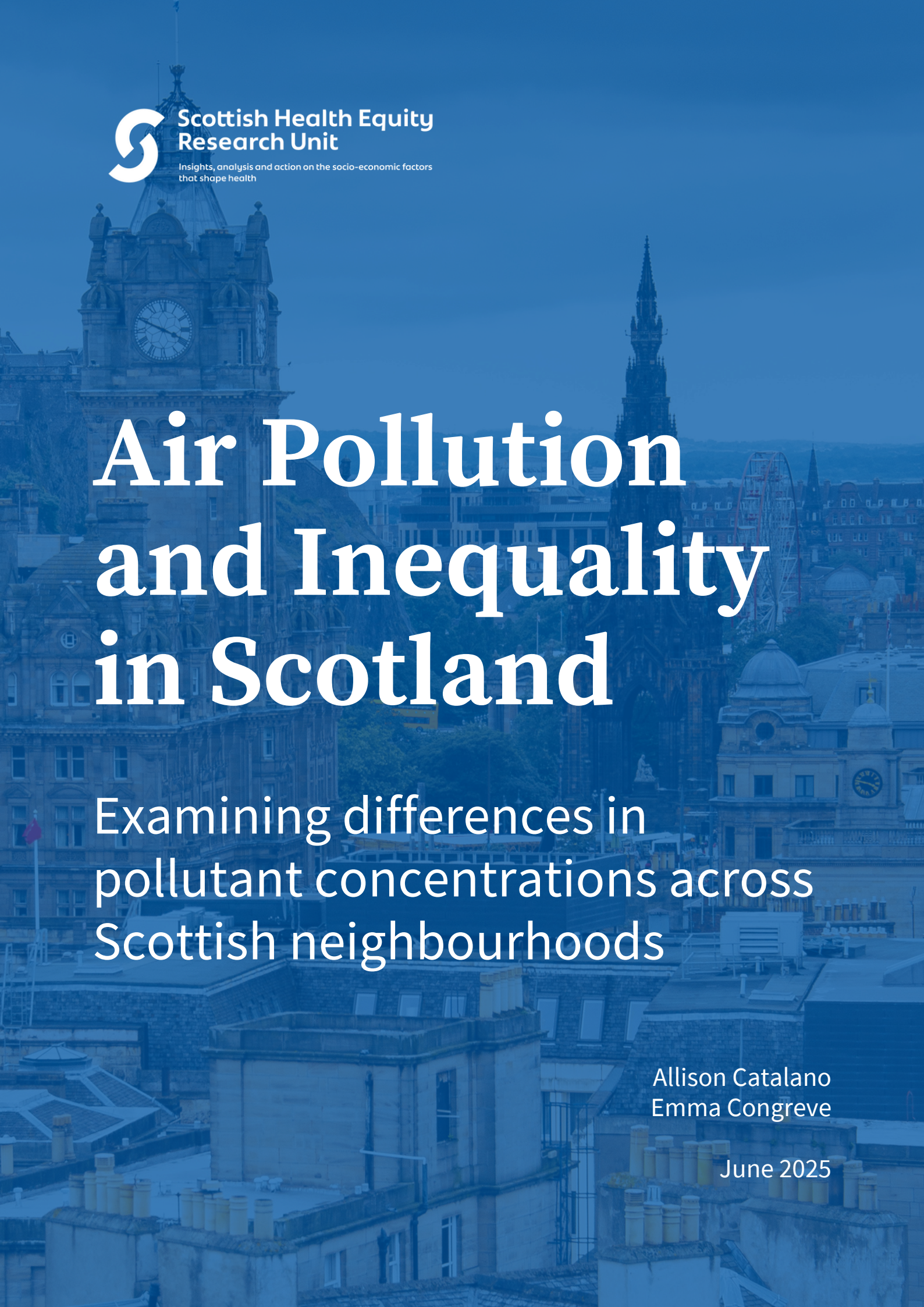

Scottish Health Equity Research Unit

Insights, analysis and action on the socio-economic factors that shape health

Air Pollution and Inequality in Scotland

Examining differences in pollutant concentrations across Scottish neighbourhoods

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June 2025

Who we are

The Scottish Health Equity Research Unit (SHERU) was set up in 2024 to provide insights and analysis on the socio-economic factors that shape health. The unit brings together expertise on public health and socioeconomic analysis in a joint collaboration between the University of Strathclyde's Centre for Health Policy and Fraser of Allander Institute.

Our work covers four main areas of focus: commentary & analysis of emerging trends; driving data improvement; supporting policy implementation, and engagement across Scotland to make connections across the socioeconomic and health inequalities stakeholder community.

Our aim is to offer an independent voice and robust scrutiny to Scottish policy debates. We will work with people from the public, private and third sectors and the wider public to drive the practical action needed to improve health and reduce inequalities in Scotland.

For more information go to www.scothealthequity.org

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Scottish Health Equity Research Unit
Insights, analysis and action on the socio-economic factors that shape health

University of Strathclyde Glasgow

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Introduction

Outdoor air pollution is a significant risk to public health, with an estimated 1,800 to 2,700 deaths in Scotland each year attributed to long-term exposure to outdoor air pollution (1). Health problems can occur because of short-term exposure to poor air quality as well, and poor air quality overall is a major contributor to preventable ill health. People living in areas with higher pollutant concentrations are more likely to experience a variety of health problems, including respiratory conditions, heart conditions, birth complications, cancers, and overall mortality (2).

High levels of pollutant exposure can compound other health risk factors, contributing to or worsening health inequality: people on low income in Scotland, for instance, are more likely to experience respiratory and cardiovascular conditions, low birthweight, and all-cause mortality (3).

Scotland has a long history of health inequality, and as we detail through this report, notable inequalities in air pollutant exposure. In particular, we explore significant markers of potential socioeconomic inequality, including income deprivation, ethnicity, disability, and housing tenure. These inequalities in exposure are visible both across Scotland and within large, urban areas, which have higher levels of health-affecting air pollutants. This means that these inequalities are not because certain groups are more concentrated in cities.

The next question, therefore, is how the policy landscape in Scotland addresses air quality, and what can be done to further improve these inequalities. Most emissions are derived from road transport, industry, and heating in domestic, commercial, or institutional spaces. This means that targeted strategy across these sectors can effectively reduce inequalities in pollutant exposure and inequalities in health overall.

Since 2011, Scotland has seen a significant decline in concentrations of nitrogen dioxide and fine particulate matter, both of which are correlated with a wide variety of health outcomes (4). 2022 also marked the first time outside of pandemic-era lockdowns where no monitoring sites in Scotland exceeded air quality objectives. This is a huge achievement for Scotland, and the result of decades of hard work, innovation, and policy across every level of government.

There is still a gap in recognising and tracking inequality in pollutant exposure. Many policy documents discuss reducing health inequalities or inequalities in air pollutant concentrations, but there is not currently a way of regularly monitoring or reporting where these inequalities lie. This can be a difficult and specialised task, so it ends up being confined to impact assessments, produced by consultancies or civil servants who are already thinly stretched, and academic reports. This means that local authorities, who are tasked with developing strategies and reporting on their progress in reducing air pollution, are not regularly able to monitor for – or develop the necessary strategies to improve – these inequalities.

If reducing inequalities in pollutant exposure – and reducing correlated health inequalities – is a goal for Scotland, local authorities need to have the capacity, data, and capability to do so. This needs to be considered further and acted upon. The methods used in this report can help attain this goal.

Key Findings

This report examines the relationship between markers of socioeconomic inequality and air quality in urban areas, discusses Scotland's air quality policy landscape, and explores opportunities for Scottish policy to improve these inequalities further.

- Large, urban areas (Aberdeen, Dundee, Edinburgh, and the Greater Glasgow region) have significantly higher pollutant concentrations than other parts of the country. Annual mean nitrogen dioxide (NO_2) concentrations in large, urban areas are more than twice as high as in all other parts of Scotland, and fine particulate matter ($PM_{2.5}$) concentrations are 18% higher.
- Within large, urban areas, people living in deprived areas, people from minority ethnic backgrounds, people with mental health conditions, and people in rented accommodation experience higher-than-average levels of both NO_2 and $PM_{2.5}$.
- Scotland's air quality policy strategy, Cleaner Air for Scotland 2, is due for review in 2026. At this point, Scotland may consider new air quality objectives, in line with European Union (EU) limit values or World Health Organisation (WHO) guidelines.
- Only 5,000 people live in areas that exceed EU limit values for annual mean NO_2 concentrations, whereas over 800,000 people live in areas that exceed WHO NO_2 or $PM_{2.5}$ guidelines.
- In large, urban areas, people in income-deprived areas, people from ethnic minority backgrounds, people with mental health conditions, and people living in rented accommodation are more likely to live in areas with pollutant concentrations that exceed WHO guidelines.
- Addressing emissions from transport, domestic and commercial heating, and industry is crucial if Scotland is to continue to see progress in air quality improvements.
- While Scotland has successfully brought NO_X concentrations down, $PM_{2.5}$ from industrial sources, point sources[1], and domestic and commercial heating has increased since 2011. $PM_{2.5}$ from industrial and point sources have actually increased by 16% since 2011, while $PM_{2.5}$ from domestic, institutional, and commercial heating sources has more than doubled.
- Scottish air quality and just transition strategies discuss reducing inequalities in pollutant exposure, but local authorities, who are responsible for monitoring and improving air quality, do not monitor these inequalities outside of conducting impact assessments for new policies and development projects. If Scotland would like to continue to make improvements in equality, it should consider ways of providing matched data for local authority use.

[1] Point source emissions are emissions derived from a single, identifiable source.

Background

Air pollution and health

Key points
Exposure to the pollutants Nitrogen Dioxide (NO_2) and Fine Particulate Matter ($PM_{2.5}$) are known to have health implications. Differences in air pollutant exposure are likely to be contributing to differential health outcomes for people across Scotland.

