Transport for the North

Transport, health and wellbeing in the North of England

Final Report

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Executive summary

This project looked at quantitative evidence on transport, health and wellbeing in the North of England

- Transport for the North (TfN) commissioned Cambridge Econometrics (CE), with Cavill Associates, to improve understanding of how transport affects health and wellbeing in the North of England.
- The purpose of this work was to shed light on the various transport impacts to inform: the further development of TfN's Strategic Transport Plan (STP), TfN's Decarbonisation Strategy, and TfN's capacity to analyse the impacts of transport in the North.
- The project considered ten areas (impacts) in which transport might affect health and wellbeing, with:
  - a review phase to: establish the state of the evidence base on each of those impacts, supported by expert consultations to augment the evidence base and our understanding of the causal relationships
  - the development of an impact framework with which to take the evidence and show whether and how it might be combined to inform quantitative assessment

A portion of the evidence base is amenable for quantitative analysis…

- The review phase identified three tiers of evidence:
  1. Evidence supported by a body of robust quantitative data permitting further analysis: these were taken forward into the quantitative analysis presented in this report – physical inactivity, incidents and safety, green space and noise pollution.
  2. Evidence supported by quantitative data but with weaker or less conclusive results, possibly with more complex causal chains and/or data limitations for analysis: one of these was taken forward for quantitative analysis and another, severance, was tested as a small example case to see if there might at least be some way to identify potential risk of social disconnectedness.
  3. Evidence on the likely direction and scale of the effects but little in the way of concrete evidence with which to carry out any quantitative analysis: user experience, access to healthcare, access to employment and environment quality.

…but other elements of the framework lack both evidence and data

- The impact framework sets out the evidence base as a whole but also a summary of the evidence most useful for quantification. In cases in which quantification is currently possible, we put forward recommendations and analysis to show how the framework can be applied. For impacts which cannot (currently) be assessed, the focus is more on limitations and how data gaps might need to be addressed.

Results

- Road transport is notable in its detrimental impacts on health, especially in the form of:[1]

[1] The analysis in this part of the report was only able to consider road transport as a whole, rather than isolating public from private transport.

  - safety i.e. accidents, especially on A roads
  - air pollution, especially in the form of nitrogen dioxide (NO_2) and particulate emissions, which raise the risk of hospitalisation and mortality much more than the other pollutants considered
  - noise, as a source of stress that raises the risks of coronary heart disease, hypertension and depression
- Our analysis shows the availability of walking and cycling routes for exercise and of parks in urban areas, highlighting that these routes should be promoting activity for those in the vicinity and that the impacts of parks are positive small.
- In terms of green space more generally, lower availability in urban centres (here, with a focus on Manchester) may have distributional implications given the tendency for people living in those centres to be younger.
- Proximity to green space appears to confer relatively widespread benefits with respect to psychosocial distress. Green space also appears to help reduce the risk of type 2 diabetes though these benefits are much less likely to be in urban centres.

Future directions

- The analysis in this report shows what is currently possible given the available evidence (knowledge of how transport affects health and wellbeing) and the availability of data with which to carry out an assessment. There remain various areas TfN might wish to explore more deeply to expand their ability to analyse health impacts. This specifically concerns: more consideration of access/use rather than simply proximity; and the context-specific nature of traffic incidents (as below). Broader evidence gaps concern access to healthcare and employment, the effects of severance, and user experience.
- Distinguishing between proximity (access/use in principle) and actual access/use is a key challenge for better understanding physical inactivity and green space. Currently proximity is the typical surrogate for usage and exploration of usage and its determinants (or, put another way, barriers) would be valuable.
- The context-specific nature of traffic incidents also makes it challenging to say much in detail because identifying the upstream effects hinders downstream analysis. It is likely that this strand of work would require more detailed and sophisticated prior modelling to augment a health assessment.
- Otherwise, given the presence of impacts of interest but which are lacking evidence and/or data, there are various ways in which further research will be needed to generate more robust analyses and, in time, link them to (possibly new) datasets to shed light on issues of importance such as access to healthcare and employment, severance and user experience.

Executive Summary Table 1: Summary of the estimated number of people at risk, by transport-related health impact and geography

Impact category	Impact	Geography analysed	Estimated number of people at risk in geography ('000s)
Physical inactivity	Lower walking and cycling activity	Greater Manchester	163
Incidents and safety	Number of traffic casualties	The North	33*
Air pollution	Higher risk of mortality from nitrogen dioxide		5,880
	Higher risk of mortality from PM_{10}		5,850
	Higher risk of mortality from $PM_{2.5}$		5,640
Limited access to green space, recreation and leisure	Higher risk of type 2 diabetes		9,720
	Higher risk of psychosocial distress		200
	Lower self-rated general health		5,750
Noise pollution	Higher risk of hypertension		2,500
	Higher risk of coronary heart disease		2,500
	Higher risk of depression		2,500

Note(s): * This number does not represent those at risk of traffic incidents but the number of traffic casualties in the North for 2019.
We did not calculate the number of people at risk for physical activity and subjective wellbeing from proximity to parks and severance.
For air pollution, only the three most harmful pollutants were considered.
Source(s): Cambridge Econometrics analysis.

1 Introduction

This project considered the impacts of transport on health and wellbeing in the North of England

Transport for the North (TfN) commissioned Cambridge Econometrics (CE), with Cavill Associates, to improve understanding of how transport affects health and wellbeing in the North of England.

The purpose of this work was to shed light on the various transport impacts to inform: the further development of TfN's Strategic Transport Plan (STP), TfN's Decarbonisation Strategy, and TfN's capacity to analyse the impacts of transport in the North.

The rest of this report is structured as follows:

- Chapter 2 sets out our approach to the project
- Chapter 3 summarises the findings of the evidence review on how transport affects health and wellbeing
- Chapter 4 explains the impact framework by which transport impacts can be related, quantitatively, to health and wellbeing
- Chapter 5 presents the results of quantitative analysis from applying the impact framework
- Chapter 6 offers concluding remarks about the work and directions for future analysis

As well as full references (in Chapter 7), the report has various appendices that provide further information from the evidence review including the system maps developed during the first part of the work (Appendix A), a summary of the expert consultations (Appendix B), and a listing of other economic assessment tools in use (Appendix C).

2 Approach

The work was divided into an evidence review phase, and then an impact framework / analysis phase

We divided the project into two phases:

4 an evidence review (led by Cavill Associates) to assemble system maps of the channels by which transport could affect health and wellbeing

5 the development of an impact framework to operationalise the causal chains (evidence-/data-permitting) and quantitative analysis to illustrate these impacts in the North of England (both led by CE)

These phases of the work correspond to the next three chapters of this report:

- Chapter 3 summarises the findings of the evidence review from Phase 1
- Chapter 4 sets out the impact framework subsequently developed, as the first part of Phase 2
- Chapter 5 goes on to present the results of the data analysis using the impact framework, as the second part of Phase 2

The following sections set out the approach to each part.

