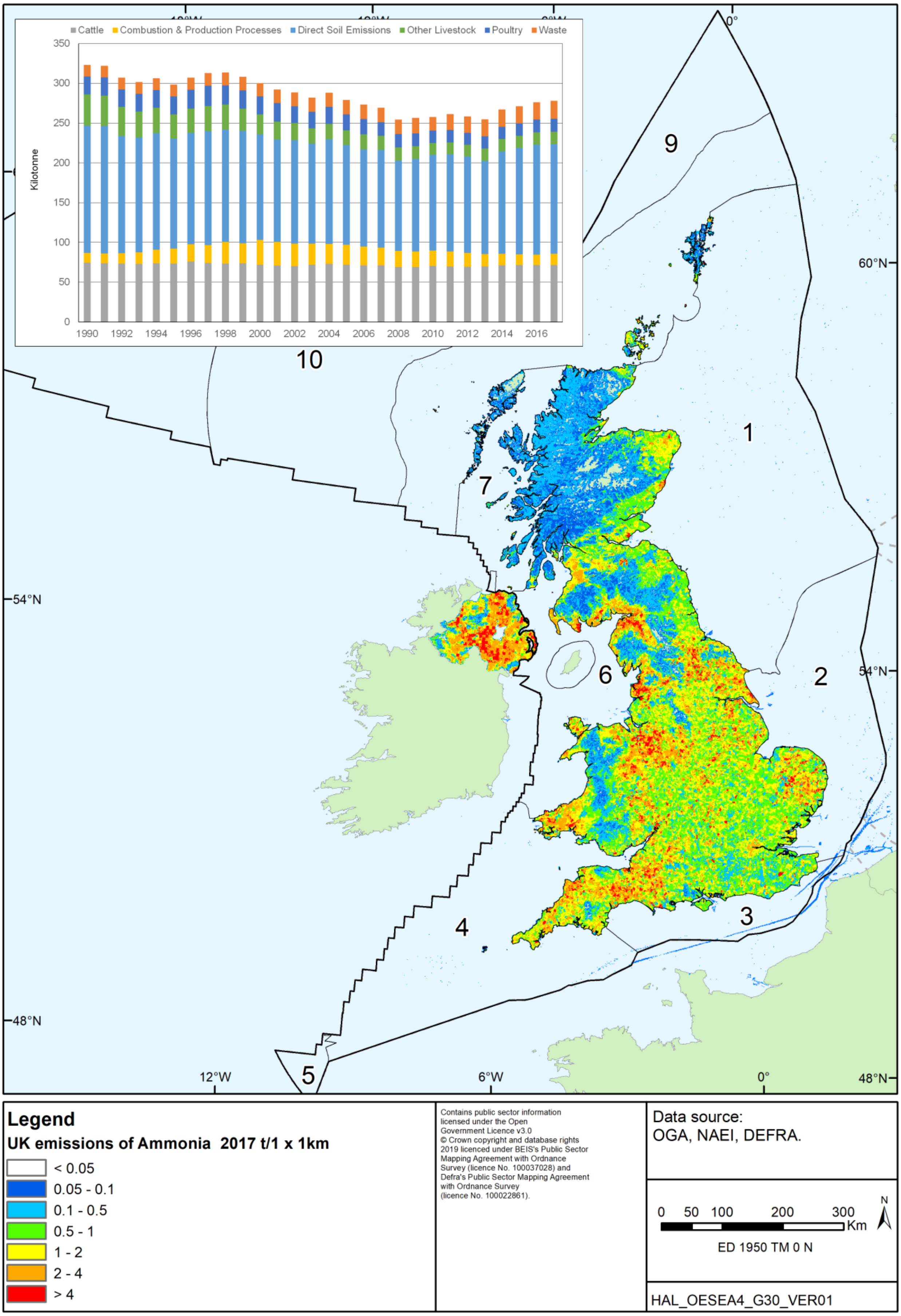
Note: See note for Figure A1e.2.

Figure A1e.6: Emissions of PM_{10} in 2017 and as a timeseries, 1990-2017



Note: See note for Figure A1e.2.