Air pollution is well known to have a significant impact on health. In Scotland, between 1,800 and 2,700 deaths each year may be attributable to long-term exposure to outdoor air pollution (1). However, the health impacts of poor air quality go even farther and can occur with both short-term and long-term exposure.

While poor air quality can affect anyone, higher levels of fine particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2) are especially likely to affect sensitive groups, which includes people with pre-existing respiratory or cardiovascular conditions, older people, pregnant women, and children. Fine particulate matter is especially dangerous: because of its small size, it is able to enter the blood system through the lungs, and can damage other organs, including the brain (6).

Air pollution is linked to a variety of cardiovascular and respiratory conditions, cancers, neonatal and early childhood conditions, even at low levels of exposure (2). Low level exposure is also associated with dementia and cognitive decline in old age (5).

At the same time, Scotland is known for having large differences in health outcomes. People living in the most deprived regions – as defined by the Scottish Index of Multiple Deprivation (SIMD) - are more likely to face a variety of poor outcomes compared to people in the least deprived regions, including in health outcomes associated with poor air quality, such as respiratory conditions and mortality, low birthweight, and all-cause mortality (3). Air pollution is likely to be one of many factors contributing to these negative health outcomes, although the extent to which it influences population health in Scotland is not clear. Understanding where inequalities in pollutant exposure lie can enrich our understanding of a known contributor to the overall state of health inequality in Scotland.

Reasons for inequalities in pollutant exposure

Key points

There is evidence from literature across the UK of there being a social gradient in air pollution, with people in deprived areas being more likely to live in areas with higher levels of air pollution. Studies have also found inequalities in pollutant exposure among other groups, especially people from ethnic minority backgrounds.

Some of these inequalities are because these groups are more likely to live in urban areas, which have higher concentrations of air pollutants compared to other parts of the country.

Within urban areas, however, there are areas with higher and lower levels of air pollution. The literature also indicates that deprived populations and people from ethnic minority backgrounds are likely to live in more polluted areas within urban settings.

Multiple studies across Scotland (8), England (4,9), and Wales alike (10) have found that people living in deprived areas experience higher levels of air pollution, although this relationship is sometimes complicated and may not be directly linear.

This begs the question: why are deprived areas more likely to have worse air quality?

One reason is that deprived neighbourhoods are disproportionately likely to be located in cities, which have worse air quality compared to rural areas or small towns, although there are also inequalities in pollutant exposure within urban areas.

Lower income households may not have the economic resources to move to neighbourhoods with less pollution. Planning processes may also add to environmental inequalities, even when planners attempt to distribute environmental resources more equitably: practices which improve local air quality, such as improved public transport or urban greening, may attract people on higher incomes into the area, pushing lower income households into areas further from these improvements (8).

Historical perceptions of neighbourhoods are also important in understanding why levels of pollution may differ among urban populations. The historical reputation of a neighbourhood can influence its reputation decades later (8). There is some evidence that air pollution and poverty are deeply interwoven in the United Kingdom. Historically, poorer areas in the UK were likely to be located to the east end of the city, because wind patterns post-industrial revolution would carry smoke from factories in that direction. Even though these pollution patterns may no longer be the same, neighbourhoods that had high levels of pollution in the 1800s were likely to have a higher share of low-skilled workers in 2011 (11).

Other groups are also disproportionately likely to live in areas with higher pollutant concentrations, such as people from ethnic minority backgrounds. Studies have also found significant differences in air pollutant exposure based on ethnicity (12,13). This is important for Scotland, where the ethnic minority population grew by more than 60% between 2011 and 2022, yet data on health inequalities among people from minority ethnic groups remains a work in progress (14,15).

Air quality guidelines

Key points

The World Health Organisation have pollutant exposure guidelines for NO_2 and $PM_{2.5}$. While is no evidence for a threshold below which no adverse health effects occur, reducing pollution levels below WHO guidelines is likely to bring about positive health impacts. Inequalities in air pollution exposure is likely to be part of the reason for health inequalities, and these inequalities are likely to be seen if levels exceed WHO guidelines.

Scotland's current set of air quality targets were met for the first time in 2022 but are less stringent than the current WHO guidelines. Scotland's air quality strategy is due for review in 2026.

To address the negative health effects of air quality, a variety of organisations have established pollutant concentration guidelines or targets. This includes recommendations by health bodies, such as the World Health Organisation (WHO), and government-mandated targets.

Air pollution management has been a devolved power in the United Kingdom since 1999, but has been managed within Scotland since 1995 (16). The task of managing and improving air quality is divided between three bodies: Local Authorities, the Scottish Government, and the Scottish Environment Protection Agency (SEPA). Local authorities are ultimately responsible for meeting targets set by the Scottish Government, and work with SEPA to meet those goals.

Scotland's current air quality objectives had target dates that were between 2005 and 2020. 2022 was the first year where all automatic monitoring sites met these objectives for the first time outside of lockdown[2] (17). There are two other air quality guidelines that are worth considering for the Scottish Government in developing future targets: the WHO Air Quality Guidelines (18) and the 2030 European Union Air Quality Standard limit values (19).

The objectives set by Scottish Government, the WHO, and the EU are provided in Table 1. Because of data availability and the increased risk associated with long-term pollutant exposure, annual mean pollutant concentrations are the focus of this report. However, air quality objectives from these three bodies are also defined by different time measurements. Certain pollutants may also need to fall below a 15-minute mean, 1-hour mean, 8-hour mean, or 24-hour mean.

Table 1: Annual mean pollutant concentration guidelines from the WHO, Scottish Government, and European Union, in µg/m³

Pollutant	NO_2	PM2.5
WHO guideline	10	5
Scottish air quality objective	40	10
2030 EU air quality limit values	20	10

Scotland does not have a statutory obligation to meet either WHO guidelines or EU limit values, and both were published after Scotland's most recent air quality objective target date in 2020. However, the previous EU limit values were retained as part of Scotland and the UK's environmental law following the UK's exit from the EU. EU countries are required to meet targets by 2030, which is extremely ambitious for countries with large, densely populated urban areas. The

[2] Excluding 2020, as travel disruption due to the pandemic was considered an anomaly

WHO guidelines are even more ambitious, although they are not obligatory targets, and do not have a deadline.

WHO guidelines could be thought of as the lowest exposure level to a pollutant where there is an increase in adverse health effects. While no level of pollutant exposure is known to be entirely safe, these guidelines give us an understanding of relative safety: the differences in health outcomes are not known for long-term exposure to pollutant concentrations below those guidelines, while there are known negative outcomes above.

To provide countries with a roadmap of moving towards these guidelines, the WHO published a series of interim targets. The EU limit values are based on the most ambitious of these interim targets, with the goal of meeting the air quality guideline by 2050 (19).

Scotland's air quality policy strategy, Cleaner Air for Scotland 2, is due for review in 2026. At this point, Scotland may consider new air quality objectives, in line with EU limit values or WHO guidelines.

Inequalities in outdoor air pollution in Scotland

Data and Methodology

Key points

This research explores 3 key areas related to inequalities in pollutant exposure in large, urban areas in Scotland based on income deprivation, ethnicity, disability, housing tenure, and age. These are:

1. Annual mean concentrations of $PM_{2.5}$ and NO_2,
2. Sources of emissions, and
3. Regions that exceed WHO guidelines.

To do so, we use GIS software to overlay the exposure pollutant data over to data zone boundaries and calculate population weighted average pollutant levels within data zones.

To produce estimates for different population groups the population weight is altered based on the size of the population in question.

We also sum the number of people of difference characteristics who live in data zones with pollutant exposure above WHO guidelines.

This research explores inequalities in population-weighted annual mean concentrations of $PM_{2.5}$ and NO_2 based on geographic data.

Two metrics are considered alongside population-weighted annual mean pollutant concentration. First, we examine annual mean concentrations and sources of pollution for people living along an urban-rural split, looking at differences among groups living in large, urban areas. The definition of large, urban areas comes from Scotland's 6-fold classification and includes settlements which have more than 125,000 people. These settlements include Aberdeen, Dundee, Edinburgh, Greater Glasgow, and Motherwell and Wishaw (20). Of Scotland's 6,976 data zones, 2,496 are classified as Large, Urban Areas.

The second metric is the proportion of people living above WHO guidelines for exposure to air pollution. This examines the number of people within a population living in areas with mean annual pollutant concentrations that are above 10 $\mu g/m^3$ of NO_2, above 5 $\mu g/m^3$ of $PM_{2.5}$, or both.

To understand inequality, we examine the population of small areas based on income deprivation, age, ethnicity, having a long-term illness or disability, and housing tenure.

Background data on mean annual pollutant concentrations are provided by the UK Department for Environment Food and Rural Affairs (DEFRA). This study uses DEFRA's 2022 projections, which are modelled based on observed traffic and meteorological data from 2021. 2022 was chosen as a base year for comparability with 2022 Scottish census data.

Mean annual pollutant concentrations are not provided at a data zone level, which is the smallest geographical level of socioeconomic data that is published by the Scottish Government. Instead, pollutant concentrations are provided in the form of a centre point of a $1km^2$ grid for the entire UK.

An overview of the data used is provided in Table 2.

Table 2: Sources of data for modelling

Indicator	Granularity	Source	Source year(s)
Outdoor air pollutant concentrations (NO_X, NO_2, $PM_{2.5}$, PM_{10})	1km^2 blocks	DEFRA	2011, 2013, 2015, 2017, and 2022 (modelled from 2021 data)
Sources of NO_X and $PM_{2.5}$			2011 and 2022 (modelled from 2021 data)
Proportion of the population that is income deprived	Data zone (2011)	SIMD	2020
Urban Rural 6-fold classification	Data zone (2011)	Scottish Government	2020
Population data	Data zone (2011)	Scottish census	2022 and 2011
Age by single year			
Ethnicity			
Long-term illness or disability			
Housing tenure			

In order to estimate the average annual concentration for an irregularly shaped data zone, we used geographic information system (GIS) software to overlay the 1km^2 grid with data zone boundaries. The average pollutant levels within data zones are based on the weighted proportion of a grid that falls within that data zone. For instance, if 75% of a data zone is covered by Grid A, and 25% is covered by Grid B, the average pollutant concentration within that data zone is the sum of 75% of the pollutant concentration in Grid A and 25% of the pollutant concentration in Grid B.