2.1 Evidence review (Chapter 3)

The evidence involved three tasks:

1 a literature review

2 a system mapping exercise

3 a series of expert interviews to augment the system maps and the literature assessed

The literature review (review of reviews) built on earlier work by TfN

TfN had previously conducted a high-level review of the main ways that transport influences health. This review identified ten impacts of transport on health and wellbeing. This prior review was taken as a starting point for a search for the best available and most up-to-date data and evidence on each impact. This search focused on reviews, synthesised evidence and high-level reports from authoritative sources (a review of reviews). Primary search engines were PubMed and Google Scholar, using search terms designed to identify as wide a range of relevant reviews as practicable (for example, including ‘review’ and ‘health’ in each search along with the specific topic). These searches were supplemented with data and evidence identified through expert consultation. This is an efficient search method that is able to identify key literature in ways that approach the sensitivity of formal systematic reviews, which were not possible given the time and resource constraints of this project.

Initial search results were screened to identify the reviews that provided direct quantitative evidence of the links between transport and the specified health outcome(s).

This literature review produced two main outputs:

- a detailed summary of the quantitative evidence and references
- a systems map showing the connections between aspects of transport and health outcomes (see Appendix A)

Expert consultation augmented and refined the evidence review

The outputs of the literature review were then used to frame interviews with thirteen leading transport and health experts identified by the team to cover the topics under consideration (see Appendix B). These interviews were 30-60 minutes long, conducted on Zoom, and attended by both Nick Cavill and Harry Rutter, and the expert consultee. These discussions were semi-structured and focused on two main tasks:

1 Reviewing and updating the systems map, adding in new issues and connections where appropriate. These were added to the map during the interview i.e. in real time (using Kumu mapping software and screen-sharing). In the first part of the discussion, any issue that could be considered to be associated with health outcomes was included, whatever the level of evidence.

2 Identifying evidence and data sources that support these transport-health connections, with a focus on quantitative evidence that might be used for an eventual assessment method.

It is important to note that this review did not consider the impacts of the transport system on carbon emissions and climate change more generally, as this issue is covered in other aspects of TfN's modelling. Acknowledging this, the importance of emissions and climate change as having an effect on health and wellbeing was highlighted through the consultation process.

Chapter 3 of the report provides a summary of the evidence reviewed during this first part of the work. As that chapter shows, not all evidence was considered robust enough to support further quantitative assessment.

2.2 Impact framework (Chapter 4)

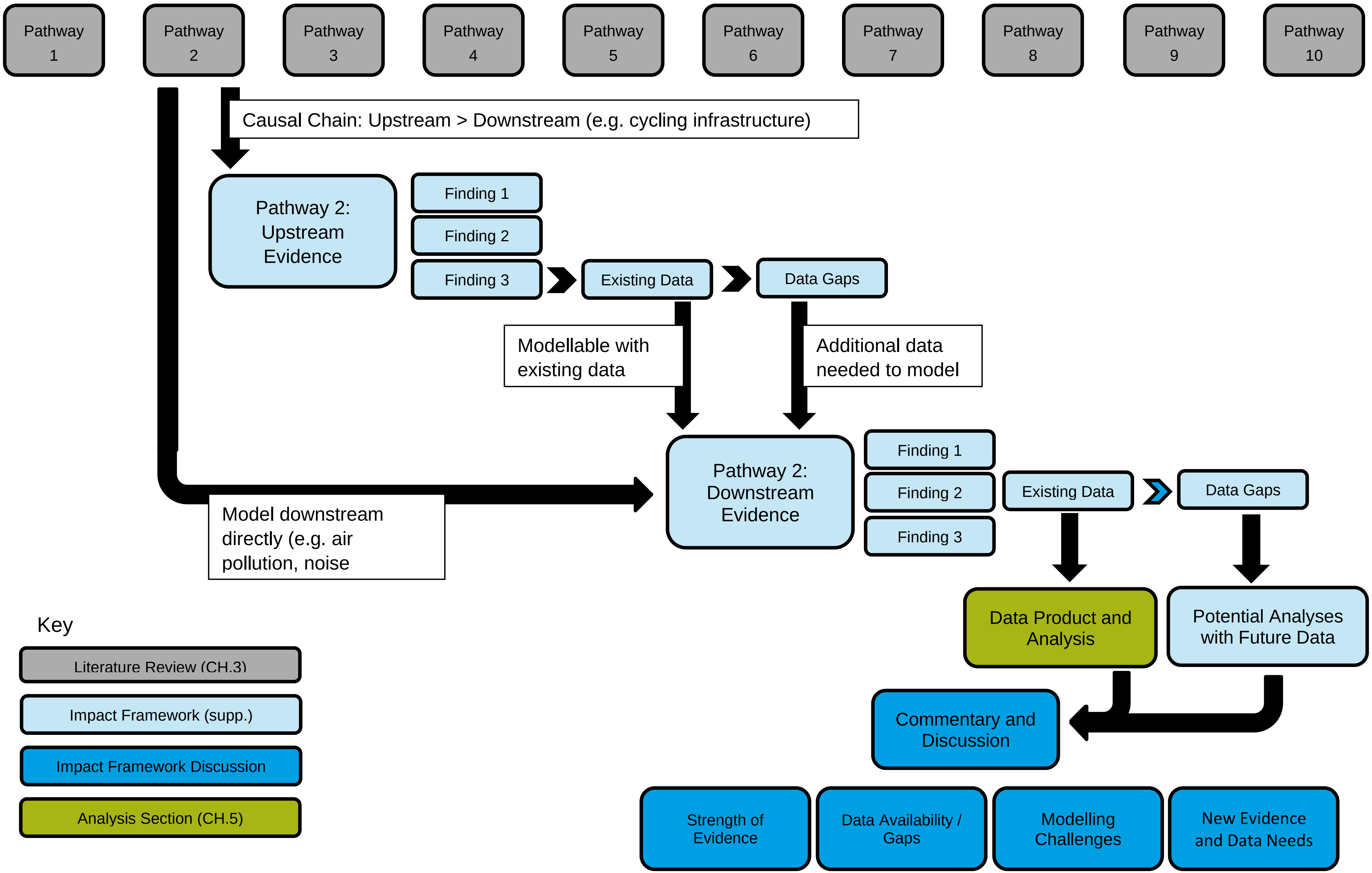
The impact framework uses the evidence base in a way that seeks to establish relevant causal links

While the focus of the evidence review was on what the available literature has to say about the links between transport and health/wellbeing, it is not necessarily the case that this leads immediately to a framework with which to assess the impacts of transport on health and wellbeing.

The purpose of the next step was to develop an impact framework that could operationalise the evidence in a way that could reasonably inform quantitative assessments for TfN's purposes. The focus was to develop the causal chains and evidence in a way that could more clearly establish an impact logic.