Figure A1e.7: Emissions of NH_3 in 2017 and as a timeseries, 1990-2017



A1e.3.2 Metals

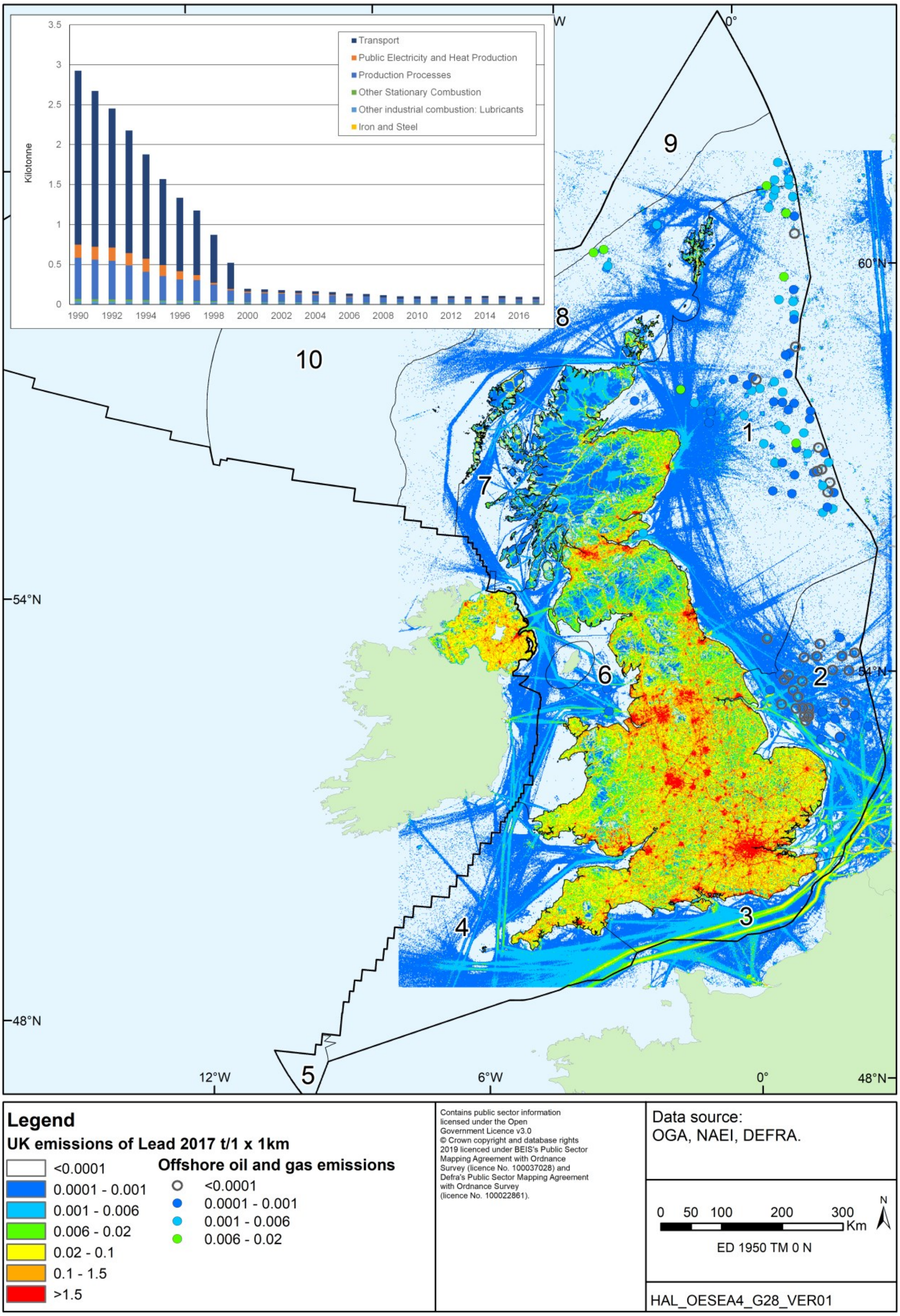
Heavy metal emissions arise from a number of different sources, but in general fuel combustion and certain industrial processes that produce dust are the main contributors. Emissions also arise from trace concentrations in fuels or in the case of industrial processes, the raw materials. In combustion, metals are emitted either as vapour or particulate matter or both. For example, one of the more toxic metals historically emitted in relatively large amounts has been lead with the largest source until 1999 coming from lead additives in petrol. From about 1990, sales of unleaded petrol increased, particularly as a result of the increased use of cars fitted with three-way catalysts. Leaded petrol was then phased out from general sale at the end of 1999 with a consequent decline in associated lead emissions (see Figure A1e.8). There has also been a significant reduction in emissions from metal production due to declining production, and from public electricity and heat production due to improved abatement measures. Emissions have also declined as a result of the decreasing use of coal (NAEI website).