Data zones feature between 300 and 5000 individuals, although the average population of a data zone is around 800 people. Because of this wide variation, aggregate data is weighted based on population. As an example of this, the mean NO_2 concentration across Scottish data zones in 2022 was 5.99 µg/m^3. However, areas of better air quality tend to be more sparsely populated. With this in mind, the mean population-weighted NO_2 concentration across Scottish data zones in 2022 was slightly higher, at 6.09 µg/m^3.

Estimations on annual mean pollutant concentrations in 2013, 2015, and 2017 assume that the total population and populations of ethnic groups underwent an even growth rate between 2011 and 2022.

Further detail the relationship between annual mean concentrations of NO_2 and $PM_{2.5}$ and the proportion of each data zone that is of an ethnic minority (excluding white minorities), is income deprived, has a mental health condition, or lives in a social or private rented accommodation is provided in Annex 1.

Air pollution in Scotland

Key points

There is variation in air pollutant concentrations across Scotland, with the highest average concentration of NO_2 and $PM_{2.5}$ in urban areas.

There have been dramatic falls over the past 10 years with people experiencing around half the mean concentration of key pollutants compared to 2011.

All data zones in Scotland met air quality objectives in Scotland in 2022, but 804,000 people lived in the 953 data zones areas that fell below the WHO guidelines for $PM_{2.5}$ or NO_2.

Annual mean concentrations

Scotland has a wide range of mean annual air pollutant concentrations, with more populated areas experiencing higher concentrations of $PM_{2.5}$ and NO_2 alike (Figure 1). Large, urban areas – classified as any settlement with more than 125,000 people - have the highest average concentrations of NO_2 and $PM_{2.5}$. 38% of the Scottish population lives in large, urban areas, where NO_2 concentrations are more than double the average in the rest of Scotland, and $PM_{2.5}$ concentrations are 20% higher.

Scotland has seen a dramatic improvement on average since 2011. On average, in 2022, people in Scotland experienced around half the mean concentration of key pollutants compared to 2011 (Figure 2).

Scottish performance against targets and guidelines

In 2022, all data zones met the Scottish annual mean air quality objectives for the first time.

Only 7 data zones, all located in Aberdeen's city centre, exceed the EU limit value for NO_2 of 20µg/m^3, and no data zones exceed the EU $PM_{2.5}$ limit values (Table 3).

Table 3: Proportion of the Scottish population living in areas that exceed WHO guidelines, Scottish air quality objectives, and EU limit values for NO_2, $PM_{2.5}$, and PM_{10} concentrations in µg/m^3, 2022

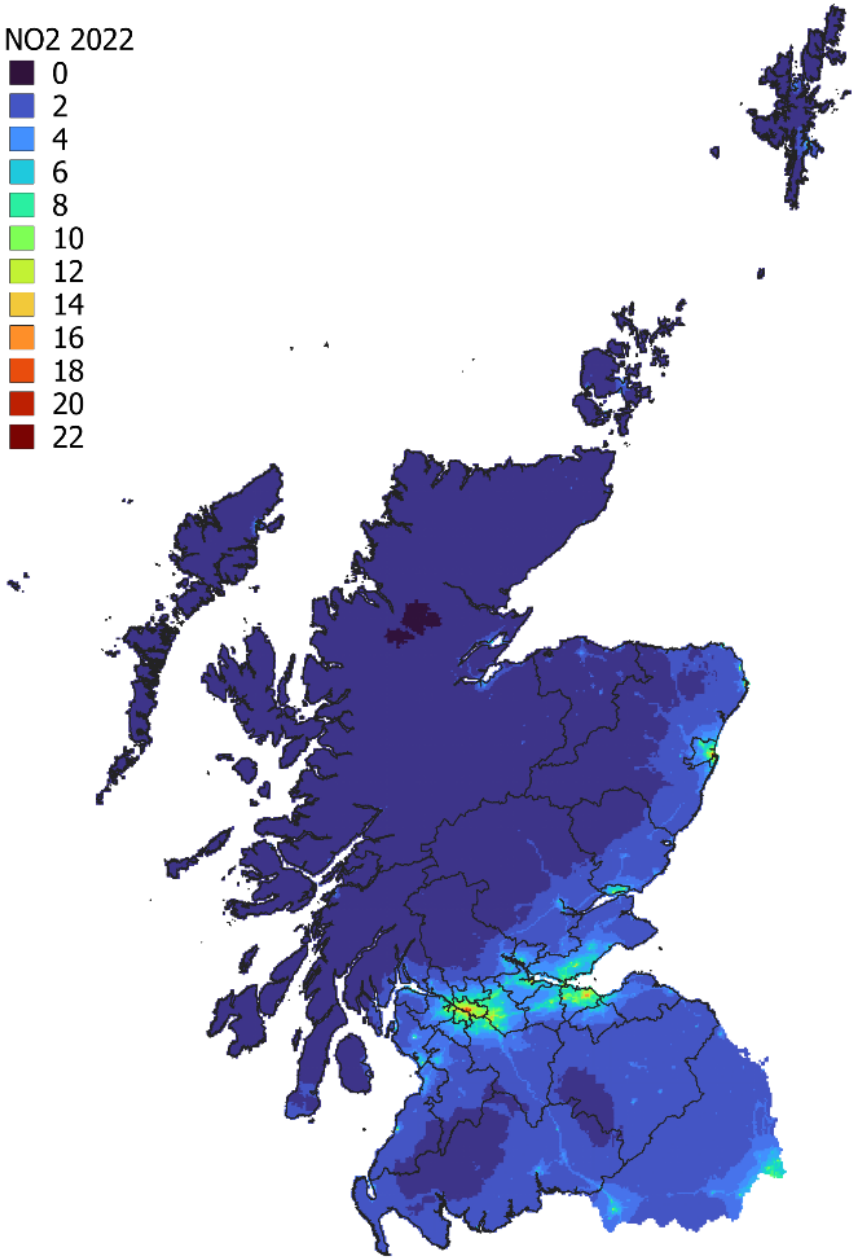
	WHO Guidelines	% Exceeding WHO Guidelines	EU limit values	% Exceeding EU limit values	Scottish objectives	% Exceeding Scottish objectives
$PM_{2.5}$	5µg/m^3	0.8%	10µg/m^3	0%	10µg/m^3	0%
NO_2	10µg/m^3	11.4%	20µg/m^3	0.1%	40µg/m^3	0%
Both		2.6%		0%		0%

953 of Scotland's 6,976 data zones are in areas that exceed WHO guidelines for $PM_{2.5}$ or NO_2. Over 804,000 people lived in these 953 data zones, making up 14.7% of the total population.

90% of the 804,000 people living in areas that exceed WHO guidelines are in large urban areas, with a further 9% living in other urban areas. Four cities are considered large, urban areas: Aberdeen, Dundee, Edinburgh, and the greater Glasgow region. Over 2,000,000 people live in these large, urban areas (Figure 3).

Interestingly, 9,000 people live in data zone in accessible areas and remote small towns which exceed WHO guideline concentrations. There are clear patterns for these areas: four are located in coastal areas, where they exceed NO_2 levels due primarily to water transport. The remaining six are interior towns which exceed $PM_{2.5}$ guidelines, for which industrial emissions are the primary source. A visual overview of areas which exceed WHO guidelines is provided in Annex 3. More information on sources of pollution is provided in a later section.

Figure 1: Annual mean NO_2 (left) and $PM_{2.5}$ (right) concentrations for Scotland in µg/m3, 2022