The starting point was the evidence base and thinking from the first phase, with the impact framework then assembled by situating that evidence in a causal chain with upstream (causes) and downstream (impacts) effects. From this, we could then consider the data requirements to assess these impacts. Comparisons to the availability of (good quality / appropriate) data then informed the final set of feasible impacts, with commentary/discussion about data gaps that might need to be filled to make other aspects of the impact framework viable.

Figure 2.1: Flow Chart from Evidence to Impact Framework



For each impact, the final impact framework consists of:

- an explanation of the impact logic, extending the causal chains from the evidence (by Chapter 3) and distinguishing upstream from downstream effects
- identification of data requirements to fill the impact framework, alongside an assessment of the extent to which the available data (as part of a data review) support such analysis
- discussion of challenges and data gaps for aspects of the impact framework that cannot (yet) be deployed

Chapter 4 sets out the impact framework with various tables that identify the effects and data requirements/availability. An accompanying spreadsheet consolidates this information, with further technical detail for reference.

2.3 Analysis (Chapter 5)

We also present the results of analysis that makes use of the impact framework

Having stepped through from evidence base to an impact framework, Chapter 5 of this report presents the results of applying that framework.

The principal outputs of this final part of the work are a set of datasets (GIS data layers / shapefiles) to inform future analyses of transport and health/wellbeing. As a demonstration of the approach, Chapter 5 presents elements of the GIS layers to show how they can be used to assess transport-related health and wellbeing effects across the North.

Details of each piece of analysis are covered in Chapter 5 but the general approach has been to:

1. use the evidence and available data to construct estimates of the 'footprint' (spatial distribution) of a health/wellbeing effect e.g. the health risks associated with certain air pollutants and how those risks vary across the North according to pollutant concentration
2. overlay this footprint of effects on to some spatial representation of the population that might be affected, to estimate the overall impacts

By making this distinction between *where the effects are*, and *how they have impacts on the population of the North*, the goal was to make, for example, the distinction between high-pollution zones with relatively small resident populations (high risk but low impact/burden) from medium-pollution zones but with very many people living there (medium risk but high impact/burden due to the number of people affected).

We note in some cases that certain kinds of effect can only be reasonably considered in certain parts of the North e.g. in cases in which the underlying literature only concerns cities, or certain impacts (e.g. of green space) in which largely rural areas may be saturated. In such situations we narrow the analysis to more meaningful areas/units of interest.

3 Evidence review

This chapter assesses the evidence on links between transport and health/wellbeing

This chapter summarises the findings from the evidence review of the connections between key aspects of transport and health outcomes. These are presented below on an impact-by-impact basis. This exercise also produced a system map connecting the various causes and effects across the piece. This can be found in Appendix A.

The evidence review focused on ten impacts, which were originally identified and assessed in earlier work by TfN. This original list set the constraints of the review and, while the expert consultation did identify other impacts, none of these additional effects were deemed to be supported by sufficient quantitative evidence to warrant extending the list from the original ten.

The results below summarise the findings from the literature review and expert interviews. They also incorporate helpful comments received from TfN colleagues and wider stakeholders on an earlier draft.

The results that follow are presented in priority order, according to the importance and scale of the health impacts for each topic, as well as the extent of evidence and availability of data for quantitative modelling purposes. This is also based on wider evidence of the health impacts of transport: for example Woodcock *et al*. (2013) found in their modelling study that 'the pathways that produced the largest benefits were, in order, physical activity, road traffic injuries, and air pollution'.

The review identified three tiers of evidence that vary according to robustness of the quantitative findings and their amenability for further analysis

The prioritisation also divides the impacts into three tiers of evidence, that reflect the extent to the various impacts might be amenable to quantitative assessment and modelling. The three tiers, in descending order of amenability are:

1 Evidence from the literature and expert interviews is supported by sufficient quantitative data and robust analysis for it to be possible to characterise the identified relations with high levels of confidence (four impacts).

2 Evidence from the literature and expert interviews is supported by sufficient quantitative data to estimate the strength of the relationship. However, either the data were insufficiently comprehensive, or econometric results were not strong enough, for this to be characterised as a robust result (three impacts).

3 Evidence from the literature review and export interviews provides insight as to the direction, approximate scale, and nature of the relationship between two or more variables; however no attempt to quantify this has yet been made (three impacts).

Table 3.1 summarises these tiers and the various impacts.

This part of the assessment only considered the quantitative evidence for relationships between transport and health/wellbeing as presented in the literature i.e., on its own terms. As such, the feasibility of translating the evidence into a useable set of causal chains and numerical values still depends on the availability of the necessary data for the North.

Table 3.1: Summary of evidence

Tier	Impact	Considerations	Main source(s) of evidence
1	Physical inactivity	Converting active travel into volume of physical activity Cycling and walking are directly correlated with all-cause mortality, when controlled for leisure time physical activity Detailed data on active mode networks	Kelly *et al*. (2014) Zheng et al. (2009) Goodman et al. (2014) Sallis *et al*. (2016)
	Incidents and safety	Measuring speed and volume of traffic Developing a multi-coefficient model for more accurate prediction (or using a single coefficient model with more limited power to explain)	Hussain *et al*. (2019) Roshandel *et al*. (2015)
	Air pollution	Measurements e.g. particulate matter, nitrogen oxides Isolating the emissions arising from traffic	Hoek *et al*. (2013) Requia *et al*. (2018)
	Limited access to green space, recreation and leisure	Modelling access, rather than proximity Translating access to use Measuring quality	Twohig-Bennett and Jones (2018) Houlden *et al.* (2018) Astell-Burt *et al.* (2014)
2	Noise pollution	Identifying the nature and distribution of exposure Upstream modelling: Forecasting noise	Münzel, Sørensen *et al*. (2018) Babisch (2014) van Kempen and Babisch (2012) Seidler *et al.* (2017)
	Severance	Quantifying severance Translating lost connections into health outcomes Quantifying severity of barriers such as roads based on their characteristics	Anciaes (2013)
	User experience	Quantifying active travel and public transport use	Kelly *et al*. (2017)
3	Limited access to healthcare facilities	Lack of evidence linking transport access and health outcomes	-
	Limited access to high-quality employment	Lack of evidence linking transport access and employment	-
	Environment quality	Lack of evidence linking transport access and environment quality	-

Note(s): Tier 1 - Evidence from the literature and expert interviews is supported by sufficient quantitative data and robust analysis for it to be possible to characterise the identified relations with high levels of confidence.
Tier 2 - Evidence from the literature and expert interviews is supported by sufficient quantitative data to estimate the strength of the relationship. However, either the data were insufficiently comprehensive, or econometric results were not strong enough, for this to be characterised as a robust result.

Tier 3 - Evidence from the literature review and export interviews provides insight as to the direction, approximate scale, and nature of the relationship between two or more variables; however no attempt to quantify this has yet been made.