A1e.3.3 Persistent Organic Pollutants (POPs)

POPs comprise a group of semi-volatile toxic chemicals characterised by resistance to degradation, significant potential to long-range transport, and harmful effects to human and wildlife health (Gusev *et al.* 2014).

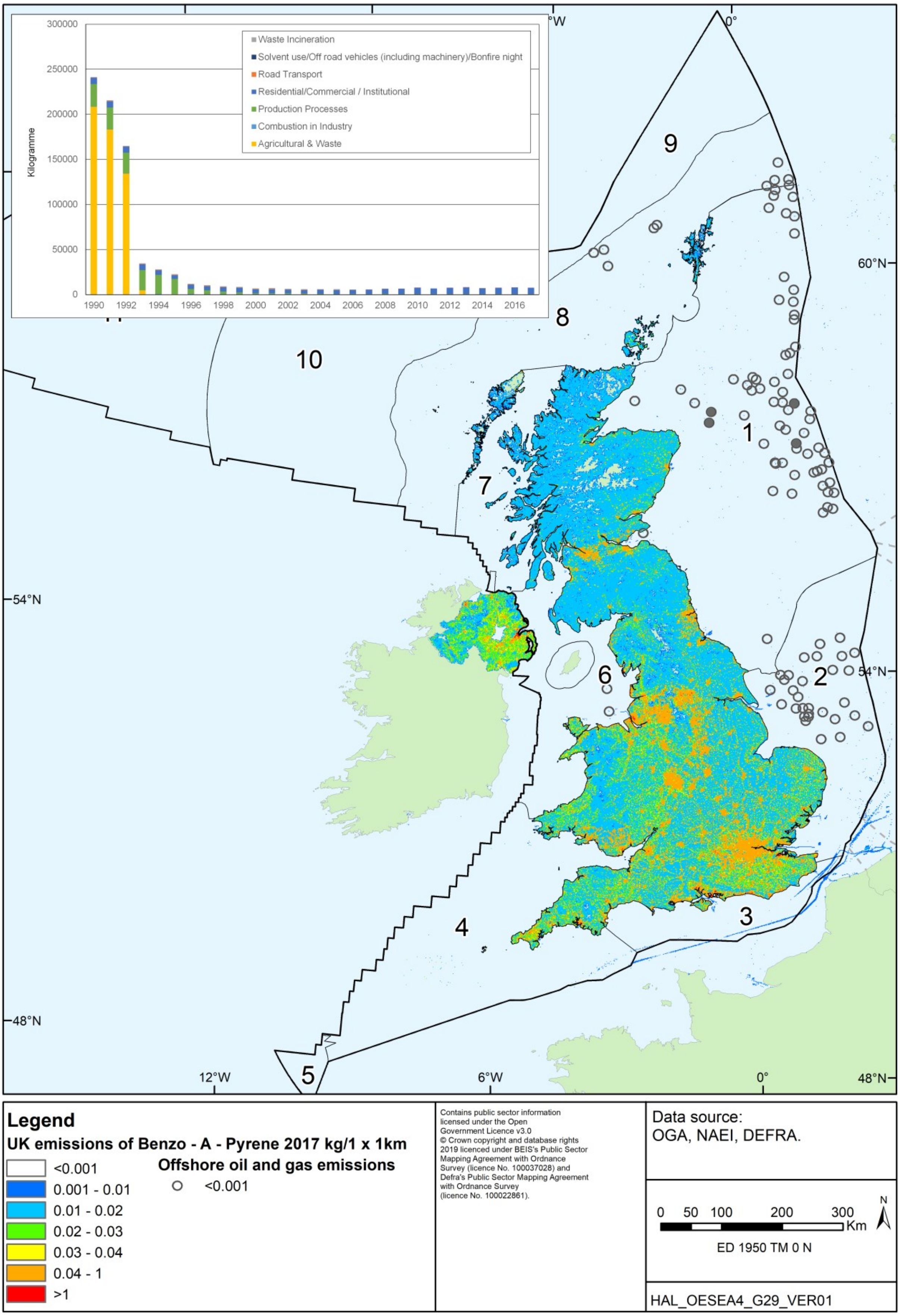
Benzo[a]pyrene (B[a]P) is used as a 'marker' for a group of compounds known as polycyclic aromatic hydrocarbons (PAHs). Emissions have decreased by 97% since 1990 (Figure A1e.9). Almost all of this reduction is due to the banning of stubble burning in 1993, since this source contributed 86% of emissions in 1990. Most of the rest of the reduction was due to improved control of emissions from aluminium production through the 1990s. Since 2000, UK emissions have increased by 11% as emissions from residential sector combustion have grown due to increasing use of wood as a domestic fuel (NAEI website). It should be noted that the NAEI's estimated B[a]P emissions for years 1990 (the earliest year for which emissions of this pollutant are estimated) to 1992 underwent a substantial increase in 2017. This is because the emission factors used by the NAEI for the agriculture and waste sector were revised. The new emission factors, particularly for stubble burning, resulted in the estimated total UK emission of B[a]P for years 1990 - 1992 increasing by a factor of four (Wakeling *et al.* 2018, Defra 2019b).