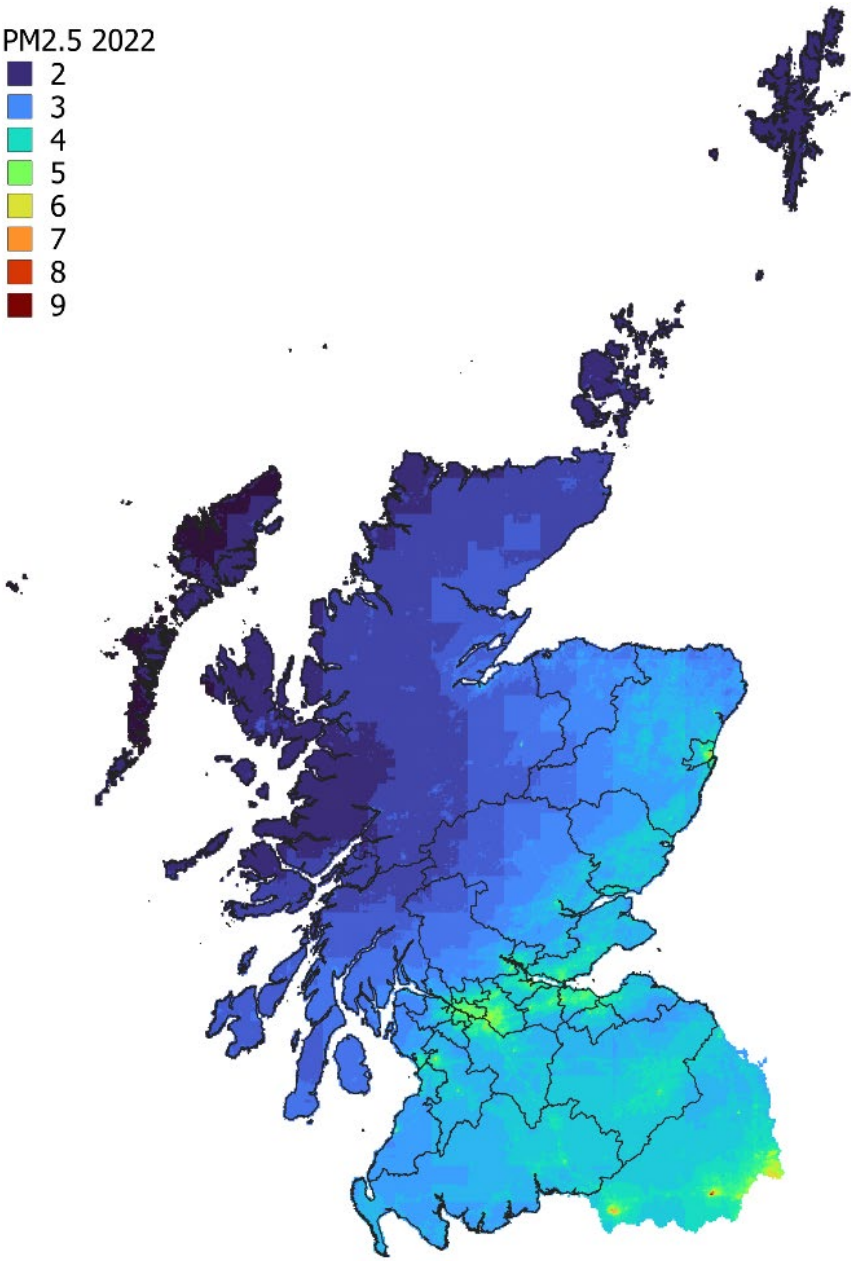


Figure 2: NO_2 annual mean concentrations, population-weighted by local authority, in 2011 (left) and 2022 (right)

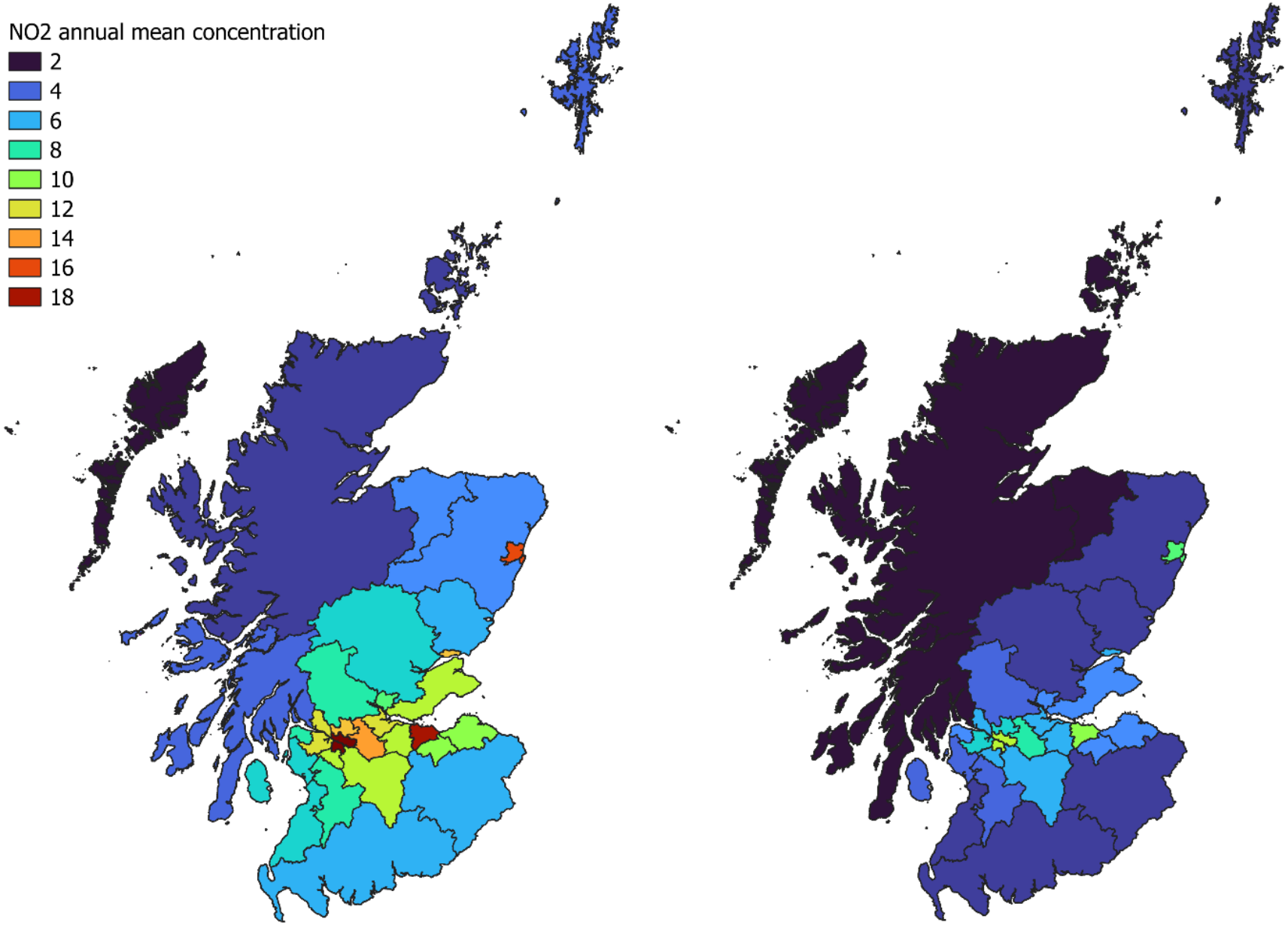
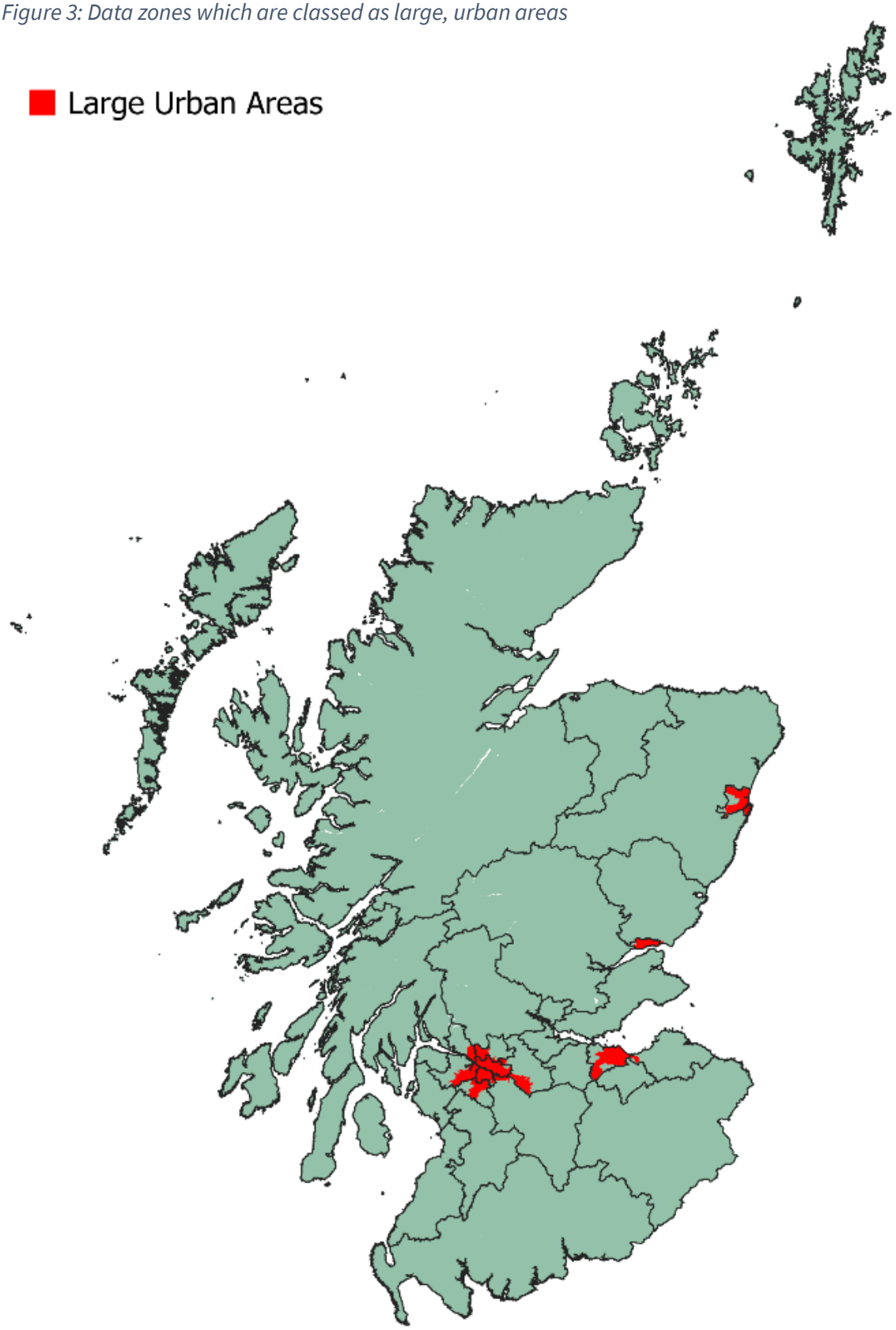


Figure 3: Data zones which are classed as large, urban areas



Inequalities in pollutant exposure

Key points

Analysis of data for Scotland confirms the literature that there is a social gradient in exposure to air pollutants. This is partly due to more people from low-income backgrounds living in urban areas, but there also evidence of social gradient of exposure to pollutants within urban areas.