Expert consultations

Before presenting the summaries by individual impact, we first summarise more general feedback by consultees, which augmented the exercise below. A summary of points discussed by interviewee can be found in Appendix B. A few points of note:

- Internal reviewers (i.e. contacts of TfN, not the consulted experts) raised a number of very pertinent issues regarding additional evidence for the health impacts of transport. Where possible they have been considered here but many of these were supported only by single studies rather than review-level evidence, so have not been included.
- A number of consultees were uncomfortable with producing a system map of transport and health without considering the impact on carbon emissions and climate change (which do of course have very important health impacts). It is understood however that TfN addresses carbon impacts in other parts of its transport models.
- A similar issue arose with biodiversity: road transport is likely to be associated with reductions in biodiversity both as more land is taken up by roads and through surface contamination, run-off, and other forms of pollution. This will have long-term negative health impacts.
- One consultee thought it was inappropriate to separate out access to employment and healthcare and not to also include access to education. Travel to school has different patterns and determinants to other forms of travel; has a great deal of policy focus; and is likely to influence future travel patterns.
- One consultee had been co-author of a high quality review of ‘Fourteen pathways between urban transportation and health’. This provided a valuable cross-check to the issues raised in this review. It did however raise some additional topics that may influence health:
    - urban heat islands: this is seen to be currently an issue of low importance in the UK (but may become increasingly important as the climate changes)
    - greenhouse gases: see above comment
    - contamination: this may be an issue worthy of consideration and relates to chemicals and pollutants that can be found on roadway surfaces due to motor vehicle traffic, as a result of road surface, brake, and tire wear – these chemicals and pollutants can contaminate water sources, soils, and air, which pose significant threats to humans and the environment. The consultation highlighted this issue's importance, leading to its inclusion in the system map, but there is currently insufficient evidence to allow it to be quantified and therefore included in the final impact framework.
- It was particularly encouraging that Dr Francesca Racioppi described a hierarchy that was almost identical to Table 3.1 (without having seen this draft report). She has been working closely on the WHO HEAT tool for over ten years, along with other economic models (see Appendix C) (World Health Organization, 2022). The HEAT covers physical activity, road traffic injuries, air quality and carbon. She considered the next ‘candidates’ for inclusion in the HEAT to be green space and traffic noise.

3.1 Physical inactivity

For physical activity, there is solid evidence on the health benefits of walking and cycling

There is a strong evidence base on the health benefits of physical activity. In adults, there is robust evidence to demonstrate the protective effect of physical activity on a range chronic conditions, including coronary heart disease, obesity and type 2 diabetes, breast and colon cancer, mental health problems, and other health-related issues including social isolation and risk of falls (Department of Health and Social Care, 2019).

High levels of car use are linked with lower levels of physical activity and higher rates of obesity, especially where car use replaces short walking journeys. Walking and cycling for transport provides sufficient health benefits to achieve recommended physical activity levels in most people: for adults, 150 minutes per week of moderate intensity physical activity (MPA) or 75 minutes of vigorous intensity physical activity (VPA), for children and young people, at least 60 minutes of moderate-to-vigorous physical activity (MVPA) per day across the week (Department of Health and Social Care, 2019).

Incorporating physical activity into daily life – primarily through walking and cycling as transport (in contrast to promoting deliberate exercise or sport) – has been consistently recommended as a public health strategy and has been shown to be an effective intervention, recommended by NICE (National Institute for Health and Care Excellence) (2012). Infrastructure for cycling and walking has been shown to be associated with reduced health inequalities (National Institute for Health Research, 2022). A 2014 study evaluating the impacts of a newly-built walking and cycling path in the UK found that proximity to the path was associated with more minutes of physical activity per week (Goodman *et al*., 2014).

Additionally, access to parks, especially within urban contexts, has a relationship to physical activity. A 2016 study of individuals across 14 different global cities found that the density of parks near residences in urban areas is linearly associated with an increase in daily minutes of moderate to vigorous physical activity (Sallis *et al*., 2016).

Robust evidence for the quantitative relationship between physical activity and mortality is provided by Kelly *et al*. (2014). Most helpfully, this focuses specifically on walking and cycling, and controls for other forms of physical activity. This means that (in theory at least) their analysis isolates the contribution of walking and cycling to decreased mortality, making the evidence particularly useful for modelling. The study was conducted specifically to provide quantitative input to the World Health Organization's (WHO's) Health Economic Assessment Tool (HEAT) for walking and cycling (World Health Organization, 2022). Kelly *et al*. (2014) report that, for a standardised dose of 11.25 metabolic equivalent of task (MET)[2] hours per week (or 675 MET minutes per week), the reduction in risk for all-cause mortality was:

- 11% (95% CI: 4-17%) for walking

[2] The amount of energy expended in a task relative to sitting at rest, which has an MET of 1. Moderate intensity cycling as an MET of approximately 8, so uses 8 times the energy of sitting at rest. Walking at normal speed on a level surface has an MET of around 3.5

- 10% (95% CI: 6-13%) for cycling

3.2 Incidents and safety

Road traffic injuries are context-specific, with the clearest relationship being to traffic speed

The WHO reports that, every year, the lives of approximately 1.3m people are cut short globally as a result of a road traffic crash. Between 20m and 50m more people suffer non-fatal injuries, with many incurring a disability as a result of their injury (World Health Organization 2021).

Road traffic injuries cause considerable economic losses to individuals, their families, and to nations as a whole. These losses arise from the cost of treatment as well as lost productivity for those killed or disabled by their injuries, and for family members who need to take time off work or school to care for the injured. Road traffic incidents cost most countries 3% of their GDP each year (World Health Organization, 2021a).

There is a wide variety of quantitative evidence to describe the nature, prevalence, and severity of road traffic injuries. For example Ang *et al*. (2017) report that 14% of older adults suffer from a road traffic incident, with mortality rates highest among the very elderly adults aged 74 years and above, and pedestrians. Risk to pedestrians is underlined by Charters *et al*. (2017) who report that pedestrians account for a high proportion of overall road traffic fatalities in high-income countries, with pedestrians admitted to hospital twice as likely to die of their injuries than vehicle occupants. There are significant inequalities in road traffic injuries in the UK with children and people from more deprived neighbourhoods disproportionately affected: The Killed or Seriously Injured (KSI) rate per 100,000 population for pedestrians aged 10-14 is approximately 2.6x higher in the most deprived quintile than in the least deprived (30 and 11 respectively). For pedestrians aged 5-9, the most deprived KSI rate is 6x higher than the least deprived rate (18.6 and 3.3 respectively). Among cyclists aged 10 to 14, the KSI rate between 2012-16 was 7.0 KSI in the most deprived quintile of areas compared to 4.2 in the least deprived (public Health England, 2018b).