Figure A1e.8: Emissions of lead in 2017 and as a timeseries, 1990-2017



Note: See note for Figure A1e.2.

Figure A1e.9: Emissions of B[a]P in 2017 and as a timeseries, 1990-2017



Note: See note for Figure A1e.2.

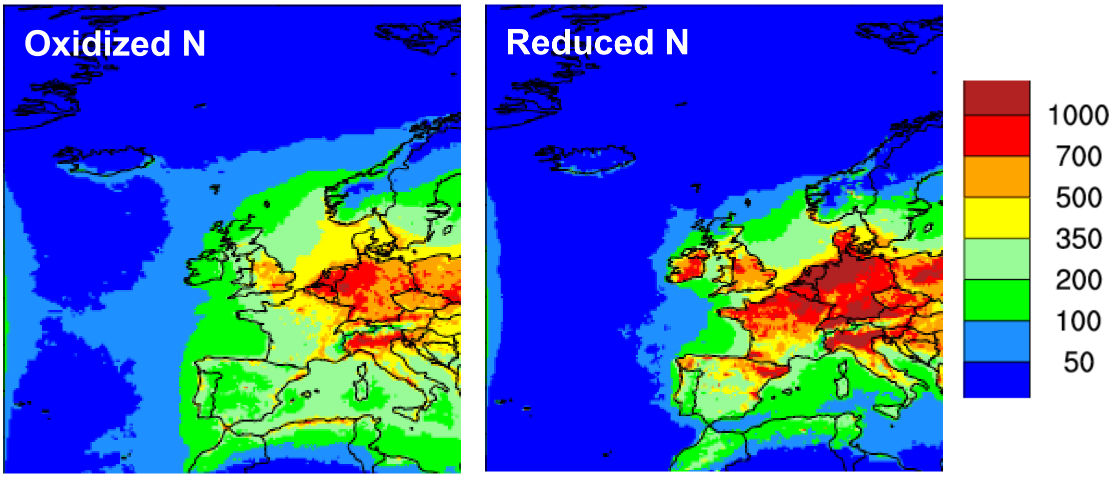
A1e.4 Atmospheric deposition of pollutants

A1e.4.1 Nitrogen

Nitrogen is an important component of air pollution due to its influence on ecosystem nutrient balance. For mid-latitude shelf seas such as the North Sea the relevant atmospheric nutrients derive mostly from nitrogen oxides (NO_X) and ammonia (NH_X) emissions (see Section A1e.3 above), which are mainly related to combustion (traffic, industry) and agriculture. When emitted to the atmosphere, these eutrophying pollutants may remain in air for several days and therefore be dispersed and carried over long distances by winds. In the atmosphere NO_X is transformed to a range of secondary pollutants, including nitric acid (HNO_3), nitrates (NO_3^-) and organic compounds, such as peroxyacetyle nitrate. Both the primary and secondary pollutants may be removed by wet deposition (scavenging of gases and aerosols by precipitation) and by dry deposition (direct turbulent deposition of gases and aerosols) (Troost *et al.* 2013).