Disabled people are not more likely to be exposed to air pollution than the general public. People from ethnic minority groups are more likely to be exposed to air pollution than non-minority ethnic groups. The reduction in pollutant exposure over the past 10 years has been proportional across all groups meaning there has not been an improvement in inequalities.

All data zones in Scotland meet current Scottish objectives for air quality pollution, but people in lower income demographics and people from minority ethnic groups in urban areas are more likely to live in data zones with air pollutant exposure above WHO guidelines.

Inequalities in pollutant exposure has overlap with socioeconomic and other potential markers of inequality, especially ethnicity, housing tenure, and having a mental health condition.[3]

Concentrations have decreased roughly proportionately for all groups. However, inequalities have remained, particularly in relation to NO_2. This section focuses on inequalities in air pollutant exposure for people facing socioeconomic disadvantage and other characteristics.

Table 4 shows mean pollutant exposure for different population characteristics across Scotland. The differences here are principally due to higher prevalence of some groups of people in urban areas. However, there are also notable inequalities within urban areas as shown in Table 5.

Table 4: Mean pollutant exposure for different population characteristics across Scotland

	Annual mean NO_2 concentrations	**Annual mean $PM_{2.5}$ concentrations**	**WHO guidelines**
Income deprivation (as measured by SIMD)	27% higher in most deprived quintile compared to least deprived.	6% higher in most deprived quintile compared to least deprived.	Of the 804,000 people in Scotland living in areas which exceed WHO guidelines, 244,000 (or 30%) live in Scotland's most income deprived areas.
Ethnic minorities	48% higher for minority ethnic communities compared to people from non-minority ethnic population	9% higher minority ethnic communities compared to people from non-minority ethnic population	49% of all people from ethnic minority groups living in urban areas are in data zones which exceed any WHO guidelines, compared to 32% of people from white Scottish or British backgrounds.
Disabled people (including long-term limiting health condition)	Slightly lower overall compared to the population average although 8% higher for people with mental health conditions	Similar compared to the population average	On average, 14% of people with disabilities or long-term conditions live in areas that exceed any WHO guidelines, compared to 15% for the Scottish population. 19% of people with a mental health condition live in areas that exceed WHO guidelines.

[3] See Annex 1 for the statistical significance and correlation between these characteristics and annual mean pollutant concentrations.

Table 5: Mean pollutant exposure for different population characteristics within large urban areas

	Annual mean NO_2 concentrations	**Annual mean $PM_{2.5}$ concentrations**	**WHO guidelines**
Income deprivation (as measured by SIMD)	8% higher in most deprived quintile compared to least deprived. 12-13% higher for children living most deprived quintile compared to least deprived	2% higher in most deprived quintile compared to least deprived. 3-4% higher for children living most deprived quintile compared to least deprived	40% of people in urban most deprived quintile compared to 29% in the least deprived
Household tenure	21% higher for private rented accommodation and 8% higher for social rented accommodation compared to owner-occupiers.	2-3% higher for rented accommodation compared to owner-occupiers.	56% of private renters and 41% of social renters live in areas that exceed WHO guidelines, compared to 29% of owner occupiers.
Ethnic minorities	13% higher for minority ethnic communities compared to people from non-minority ethnic population	2% higher minority ethnic communities compared to people from non-minority ethnic population	48% of people from ethnic minority groups live in areas that that exceed WHO guidelines compared to 32% from non-minority ethnic population
Disabled people (including long-term limiting health condition)	Slightly lower overall compared to the population average although 4% higher for people with mental health conditions	Similar compared to the population average	Similar overall. Slightly more people with mental health conditions live in areas that exceed WHO guidelines.

A full breakdown of population-weighted annual mean concentrations is provided in Annex 2.

Sources of air pollution

Key points

Pollution exposure varies by region, with transport being the main source of Nitrogen Oxides (NO_x, which includes NO_2) in most areas, except coastal towns where shipping contributes significantly.

NO_x has declined significantly since 2011 across all sources, with the exception of aircraft (which has stayed the same) and point sources, which are emissions derived from a single, known source (which have increased slightly).

The main source of $PM_{2.5}$ is heating and industrial emissions. The largest increase over the last 10 years has been the increase in $PM_{2.5}$ from heating sources. This is thought to be due to an increased use of woodburning stoves in domestic settings.

Sources of air pollution come from a range of sources including transport, heating, and industry. There are several reasons why emissions have fallen in the last decade, but policy, especially towards emissions standards and regulations, are a major part of this story (21). This section provides an overview of sources of pollution and the various policy measures in place that tackling these sources.

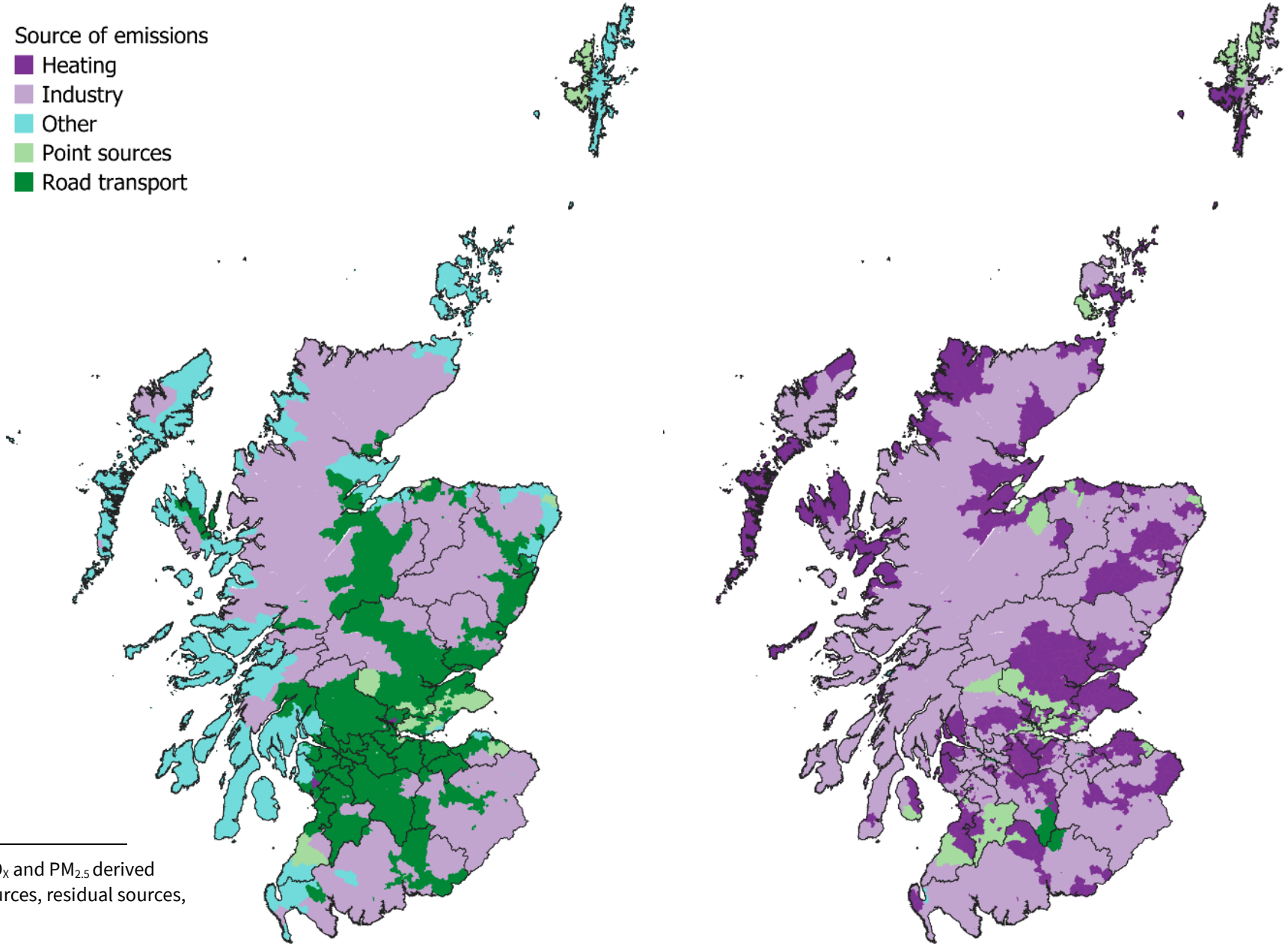
Road traffic is a major contributor to air pollution, as is clearly visible in Figure 1. Roads are also a contributor to particulate matter concentrations, both through exhaust emissions and through brake and tyre wear, albeit a less significant one.

Particulate matter and NO_2 are closely – but not entirely – related. Most $PM_{2.5}$ in Scotland comes from secondary sources, which occurs in the atmosphere when other pollutants interact with each other. For instance, nitrogen oxides are gaseous pollutants, but chemical reactions can occur resulting in the formation of solid nitrates. Excluding secondary sources, natural sources, including sea salt and dust, are the largest category of pollutant.

The main source of pollution experienced by people living in Scotland varies by region. Road transport is the largest source of nitrogen oxides (NO_x, which includes NO_2)[4] in most inhabited areas of Scotland except for some coastal small towns, where "other" is the largest source. This category features a variety of sources, but notably includes shipping emissions. These small towns include several coastal towns with ports, hence the elevated proportion of NO_x emissions in this category. $PM_{2.5}$, by contrast, largely comes from heating and industrial emissions (Figure 4).

4 NO_x is used to understand emissions sources instead of NO_2 because NO_2 background emissions tables do not include source disaggregation. DEFRA has a tool which allows users to derive NO_2 sources by local authority using NO_x background concentration tables, but examining NO_x sources without this tool is sufficient for our purposes.

Figure 4: Population-weighted leading source of emissions for NO_X (left) and $PM_{2.5}$ (right)[5]



[5] excluding rural NO_X and $PM_{2.5}$ derived from secondary sources, residual sources, and salt, 2022

Since 2011, although pollution has dropped on the whole, pollution from certain sources has increased. Point source emissions, which are emissions that are reported directly to SEPA from a single identifiable source (such as a power station or a factory chimney), have increased overall for people living in Scotland since 2011. $PM_{2.5}$ from industrial sources overall has also increased since 2011.