Some areas of the UK have adopted the Vision Zero approach to road safety (Transport for London, 2021). This approach is common in much of Europe and involves encouraging safe behaviours and designing vehicle and infrastructure to reduce risks.

It is important to note that the risk of a road traffic crash is highly context-specific, making an input into modelling quite challenging. Multiple factors such as collision speed, speed difference, traffic volume and density predict the probability of a collision taking place (Roshandel et. al., 2015).

3.3 Air pollution

Air pollution is a major risk factor for premature mortality

In the WHO global burden of disease study, air pollution was ranked fourth as a risk factor for premature mortality, exceeded only by hypertension, smoking and dietary risks. Among environmental risk factors, ambient air pollution was the most important cause of disease, leading to more than 4m premature deaths and more than 100m disability-adjusted life years lost annually worldwide. In 2021, at the launch of new WHO global air quality guidelines, air pollution was called ‘one of the biggest environmental threats to human health, alongside climate change’ (World Health Organization, 2021b).

Transport-related air pollution contributes to an increased risk of death, particularly from cardiopulmonary causes, with significant social inequalities in the distribution of the impacts (Barnes *et al*., 2019). It increases the risk of respiratory symptoms and diseases that are not related to allergies. While only a few studies have been conducted on the effects of transport-related air pollution on cardiovascular morbidity, they report a significant increase in the risk of myocardial infarction (heart attack) following exposure. Other studies and the experimental evidence indicate that exposure results in changes in autonomic nervous system regulation and increased inflammatory responses. The WHO International Agency for Research on Cancer has concluded that there is sufficient evidence that outdoor air pollution, including particulates, causes lung cancer to be classified as a carcinogen (Krzyzanowski et al., 2005; IARC, 2013). Of particular concern is exposure to particulates, notably $PM_{2.5}$ and PM_{10} [3], especially in areas of housing or schools near busy roads.[4]

Particulates and nitrogen dioxide have the highest health risks

Quantitative evidence is provided by a number of reviews of epidemiological studies. Hoek *et al*. (2013) reports an excess risk per 10 µg/m^3 increase in $PM_{2.5}$ exposure of 6% (95% CI 4-8%) for all-cause and 11% (95% CI 5-16%) for cardiovascular mortality. Long-term exposure to $PM_{2.5}$ was more associated with mortality from cardiovascular disease (particularly ischemic heart disease) than from non-malignant respiratory diseases (pooled estimate 3% (95% CI -6-13%).

Requia *et al*. (2018) report that people aged 65+ showed the highest mortality risk for PM_{10}, whereas the youngest age group demonstrated the highest risk for ozone (O_3). There are no studies reporting association between children (aged <5 years) and the pollutants $PM_{2.5}$ and SO_2.

Hoek *et al*. (2013) found respiratory diseases to show the highest risk for:

- PM_{10} (1.3%; 95% CI: 0.9-1.7%)
- $PM_{2.5}$ (2.7%; 95% CI: 0.9-7.7%)
- O_3 (0.8%; 95% CI = 0.2%, 2.3%)

whereas cardiovascular diseases demonstrated highest risk for:

- SO_2 (1.1%; 95% CI: 0.8-1.6%)
- NO_2 (1.6%; 95% CI: 1.2-2.2%)

[3] The subscripts of 2.5 and 10 refer to the fineness of these particulate matters – their diameters in micrometres (0.001 millimetres).

[4] And this is in addition to any other effects of road transport in such areas, including perceptions of safety and risks of social exclusion/isolation.

3.4 Limited access to green space, recreation and leisure

Evidence suggests that green space confers numerous health benefits

There is a strong and growing evidence base in support of the health benefits of green space. One direct pathway to health benefits comes from the extent to which natural and green areas promote health due to the opportunities for physical activity. In addition, there is evidence that exercising in a green environment may provide additional health benefits compared to exercising in an indoor gym environment. Public green spaces have also been associated with social interaction, which can contribute towards improved well-being, notably through improved mental health. Other benefits may come from exposure to sunlight (thought to counteract seasonal affective disorder, and by providing vitamin D); and exposure to a range of micro-organisms, including bacteria, protozoa and helminths, which are abundant in nature and may be important for the development of the immune system and for regulation of inflammatory responses.

Access to green space can be measured as either the proportion of green space within a certain distance of one's place of residence or as the number of parks or green spaces accessible nearby.

Quantitative evidence for the association between green space and health outcomes comes from a recent high-quality systematic review and meta-analysis (Twohig-Bennett and Jones, 2018). This provides strong evidence for a range of health outcomes due to green space exposure notably reduced risks of:

- all-cause mortality: 0.69 (95% CI: 0.55-0.87)
- type 2 diabetes: 0.72 (95% CI: 0.61-0.85)
- cardiovascular mortality: 0.84 (95% CI: 0.76-0.93)

as well as a range of cardiovascular and other risk factors.

A 2019 study from Australia found that the proportion of green space within a 1-mile (1.6-km) radius of one's place of residence is associated with significantly reduced risk of psychosocial distress (Astell-Burt & Fend, 2019). This same study also found that the proportion of tree canopy cover (a subset of green space) within a 1-mile radius of place of residence is associated with a lower risk of self-reporting fair or poor general health on a survey (*ibid*).

Additionally, a study in London found that living within 300m of green space has statistically significant wellbeing impacts. These are measured in 'Happiness', 'Life satisfaction' and 'Sense of worth', and depend on the area of accessible green space (Houlden *et al*., 2018).

This strong evidence for the association between green space exposure and health outcomes can be used for modelling purposes if the challenge is overcome of finding measures for green space exposure and use that can be related to transport interventions (rather than simply green space proximity). We were unable to find such evidence, but we did find data that would support such analysis if the evidence were to be found (see Section 4.4 and the supplementary impact framework tables)

3.5 Noise pollution

Noise generates stress which can lead to both physical and mental ill-health

Traffic noise exposure is linked to cardiovascular diseases such as arterial hypertension, myocardial infarction, and stroke. Chronic low levels of noise can cause disturbances of activity, sleep, and communication, which can trigger a number of emotional responses, including annoyance and subsequent stress. In turn, chronic stress is associated with cardiovascular risk factors such as increased blood pressure and dyslipidaemia[5], increased blood viscosity and blood glucose, and activation of blood clotting factors. Persistent chronic noise exposure increases the risk of cardiometabolic diseases, including arterial hypertension, coronary artery disease, diabetes mellitus type 2, and stroke (Münzel, Sørensen *et al*., 2018).