Modelled atmospheric deposition of nitrogen has decreased in the Greater North Sea region over the period 1995-2014 largely due to the emission reductions of NO_X in major contributing countries like the UK, where contributions to nitrogen deposition reduced from 33% in 1995 to 22% in 2014 (OSPAR 2017). The deposition of nitrogen (oxidized and reduced nitrogen) shows a clear geographical gradient, with the largest values close to land areas and largely decreasing towards the open sea (OSPAR 2009). Modelled total depositions of oxidized and reduced nitrogen are presented in Figure A1e.10 which combines meteorological information and emissions with numerical simulations using the EMEP[13] MSC-W model together with observed air concentration and deposition data (Fagerli *et al.* 2019).

Figure A1e.10: Modelled deposition of nitrogen (mg/m²) in 2017



Source: Modified from Fagerli *et al.* (2019).

[13] The European Monitoring and Evaluation Programme (EMEP) is a programme under the Convention on Long-range Transboundary Air Pollution (CLRTAP), with the objective of providing governments and subsidiary bodies under the LRTAP Convention with qualified scientific information to support the development and further evaluation of the international protocols on emission reductions negotiated within the Convention.

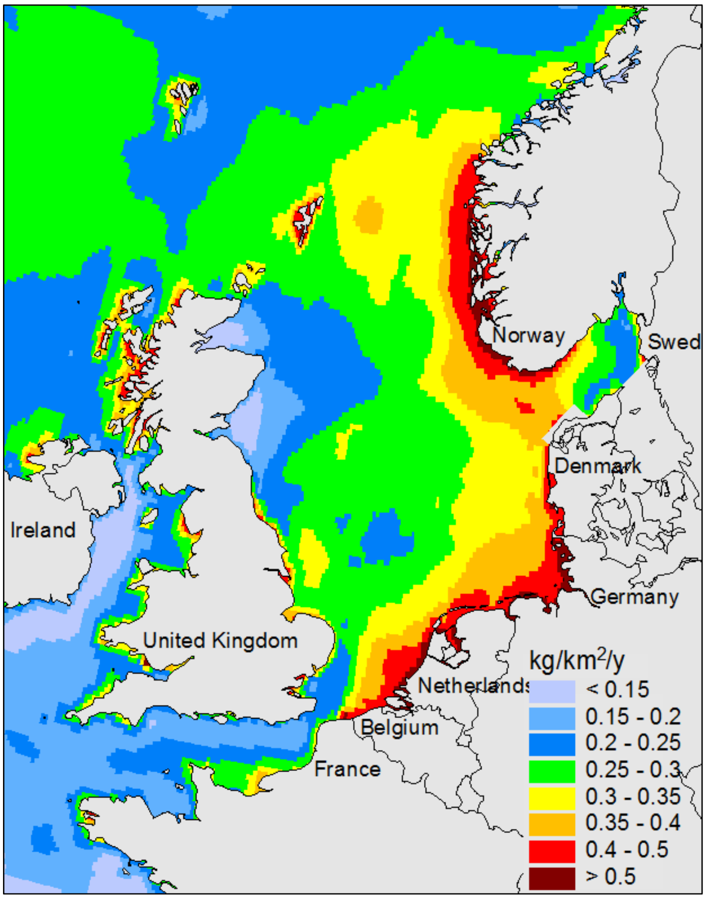
In general, oxidized nitrogen originates from fossil fuel combustion emissions (for the Greater North Sea region these contributed approximately 53% to the total nitrogen deposited in 2014, compared to 62% in 1995), whilst the remaining reduced nitrogen originates from agricultural activities (OSPAR 2017). Monitoring at coastal monitoring stations as part of the Comprehensive Atmospheric Monitoring Programme indicated that for 2017, concentrations of oxidized nitrogen in air (NO_2) were highest around major emission sources, such as ship traffic in the North Sea, Kattegat and in the English Channel (OSPAR 2019).