The largest increase was across $PM_{2.5}$ from heating sources, which have more than doubled since 2011. This is largely due to households increasingly using woodburning stoves and fireplaces over time, and is a trend reflected in other parts of the UK, as well as in Europe (22).

At the same time, transport emissions dropped by more than half for both $PM_{2.5}$ and NO_X over the decade (Table 6).

Table 6: Population-weighted change in annual mean PM2.5 and NOX concentrations by source in µg/m^3, 2011 to 2022

$PM_{2.5}$		**NO_X**	
Source	**Change, 2011-2022**	**Source**	**Change, 2011-2022**
Road transport	-0.39	Road transport	-3.24
Other	-0.20	Other	-1.36
Rail	-0.01	Rail	-0.40
Industrial emissions	0.01	Domestic, commercial, and institutional heating	-0.32
Point Sources	0.04	Industrial emissions	-0.28
Domestic, commercial, and institutional heating	0.18	Aircraft	0.00
		Point sources	0.08

Policy on air quality and reducing inequalities in Scotland

Key points

Delivering air quality improvements is complex and involves multiple levels of government. Many policy ambitions are set by national government and implemented by local government through local enforcement.

The Scottish Government is currently reviewing its approach to setting air quality targets. While air quality policy in Scotland does aim to protect public health, it does not currently include specific targets to address inequalities in pollution exposure.

Introducing targeted measures for deprived areas could help reduce these inequalities and shift policy priorities toward the communities most affected. An investment in skills and resources to analyse and monitor changes over time would be required.

The Environment Act 1995 introduced the system of local air quality management in Scotland and the rest of the UK, and also established SEPA as Scotland's environmental regulator. However, the history of air pollution policy goes back to the 1950s and is embedded in numerous areas of policy and strategy. This means that there are potentially hundreds of goals, strategies, and policies which could be relevant to reducing inequalities in air pollution exposure.

In addressing these inequalities, however, there are three specific areas in which the Scottish Government can be the most effective: transport, domestic and commercial heating, and industrial emissions account for 30% of $PM_{2.5}$ emissions and nearly 90% of NO_X emissions in large, urban areas.

There are further two ways of categorising Scottish Government policy and strategy across these three areas:

1. Policies and strategies that improves air quality for all groups
2. Policies and strategies that reduce inequalities in pollutant exposure

Cleaner air for Scotland 2 (CAFS2), which was published in 2021, is Scotland's current air quality strategy. The strategy discusses the wide range of policy areas which are crucial in continuing to reduce levels of air pollution. Other key strategy documents which discuss these areas are the National Transport Strategy (2020), the Infrastructure Investment Plan (2021), the Update to the Climate Change Plan (2020) and the Heat in Buildings Strategy (2021).

Regulating air quality in Scotland is a responsibility shared by multiple governing bodies. National government sets a number of policies and strategies with many, but not all, delivered by local authorities. Local authorities also have their own responsibilities to monitor and develop policy in their own areas through the Local Air Quality Management (LAQM) process as set out in Box 1.

Sources of emissions are not always within local authority control, however. Pollution created in one area directly affects pollutant concentrations in neighbouring areas. This explains why it is necessary for the Scottish Government to have a role in setting the overarching air quality strategy for Scotland, as seen with CAFS 2.

Box 1: Local Air Quality Management (LAQM) process

If a local authority has an area which may be at risk of exceeding certain air quality objectives, they must declare the area an Air Quality Management Area (AQMA). An AQMA may consist of a few streets, or an entire local authority. A local authority may declare an AQMA for any of the air quality objectives set out in legislation.

Following declaration of an AQMA the local authority must produce an air quality action plan setting out measures it intends to implement to improve air quality in the area of concern. At the time of writing, Scotland had 21 AQMAs declared, although this number changes frequently (23).[6] The number and location of AQMAs in Scotland are published by Air Quality in Scotland.

As already discussed, progress has been made across many areas, and there are a number or policies in place that should improve air quality further, including Low Emission Zones (LEZs), which limit the most polluting vehicles from entering city centres, being set up in large urban areas in recent years.

Whilst we know that reducing average emissions across urban areas should have a positive benefit on those most exposed to pollutant exposure, it is also possible for there to be unintended consequences. For example, when designing LEZs, a concern was that drivers of polluting vehicles would opt to drive just outside the zone, displacing emissions into potentially disadvantaged areas. It will be a few years before the data is available to determine whether that happened for cities in Scotland, but research into London and Madrid has shown some positive signs: while there may be some displaced traffic, both cities found an overall reduction in emissions (24–27).

There have also been concerns noted as to the financial impact on households of the plans to decarbonise heating sources in domestic properties. For instance, the Scottish Government recently paused the Heat in Buildings bill, which would have legally required homeowners to replace heating systems by 2045, a rule which would have affected household finances unequally across Scotland (28). This follows an earlier decision to step back from plans to ban installation of wood burning stoves in new build homes, after strong opposition from those representing rural areas (29). How the public perceive new regulations, and the extent to which they believe they are requisite to the health risks of not having these policies in place feels like a gap in evidence that qualitative research could help bridge.

Reforms are complex to navigate, and many factors have to be considered, but one element that is missing from both local and national strategies is an explicit method for reducing inequalities in exposure to emissions.

Impact assessments are the primary mechanism that the Scottish Government and local authorities have at their disposal for addressing these environmental inequalities. New policies and any infrastructure or development project may need (or choose) to consider how the project may impact the economy, the environment, equality, health, island communities, human rights, and noise levels (30). This can be a complicated and expensive process but appears to be the only way that these inequalities are considered and addressed at any scale.

Importantly however, impact assessments are one-off processes and are not revisited or monitored over time. Whilst air quality, transport, planning, and heating policy documents all discuss

[6] Although all air quality targets had been met in 2022, these areas are still considered at risk of exceeding Scottish Government air quality objectives, falling only slightly below compliance levels.

inequality and pollution to an extent, but ongoing monitoring of these inequalities is not widely done outside of research organisations.

Although the data needed to conduct this monitoring is publicly available (see Table 2), combining these datasets is a specialised and time intensive skill. This means that it is not easy to understand where opportunities for improvement lie, and it is therefore not easy for local authorities to make targeted changes.

For example, the LAQM process or local authority annual air quality progress reports, do not include any discussion of inequalities. These areas – especially air quality progress reports – may hold an opportunity to include inequality in the future. However, any changes in Scotland to improve inequality monitoring needs to be feasible given the current skills and workforce available to the Scottish Government and local authorities. This would mean developing data on inequality and pollution and making it more readily available to people working in air quality management across the country.

The Scottish Government is currently considering how to move forward with its air quality objectives and a revisited strategy to be published in 2026. There have also been calls from third sector organisations, such as Asthma and Lung UK, for the WHO guidelines to be adopted into Scottish legislation (31). Introducing specific targets to reduce exposure in deprived areas could help place greater emphasis on addressing inequalities in air pollution, potentially shifting policy priorities to better reflect the needs of the most affected communities and ensuring there are no unintended consequences that could deepen inequalities.

Conclusion

Scotland has done a considerable amount of work in reducing pollutant concentrations for NO_2 and $PM_{2.5}$, meeting statutory targets for both pollutants for the first time in 2022.

Concentrations have also decreased relatively evenly – by around 45% for NO_2 and 50% for $PM_{2.5}$ – for people from different income and ethnic backgrounds, and across different ages and tenures, since 2011. Although these reductions have been equitable, there are still persistent gaps, with people from ethnic minority backgrounds, people in deprived areas, and people in rented accommodation experiencing higher-than-average concentrations (see Annex 1). This means that there is still work to be done, not just in reducing pollution in general, but in reducing this persistent inequality.

Current policies in place – like LEZs in Aberdeen, Dundee, Edinburgh, and Glasgow, efforts to extend and decarbonise bus transport, and working to reduce reliance on high-emissions heating sources – are critical for reducing pollution. These policies also have the potential to either bridge or deepen these gaps, depending on how they evolve over time, and what efforts are taken to mitigate unintended consequences. While inequality was considered in creating and enacting these policies, there is not an ongoing process for monitoring them over time. Ongoing monitoring is crucial in driving policy development and implementation in local areas.

This is not surprising – monitoring things like this can be difficult and resource-intensive, and relative to other parts of the UK and Europe, Scotland's air quality is pretty good at this point.

However, the Scottish Government has made it clear that socioeconomic and health inequalities are important considerations. Between 1,800 and 2,700 deaths each year attributable to long-term exposure to outdoor air pollution, but the health impacts of poor air quality go even farther and can occur with both short-term and long-term exposure. The benefit from addressing these inequalities can make a significant contribution to reducing them.

There are opportunities to embed approaches that reduce inequality in the future, and we encourage the government to consider new methods of measuring, reporting, and monitoring inequality. A potential time to explore these options will be in 2026, when Scotland reviews its current clean air strategy, Cleaner Air for Scotland 2. Scotland may choose to update air quality objectives, moving closer to EU limit values or WHO guidelines. Because people in income deprived areas, people from minority ethnicities, people with mental health conditions, and people living in rented accommodations are more likely to live in places that exceed WHO guidelines, reducing guidelines to this level would require local authorities to act in these neighbourhoods. In order for local authorities to do so, however, they need to have the capacity, data, and capability to do so.

Implementing a protocol for monitoring of inequalities could also be considered in updating the clean air strategy. Central to this would be to build an internal process for updating the analysis included in this report and providing relevant data to local authorities. The analysis in this report shows what is possible. Qualitative evidence is also important in informing and driving effective policy implementation: understanding how people view pollution in their neighbourhoods and how policies affect people living in these areas is important and should be appropriately considered alongside quantitative analysis.