Quantitative evidence is provided by a range of sources, many of which were associated with the 2018 WHO noise guidelines. Babisch (2018), in a meta-analysis on the relationship between road traffic noise and coronary heart disease, found that the risk of coronary heart disease increased by 8% for each additional increment of 10 decibels (dB) of road traffic noise between 55dB and 75dB. A similar meta-analysis on the relationship between road traffic noise and hypertension found the risk of hypertension increase by 3.4% for each additional 5dB of road traffic noise between 45dB to 75dB (van Kempen & Babisch, 2012). A 2017 study with data from Germany found a relationship between both road and rail traffic noise and depression, with the relationship being linear for road traffic noise and u-shaped for rail traffic noise, likely because of the small subset of sample households exposed to higher levels of rail traffic noise (Seidler *et al*., 2017).

3.6 Severance

While the relationship between transport and severance is recognised, evidence on the precise health effects is less clear

Community severance occurs where speed and volume of road traffic inhibit access to goods, services, or people. This can occur directly (i.e. through an inability to cross busy roads) or due to reduced perceptions of safety. There is evidence that strong social networks are associated with healthy behaviours and improved health, with high levels of social integration associated with reduced mortality (with an effect size of similar magnitude to stopping smoking) (Mindell and Karlsen, 2012). However, the evidence for a direct quantifiable relationship between transport-related severance and outcomes in terms of either health or social networks has not been established. Vaughan et al (2020) state that “Many publications assert that community severance affects health; while plausible, no study has examined this explicitly”. Mindell and Karlsen (2012) provide an excellent overview of the topic, concluding that ‘there is empirical evidence that traffic speed and volume reduces physical activity, social contacts, children’s play, and access to goods and services. However, no studies have investigated mental or physical health outcomes in relation to community severance. While not designed specifically to do so, recent developments in road design may also ameliorate community severance.’

[5] A broad term describing a number of conditions in which disturbances in fat metabolism lead to changes in the concentrations of lipids (e.g. triglycerides, cholesterol and/or fat phospholipids) in the blood and which is a risk factor for the development of cardiovascular disease.

There is little or no quantitative evidence to describe the relationship between severance and health outcomes. However, Anciaes *et al*. (2016) provide an interesting overview of how to value severance, which may be useful for modelling purposes. This includes ideas for measures of severance including ‘crossability’: how easy it is to cross a barrier (such as a road)?; ‘walkability’: Does the barrier reduce the ability to walk around an area?; ‘accessibility’: Does the barrier prevent people from reaching certain destinations?; and ‘quality’: Does the barrier reduce the quality of the walking experience?.

3.7 User experience

The evidence emphasises differences in experience by mode…

The primary function of transport is to reach a destination. However, the experience of the journey can differ between modes of transport: people in cars; on buses; or walking and cycling experience the same journey quite differently. There is good evidence linking travel mode choice to mental health and subjective wellbeing, particularly in the case of journeys for work, with car travel shown to be a significant contributor to user stress and anxiety, compared to active travel or public transport use. Shorter travel times in general improve wellbeing, with commutes lasting between 60 and 90 minutes having the biggest negative impact on wellbeing (Office for National Statistics, 2014).

The strongest quantitative evidence was found between active travel (walking and cycling) and psychological wellbeing. Martin *et al*. (2014) found significant associations between overall psychological wellbeing and:

1 active travel (0.185; 95% CI: 0.048-0.321) and public transport (0.195; 95% CI: 0.035-0.355) when compared to car travel

2 time spent (per 10-minute change) walking (0.083; 95% CI: 0.003-0.163) and driving (-0.033; 95% CI: -0.064 to -0.001)

3 switching from car travel to active travel (0.479; 95% CI: 0.199-0.758)

…but some conflict about a statistically significant relationship with depression

However, ascribing an economic value to overall psychological wellbeing is challenging. Incidence of depression is more amenable to valuation (as it is associated with high financial burden to the NHS and society) but quantitative evidence for an association with transport is conflicting: Marques *et al*. (2020) found two studies that related active travel to depression but five studies that found no significant association.

3.8 Limited access to healthcare facilities

Research has tended to focus on healthcare access, rather than outcomes

Variations in access to health services are clearly likely to be associated with health outcomes, particularly access to GPs, pharmacies, and hospitals. A number of studies explore variations in access to healthcare, but these are usually based on the assumption that this is associated with health outcomes i.e., the positive benefit is taken as given, rather than examined/quantified. Direct review-level evidence is rare: one review explored rates of heart disease and stroke mortality related to geographical location of healthcare services (in the USA) and found unequal access and unequal health outcomes for many priority populations (by ethnic origin; gender and geographical region). It is unclear if this can be applied to the UK’s health system. Access to healthcare (and other services) is also likely to be related to socioeconomic status, especially due to socioeconomic patterning of car ownership (half of all people in the lowest income quintile do not have access to a car).

3.9 Limited access to high-quality employment

Similarly, employment is understood as beneficial for health but the link from transport to health is little explored

Access to high-quality employment raises similar issues to access to healthcare: there is evidence from a wide range of sources (including systematic reviews) that links employment to positive health outcomes. For example, van der Noordt *et al*. (2014) conclude that 'employment is beneficial for health, particularly for depression and general mental health' while Hergenrather *et al*. (2015) state that 'unemployment and job loss were associated with poorer physical health. Employment and re-employment were associated with better physical health.' Other studies investigate links between the transport system and access to employment, reporting socioeconomic inequalities in access. However, there are no reviews that look at the direct quantitative relations between transport-related access to employment and health outcomes.

3.10 Environment quality

Intuitively, environment quality should have some bearing on health and wellbeing, but the literature remains quite sparse

It could reasonably be assumed that the nature and quality of the built environment has an influence on health through a number of mechanisms, notably: improvements to mental health and wellbeing (as discussed in the green space section); loss of green space due to road (and car park) building; providing environments for social interaction; or enabling active travel. It is only the last of these aspects that has been studied extensively: there is strong evidence for the influence that the nature of the built and natural environment has on rates of walking and cycling. For example, Van Cauwenberg (2011) shows the impact on walking and cycling of a wide range of factors including: walkability; residential density; land-use mix; presence of shops; access to services; walking and cycling facilities. However, there is no review that relates these components to quantifiable health outcomes.

4 Impact framework

This section sets out the approach to operationalising the evidence from the previous chapter. Covering each of the ten impacts in turn, we first outline the main findings of the evidence, and to which health outcomes they pertain, then include a discussion on how these may be used in modelling, the methodological and operational challenges and considerations in doing so, and the data requirements and data gaps that a modeller would face.

For the impacts that we have modelled in Chapter 5, we outline the reasons for our choices here: why we favoured using particular parts of the evidence to exemplify analysis over others. Often this is linked to data availability but in some cases, relates to selecting evidence that better conveys a range of approaches. For the impacts that we did not model we outline the evidence and/or data gaps that prevented this.

4.1 Physical inactivity

Physical activity is beneficial for health and fitness

The evidence is comprehensive and strongly supportive of physical activity being beneficial for health. Limited opportunities to engage in physical activity as a consequence of transport impediments is therefore an area that planning policy can add value by addressing.