A1e.4.2 Metals

With the exception of mercury, the deposition of all metal components in the OSPAR area has fallen since 1990 (OSPAR 2019). The reduced use of lead in fuels has resulted in a substantial reduction in its emission (approximately 97% between 1990 and 2018) and associated deposition across the UK.

The long range transport and deposition of a range of heavy metals across the North Sea was modelled using the GLEMOS model, meteorological information and the latest available officially submitted emission data (Gusev *et al.* 2019). This provides information on the spatial distribution of deposition fluxes of a number of heavy metals with an example of the modelled distribution of lead deposition to the North Sea in 2017 shown in Figure A1e.11 (given that lead emissions were described in Section A1e.3.2). There is a general reduction in the atmospheric deposition of lead offshore though the proximity of the southern North Sea to industrialised areas on land exposes certain areas to higher levels of atmospheric deposition (OSPAR 2000). Elevated precipitation at windward slopes of mountain regions favours increase of deposition resulting in higher deposition along the western part of Norway (Gusev *et al.* 2019).

Figure A1e.11: Lead deposition to the North Sea in 2017

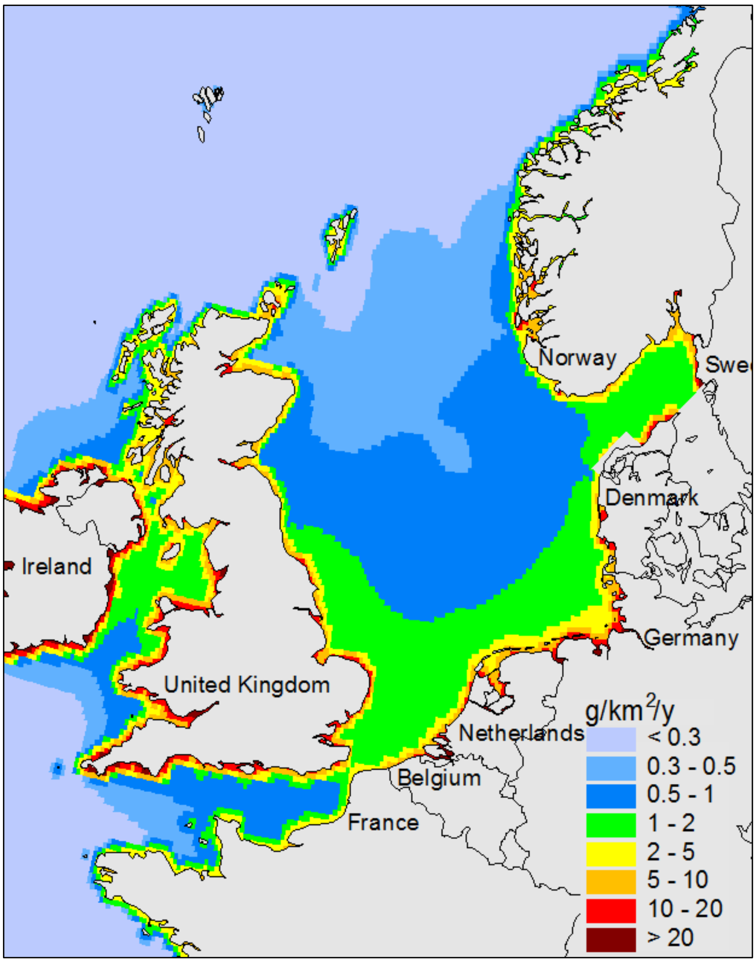


Source: http://en.msceast.org/index.php/pollution-assessment/marginal-seas/north-sea

A1e.4.3 Persistent Organic Pollutants (POPs)

For 43% of the countries in the EMEP region, the deposition of polycyclic aromatic hydrocarbons from transboundary transport, exceeds the deposition from national emission sources (Gusev *et al.* 2019). However, the UK is less affected by transboundary transport of pollution due to its geographical location and levels of pollution are determined mostly by national emissions (approximately 90%, Gusev *et al.* 2019). Between 1990 and 2018, UK emissions of B[a]P decreased by 97% (see Section A1e.3.3). The long range transport and deposition of a range of POPs across the North Sea was modelled using the GLEMOS model (Gusev *et al.* 2019) with Figure A1e.12 showing the modelled distribution of B[a]P deposition to the North Sea in 2017.