This is not an easy task and would require resource and buy-in across Scottish Government, local government, and other bodies. If addressing these inequalities is a priority for Scotland, however, this is a necessary step.

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Annex

Annex 1: Correlation coefficients and statistical significance of examined variables across Scotland and in urban areas, 2022

To understand the relationship between markers of inequality and concentrations of NO_2 and $PM_{2.5}$ within a data zone, we ran a series of bivariate regressions of the form $y_i = c + bx_i + \in$, where i represents an individual data zone, and the values for y are the proportion of data zone that:

- Is income deprived
- Is from an ethnic minority (excluding white minorities)
- Has a mental health condition
- Lives in socially rented accommodation, or
- Lives in private rented accommodation.

x_i represents the annual mean concentration of either NO_2 or $PM_{2.5}$ within that data zone in µg/m^3.

Finally, each coefficient b listed in Tables 7-10 represent the change in NO_2 or $PM_{2.5}$ in µg/m^3 for every 1 percentage point increase in the examined population within a data zone.

Table 7: Correlation coefficients and standard errors between NO_2 concentrations in µg/m^3 and the proportion of the population that meet examined variables, Scotland

	Ethnic Minorities (excl. white minorities)	Income Deprivation	Mental Health Condition	Socially Rented Accommodation	Private Rented Accommodation
NO_2 Concentration	0.015***	0.006***	0.004***	0.009***	0.012***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-0.022***	0.089***	0.087***	0.151***	0.049***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
R-squared	0.393	0.041	0.118	0.024	0.146
N	6972	6973	6972	6972	6972

* p<0.05, **p<0.01, ***p<0.001

Table 8: Correlation coefficients and standard errors between $PM_{2.5}$ concentrations in µg/m^3 and the proportion of the population that meet examined variables, Scotland

	Ethnic Minorities (excl. white minorities)	Income Deprivation	Mental Health Condition	Socially Rented Accommodation	Private Rented Accommodation
$PM_{2.5}$ Concentration	0.050***	0.027***	0.018***	0.042***	0.034***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-0.137***	0.016*	0.040***	0.035*	-0.017*
	(-0.01)	(-0.01)	(0.00)	(-0.01)	(-0.01)
R-squared	0.179	0.033	0.076	0.021	0.045
N	6972	6973	6972	6972	6972

* p<0.05, **p<0.01, ***p<0.001

Table 9: Correlation coefficients between NO_2 concentrations in µg/m^3 and the proportion of the population that meet examined variables, large, urban areas

	Ethnic Minorities (excl. white minorities)	Income Deprivation	Mental Health Condition	Socially Rented Accommodation	Private Rented Accommodation
NO_2 Concentration	0.017***	0.003**	0.005***	0.007***	0.026***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-0.025***	0.116***	0.075***	0.165***	-0.079***
	(-0.01)	(-0.01)	(0.00)	(-0.02)	(-0.01)
R-squared	0.221	0.004	0.096	0.006	0.251
N	2493	2493	2493	2493	2493

* p<0.05, **p<0.01, ***p<0.001

Table 10: Correlation coefficients between $PM_{2.5}$ concentrations in µg/m^3 and the proportion of the population that meet examined variables, large, urban areas

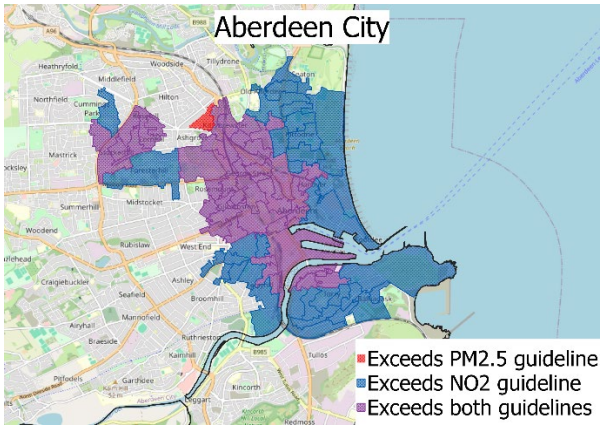
	Ethnic Minorities (excl. white minorities)	Income Deprivation	Mental Health Condition	Socially Rented Accommodation	Private Rented Accommodation
$PM_{2.5}$ Concentration	0.073***	0.020***	0.026***	0.065***	0.102***
	(0.00)	(-0.01)	(0.00)	(-0.01)	(-0.01)
Constant	-0.196***	0.05	0.01	-0.064	-0.295***
	(-0.02)	(-0.03)	(-0.01)	(-0.05)	(-0.03)
R-squared	0.083	0.005	0.044	0.013	0.077
N	2493	2493	2493	2493	2493

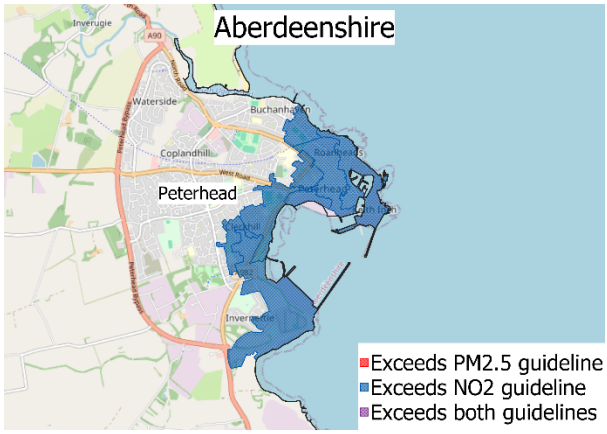
* p<0.05, **p<0.01, ***p<0.001

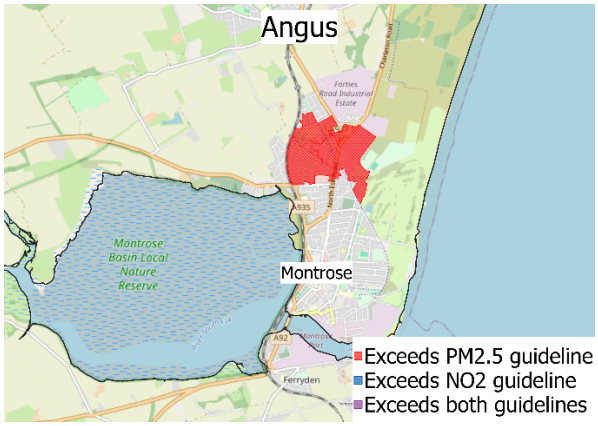
Annex 2: Summary statistics on annual mean concentrations, populations living in areas that exceed WHO limits, and annual mean concentrations by source

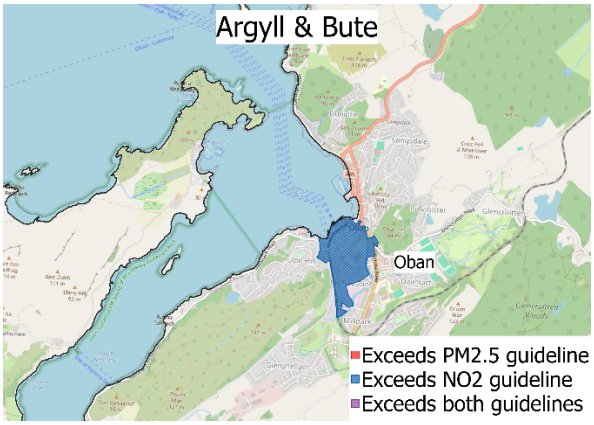
See attached excel document

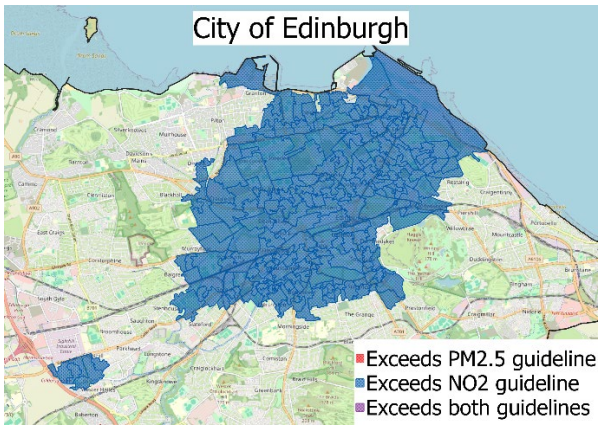
Annex 3: Maps of data zones which exceed WHO NO_2 or $PM_{2.5}$ guidelines