The impact framework table for physical inactivity is shown as a sheet in the supplementary workbook, and summarises the evidence on impacts from the literature distinguishing, respectively, upstream causes (here, factors that influence the amount of physical activity people engage in, or their likelihood of engaging) from downstream impacts (the health outcomes of physical activity. The tables also summarise the data that would be needed to model these impacts ('Data requirements') alongside our assessment of which data are currently available for the current purpose ('Available data'). Within the evidence shown, there are systematic reviews which cite multiple studies and coefficients that could be used for modelling.

There is strong evidence of physical activity's beneficial effects on a range of health outcomes

Physical inactivity is judged to have Tier 1 evidence by our assessment framework (from Chapter 3). As is apparent from the supplementary impact framework table, there is strong evidence of physical activity's positive effects on mortality, obesity, fitness, and cardiovascular risk factors. The upstream evidence for physical activity is of three main types: proximity – or in some cases access – to infrastructure or places where physical activity takes place, such as green space or cycling tracks; the qualities of such infrastructure, such as safety and comfort; and interventions to encourage use, such as bike-share programs. The downstream evidence could be described as quantifying the numerous health benefits that come about as a direct effect of exercise.

Modelling is a two-stage approach with upstream causes and downstream outcomes

The approach to modelling impacts of interventions to encourage physical activity depends on the intervention but in most cases should include:

For the upstream:

- A buffer zone around the intervention. This buffer zone may be a simple straight-line boundary (Sallis *et al*., 2016), or may require modelling of access to the infrastructure via roads or footpaths (Goodman *et al*., 2014), or neighbourhoods included in a program (Fuller *et al*., 2013).

- Incorporating measures of the quality of the intervention, such as safety and comfort.
- Controlling for factors such as existing similar infrastructure. For example, attempting to isolate the health impacts of a stretch of active mode infrastructure without capturing the effects of other nearby infrastructure. (this is not covered in the impact framework)
- Translating the coefficients of likelihood of use, and/or amount of use into a dose to align with the downstream impacts.

For the downstream:

- Selecting health outcomes of interest and determining metrics that both align with the upstream and downstream coefficients and for which there are data.
- Quantifying the impact by calculating the number of residents within the affected zone(s), perhaps tightening the focus by also including prevalence of health conditions of interest in the affected area.

Challenges arise in aligning upstream and downstream coefficients

The evidence is more robust for the downstream effects, with more systematic reviews and clearer dose-response coefficients. While the upstream evidence is amenable to modelling, the challenge lies in aligning the coefficients of the upstream and downstream. For example, an increased number of minutes of physical activity or a proportional increase in physical activity needs to be translated into the metric used for downstream impacts, such as MET hours of cycling. Where outcomes fall into discrete ranges, such as 11.25 MET hours cited in Kelly *et al.* (2014), these ranges may be too wide to capture variation in the upstream effect (a constraint of the available data), meaning the granularity of existing data make it difficult to apply the evidence (which is robust) to the available data. This is mentioned in the analysis in Section 5.1.

Data gaps and challenges

Existing data on cycling infrastructure supports the basics of the upstream approach, but only the Greater Manchester cycling data has sufficient detail to incorporate infrastructure qualities, such as degree of segregation of cycling paths, and this is not to the level of detail cited in the evidence. Data on health outcomes are available from Fingertips and, in some cases ONS, but only go to the level of geographical detail of local authorities. The ideal infrastructure data for modelling the upstream would be similar to the Greater Manchester cycling infrastructure data but cover the whole North of England and would go beyond it in showing degree of safety of the lanes: segregation, smoothness, indications to traffic of separateness, and how far this is enforced. Additional evidence would further focus on people’s preferences to use cycling infrastructure based on these qualities.

Additional evidence that either expressed health outcomes in smaller bin widths (the bin width was 11.25 MET. Hours in Kelly *et al.* (2014)) or that incorporated a larger number of coefficients to predict more accurately a larger total amount of physical exercise (so the outcome size was large enough to span several bins) would also improve estimation.

Evidence for analysis

The strongest evidence on the health outcomes of physical activity can be found in:

- Kelly *et al.* (2014): Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship
- Zheng *et al*. (2009): A meta-analysis quantifying the dose-response of walking in reducing coronary heart disease risk
- Mueller *et al*. (2015): A systematic review - health impact assessment of active transportation

All of these studies have high methodological robustness and are amenable to modelling health outcome for a given amount/change in physical activity. However, these are downstream effects. For our analysis in Section 5.1, we also wanted to convey the upstream – the change in physical activity that would result from an environmental stimulus. For this we used:

- Goodman *et al*. (2014): A study measuring increased physical activity following the construction of active mode infrastructure in the UK
- Sallis *et al*. (2016), as cited in the systematic review by Gianfredi *et al*. (2021): A study assessing increased physical activity based on proximity to green space

These are not systematic reviews but have the advantage of quantifying upstream causal drivers of physical activity, which is useful for GIS modelling.

The first paper, Goodman *et al.* (2014), estimates the change in physical activity (walking and cycling) that results from newly-built infrastructure that pedestrians and cyclists can use for transport and leisure travel, and expresses its results in the form of coefficients that are amenable to spatial modelling against existing or planned infrastructure.

The second, Sallis *et al.* (2016), found that the density of parks near residences in urban areas is linearly associated with an increase in moderate to vigorous physical activity (MVPA).

We chose these two papers because of the availability of data and because they effectively convey some different approaches that have broader applicability for similar analysis: proximity to infrastructure and proportion of green space in a neighbourhood.

4.2 Incidents and safety

Road traffic incidents cause huge loss of life worldwide

The literature review cites statistics on how extensive are deaths and injuries globally from road traffic incidents (RTIs). The UK has one of the lowest rates of deaths from RTIs in the developed world. But variations exist between areas and, given the devastating impacts of RTAs, further insight into the causes and how to mitigate them is warranted.

The impact framework table for incidents and safety is shown as a sheet in the supplementary workbook and summarises the upstream and downstream evidence respectively. Here the upstream evidence concerns those factors affecting the risk of an RTI while the downstream evidence concerns the impacts of accidents in terms of mortality (including demographics) and physical and mental health impacts.

Speed, volume, density, and regulations affect crash likelihoods

The upstream evidence in the supplementary impact framework table includes systematic reviews and individual studies. The factors affecting the likelihood of a crash include traffic speed measures, traffic volume, and interventions such as speed cameras and traffic calming regulations. They also include coefficients that connect directly to outcomes, such as: speed increases the likelihood of a *fatal* crash (rather than increases the chances of a crash, combined with a separate coefficient for the chances of mortality from a crash). Downstream impacts in the supplementary impact framework table are not in the form of 'dose-response' coefficients as much as for the other impacts.[6] They include the prevalence of incidents, baseline mortality rates, the proportion of pedestrians involved, and mental health impacts from crashes.

Crash prediction is complex and should be approached with caution…..