Figure A1e.12: B[a]P deposition to the North Sea in 2017



Source: http://en.msceast.org/index.php/pollution-assessment/marginal-seas/north-sea

A1e.5 Evolution of the baseline

As part of the National Atmospheric Emissions Inventory, projections of UK emissions of key air quality pollutants are compiled to inform policy development and to enable comparisons to be made with international commitments. The Gothenburg Protocol sets emission reduction commitments (ERCs) for NO_x (as NO_2), SO_x (as SO_2), NMVOCs, NH_3 and for $PM_{2.5}$ to be achieved in 2020 and beyond. The NECD sets emission reduction commitments for 2020 (in line with the Gothenburg Protocol commitments) as well as more stringent targets for 2030 for the same air pollutants.

Table A1e.1 shows how the latest projections of emission totals compare with 2020 and 2030 targets based on applying the NECD and Gothenburg emission reduction commitments to the current 2005 baseline (Richmond *et al.* 2020). This shows that the 2030 reduction commitments for SO_x (as SO_2) and NMVOC emissions have already been met but based on the projections, the UK will need to take further action to meet its ERCs for NH_3, $PM_{2.5}$ and NO_x. The UK Government published its Clean Air Strategy and NAPCP in 2019, which sets out how it will work towards its 2020 and 2030 emission reduction commitments.

Table A1e.1: Comparison of UK 2018 national emissions, projected emission estimates and emission reduction commitments (in kilotonnes) for years 2020 and 2030

Year	NH_3	$PM_{2.5}$	NO_X (as NO_2)*	SO_x (as SO_2)	NMVOCs*
2005 national total (base year)	279	124	1,699	773	1,060
2018 national total	**276**	**107**	**796**	**160**	**703**
2020 target (emission reduction commitment from base year)	257 (8%)	87 (30%)	765 (55%)	317 (59%)	721 (32%)
Projected 2020 national total	284	97	703	119	692
Exceedance of, or amount below 2020 targets	**27**	**10**	**-62**	**-198**	**-29**
2030 target (emission reduction commitment from base year)	234 (16%)	67 (46%)	459 (73%)	93 (88%)	647 (39%)
Projected 2030 national total	283	91	530	92	646
Exceedance of, or amount below 2030 targets	**49**	**24**	**71**	**-1**	**-1**

Note: *The NMVOCs and NOx figures quoted in this column exclude emissions from 3B (manure management) and 3D (agricultural soils). Under the NECD, NMVOCs and NOx emissions from 3B and 3D are not accounted in the National Total for the purpose of complying with the 2020 (or 2030) emission reduction commitments. Source: Richmond *et al.* (2020).

A1e.6 Environmental issues

Air pollution is a local, regional and international problem caused by the emission of pollutants, which either directly or through chemical reactions in the atmosphere lead to negative impacts on human health and ecosystems. Whilst there have been significant reductions in recent decades of emissions of air pollutants (see Section A1e.3 above), the relationship between emissions and ambient air quality is not straightforward (Defra 2019b).

In their review of interventions to improve outdoor air quality and public health, Public Health England (Bradley *et al.* 2019) identified the main air pollutants of health concern as particulate matter (PM) and NO_2, with ammonia (NH_3), SO_2, NMVOCs and ozone (O_3) also identified as important pollutants.