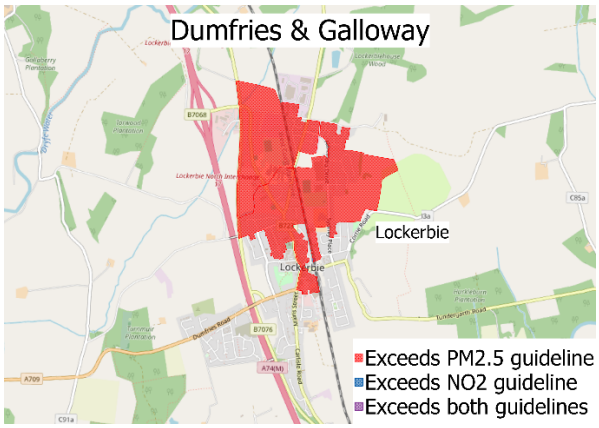


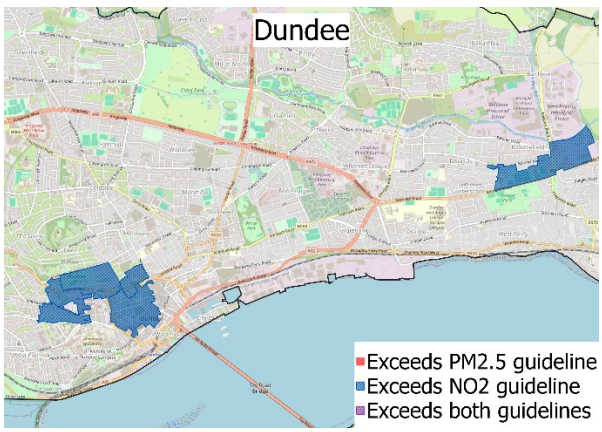


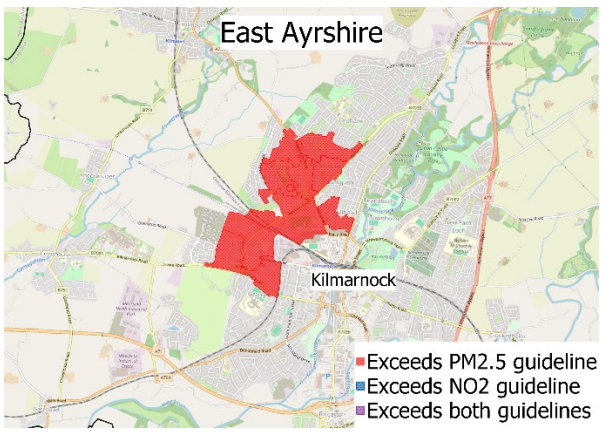

Angus
Montrose
Montrose Basin Local Nature Reserve
Ferryden
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

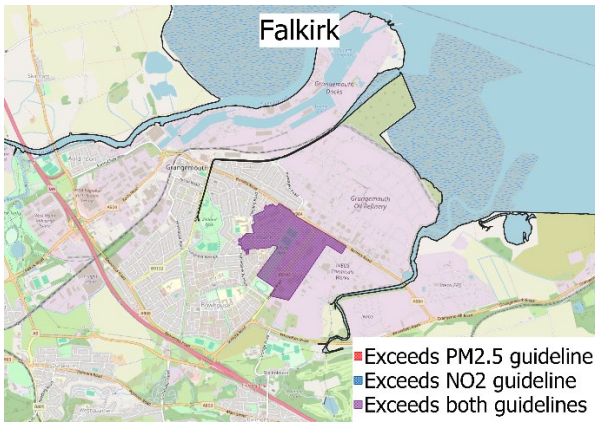

Argyll & Bute
Oban
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

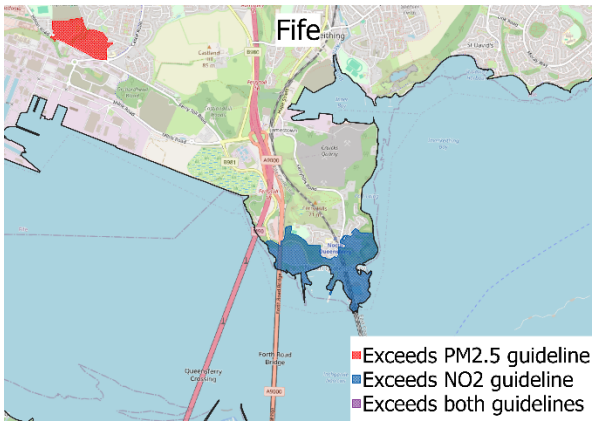

City of Edinburgh
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

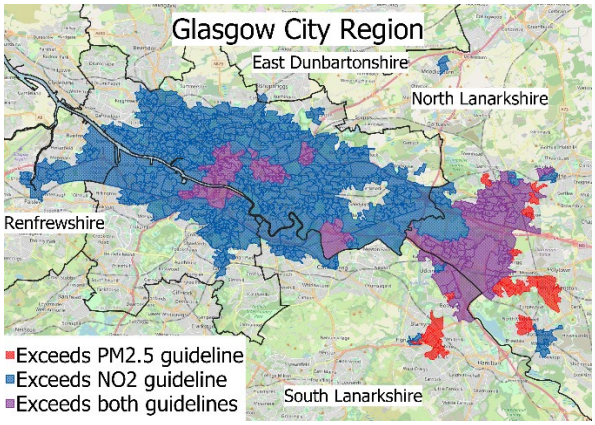

Dumfries & Galloway
Lockerbie
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

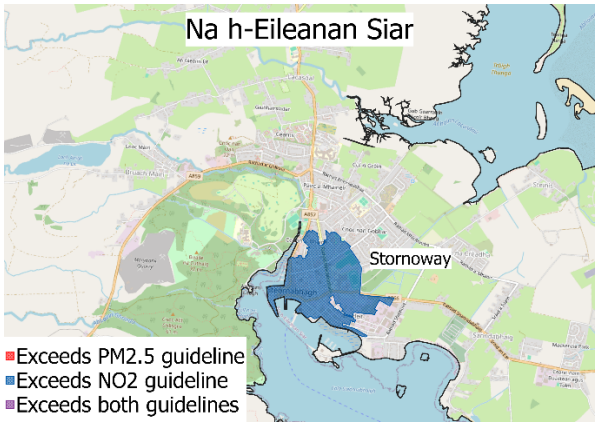

Dundee
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

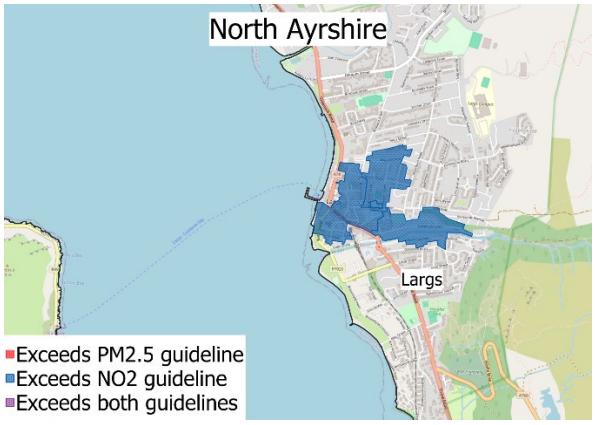

East Ayrshire
Kilmarnock
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

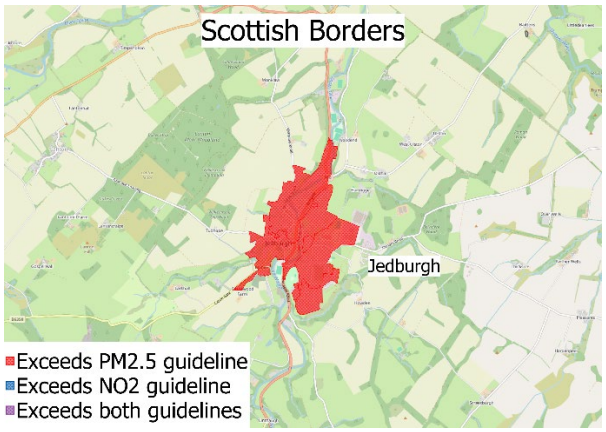

Falkirk
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

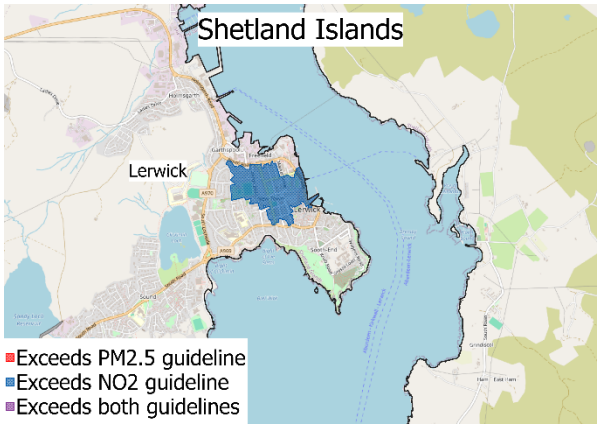

Fife
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

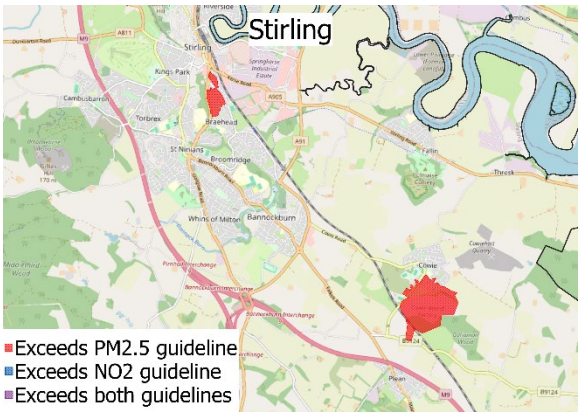

Glasgow City Region
East Dunbartonshire
North Lanarkshire
Renfrewshire
South Lanarkshire
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines

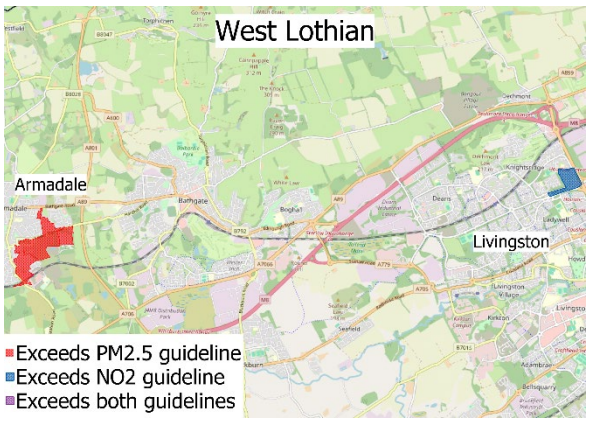

Na h-Eileanan Siar
Stornoway
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines


North Ayrshire
Largs
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines


Scottish Borders
Jedburgh
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines


Shetland Islands
Lerwick
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines


Stirling
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines


West Lothian
Armadale
Livingston
Exceeds PM2.5 guideline
Exceeds NO2 guideline
Exceeds both guidelines