PM emissions have decreased over recent decades, with the rate of decline being most pronounced during the 1990s. Secondary particles are the predominant components of $PM_{2.5}$ in the UK, making up about 60% to the overall mass of $PM_{2.5}$ in urban areas annually (AQEG 2012); and even more during high pollution episodes (e.g. Vieno *et al.* 2016). Secondary particulates (also called secondary aerosols) consist of both organic and inorganic (sulphate, nitrate, ammonium) components, which are formed in the atmosphere largely through the chemical reaction of gaseous precursors. Only about half of secondary aerosol pollution in the UK is formed from precursor species emitted in the UK, with around 33% arising from other countries and 17% from shipping (based on 2012 data) (AQEG 2012). The main precursor gases for secondary inorganic aerosols are ammonia (NH_3) and oxides of nitrogen and sulphur. Volatile organic compounds (VOCs) contribute to the organic secondary PM. The evidence of the public health impact of PM exposure is consistent in showing adverse health effects at exposures that are currently experienced by urban populations. There is a close relationship between exposure to high PM concentrations and increased mortality or morbidity, both daily and over time. Air pollution is considered a contributory factor rather than the sole cause of death in most cases (Bradley *et al.* 2019).

Epidemiological studies have shown associations of outdoor NO_2 with adverse effects on health, including reduced life expectancy. It has been unclear whether these effects are caused by NO_2 itself or by other pollutants emitted by the same sources (such as road traffic) (Bradley *et al.* 2019). Evidence associating NO_2 with health effects has strengthened substantially in recent years but there is debate as to whether it is causal or a marker for other traffic-related pollutants (COMEAP 2018, Bradley *et al.* 2019).

NH_3 is a gas released into the atmosphere from natural and anthropogenic sources. Once emitted into the atmosphere, NH_3 can be rapidly deposited over the areas near the emission source and can be a major source of pollution, causing nitrogen enrichment (eutrophication) and acidification of soil and water sources. Atmospheric NH_3 also reacts with acid gases, such as sulphuric and nitric acid, to form secondary $PM_{2.5}$. From 2013 onwards, NH_3 emissions have slightly increased, driven largely by the intensification of agricultural production. The main health impacts of NH_3 arise through its role in secondary $PM_{2.5}$ formation (see above).

NMVOCs react with NO_x in the presence of sunlight to form tropospheric O_3, known to be harmful to health and the environment. NMVOCs also contribute to the formation of secondary organic aerosols that can harm human health (see above). Certain NMVOCs, such as benzene and 1, 3-butadiene, have also been shown to be toxic, mutagenic and carcinogenic.

Ground level, or tropospheric O_3, is not emitted directly into the air, but is created by means of photochemical reactions involving the precursor pollutants NO_x and VOCs. Several epidemiological studies have reported adverse associations between short-term exposure to O_3 and human health. The effects of exposure to O_3 are predominantly respiratory, but adverse effects on the cardiovascular system have also been reported (Atkinson *et al.* 2016). Ground level O_3 also has negative effects on ecosystems, including loss of species diversity (Bradley *et al.* 2019).

A rapid evidence review by the Air Quality Expert Group (AQEP) on estimated changes in air pollution emissions, concentrations and exposure during the COVID-19 outbreak in the UK reported in June 2020. The ongoing nature of the outbreak and the preliminary nature of much of the evidence collected reflects a level of uncertainty with expert judgement used to inform the review's conclusions. Initial conclusions include:

- The most pronounced changes in UK air quality during lockdown were in the urban environment, notably for nitrogen oxides (NO_x). Once weather effects were accounted for, mean reductions in urban NO_x averaged over the lockdown period considered were typically 30-40%, with mean NO_2 reductions of 20-30%.

- Meteorological conditions led to higher $PM_{2.5}$ during lockdown than the average experienced in equivalent calendar periods from previous years. This was due to the persistence of anticyclonic weather, leading to a higher incidence of easterly winds bringing $PM_{2.5}$ and its precursors from the rest of Europe into the UK.
- Increased ozone was observed at some urban monitoring stations, a result of lower local NO.
- Long-term exposure to air pollution is associated with increased morbidity and mortality from chronic diseases, some of which have also been identified as increasing the risk of severe COVID-19 symptoms. Given this, there may be a link between exposure to air pollution (past or present) and the occurrence or severity of COVID-19 infection. Whilst several unpublished studies have examined this effect, and have reported associations with past exposure to both $PM_{2.5}$ and NO_2, there is currently no consensus on the pollutant responsible or the magnitude of any effect (AQEP 2020).

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