The upstream evidence on this impact includes coefficients on speed, density, and volume. But crash forecasting is complex and more involved than isolated coefficients might suggest. Causal factors in crashes are numerous and arise from factors including behavioural, vehicle-specific, traffic conditions, road geometry, and weather conditions. Of these, behavioural factors are thought to be most important but are least amenable to data collection (Roshandel *et al*., 2015). Data are readily available on traffic conditions and a focus in the literature has been on which combination of traffic conditions are more crash prone (*ibid*). The traffic-based coefficients cited in this impact framework should therefore be contextualised as 'other things equal', and used to model changes in that upstream variable in isolation rather than as part of a multi-coefficient model with multiple and possibly interacting effects. Such a full prediction model would be more in the realm of specialists and beyond the scope of this work (to consider existing evidence as it might apply to the North).

…further research is needed for a comprehensive approach

Because the risks of road traffic crashes are highly context-specific, forecasting them using available evidence and data with any accuracy is quite challenging. A modeller would first need to be cognisant of the limits of any forecast. They might then proceed by forecasting likelihood of a crash perhaps using isolated upstream coefficients, such as traffic density, and frame estimations in the form of "Were density to reduce by x%, other things equal,

[6] That is, where the dependent variable changes by a number of units in response to a change in the independent variable.

we would expect the likelihood of a crash to reduce by y%". A more robust approach would be to develop a multivariate crash forecasting model using multiple upstream coefficients, such as traffic speed combined with traffic volume, but further research would be needed to achieve this, as we did not find such a complete model in the evidence. Both approaches should note the previously stated caveats, that crashes are highly context-specific and traffic characteristics are only part of the picture.

With the isolated or a multivariate model, analysis could be done in a given population of traffic and based on upstream coefficients such as traffic characteristics (speed, volume etc). It could in principle forecast crash numbers in a given period. Some of the upstream evidence on traffic regulation, such as speed cameras or traffic calming zones, could enter this model since they affect speed, which is a crash predictor. The model could then forecast health outcomes by multiplying crash likelihood by a scalar such as the rate of mortality or injury, such coefficients being available in, for example, Ang *et al* (2017) or the rates of mental health impacts, such as those in Craig *et al*. (2016), to estimate likely incidences of injury, mortality, and/or mental health impacts due to RTAs. The evidence from Hussain *et al* (2019) would could be used here (since it relates to impact speed, which presupposes a crash has already occurred) as a predictor of the *severity* of a crash.

Evidence for analysis

The strongest evidence on incidents and safety can be found in:

- Hussain *et al.* (2019): A systematic review and meta-analysis on the relationship between impact speed and the probability of pedestrian fatality during a vehicle-pedestrian crash
- Charters *et al*. (2017): A systematic review on population incidence of pedestrian traffic injury in high-income countries
- Roshandel *et al*. (2015): A systematic review providing a summary impact of traffic characteristics on crash occurrence

The first two of these are rated as robust and useful. However, the nature of the evidence makes it difficult to relate the estimates to readily available data. For example, we could not obtain data on impact speed which could have been used in the first of these studies or pedestrian patterns which could have been used in the first two of these studies.

We subsequently identified the third study, which reported results relating to traffic volume, which is an input into crash likelihood estimation, though one of many, and not the most important one (which is thought to be behavioural characteristics).

Our approach then, by necessity, was to be more descriptive, and show accident data around traffic volume, to allow visual comparison, rather than demonstrating cause-effect quantification.

Data gaps and challenges

Data exist for traffic volume and speed throughout the UK, but these are point data, rather than area data for specific roads or sections of roads. It is challenging to obtain from these variables such as traffic density (which would need volume to be combined with space, which is not possible for point data). Data which show the incidence and type incidents for a given area tend to cover fairly broad geographical areas, for example, number of fatal or serious incidents within Liverpool. There are some data at LSOA level, but only for London. We also located more detailed data for Greater Manchester for individual incidents. These are 'point' data – showing the location on a map of individual incidents, as opposed to area data that might show the average number of incidents in an area.

4.3 Air pollution

Air pollution is a major contributor to premature deaths and illnesses

Air pollution is a major contributor to mortality, hospitalisation, and health conditions such as asthma. Of particular danger are fine particulates such as $PM_{2.5}$ and PM_{10}

The impact framework table for air pollution is shown as a sheet in the supplementary workbook, and summarises the downstream evidence, the health impacts of pollutants. The evidence review did not uncover upstream causal drivers of air pollutants. Subsequent scoping (not being robust enough to be listed in the impact framework) suggests this includes such factors as traffic volume, weather conditions, and topography.

The downstream evidence is detailed and amenable to modelling

The evidence is more extensive, and amenable to modelling because it is in dose-response form, in the downstream impacts in the impact framework table. Here the increased risks of mortality, hospitalisation, or health conditions are expressed for individual pollutants and as continuous coefficients.

Modelling impacts is straightforward for the downstream

The downstream health impacts are well documented and robust, including reviews and epidemiological studies, while spatial data exist for each of the most important pollutants covering the whole UK. A straightforward methodology is to clip these spatial data to areas of interest and overlay onto population data, translating likelihoods of impacts of interest into headcounts i.e. areas in which large number of people coincide with areas of high pollution (health risk). At its most detailed, the approach could use finely-grained population data (well below typical area-based datasets) to account for how populations are distributed around pollutant hotspots. A further refinement might display the prevalence of the health outcomes caused by pollutants in affected populations, such as asthma or cardio-respiratory diseases. The most detailed population data available from TfN is in point form and combining this with the point data on pollutants would shed (detailed) light on the burden of transport-related health impacts.

It would be more challenging to predict the upstream causes of air pollution, for example to assess the effects of a transport intervention on pollution. Our systematic evidence review did not uncover upstream causes, but subsequent searches suggest this is more of a specialist field, where modelling would necessitate controls such as weather, vehicle type, geometry of the area, and thus require data and evidence beyond the scope of this project (but which may be possible in TfN's existing models and other programmes of work).

Data gaps and challenges

Point data on emissions from Defra in vector format are available for all of the pollutants discussed in the supplementary table and have sufficiently detailed coverage to resemble area data when formatted appropriately. But, and as the principal limitation, these are total emissions (including from non-transport sources) and do not identify the source of these emissions. That is, the available data do not clearly identify which emissions are from transport and which are not. As an alternative, coarser data are available from BEIS which do identify sources of emissions, but these are either in raster files, which do not have the geographical resolution of the aforementioned point data, or in shapefiles which show emissions only from single site sources, such as factories, rather than as emissions covering an area. This would, however, come at a loss of resolution that may not be so desirable given the location-specific nature of air pollutants and the importance of understanding them at a localised level.

Evidence for analysis

The strongest evidence on the health impacts of air pollution can be found in:

- Requia *et al*. (2018): a meta analysis of increased hospitalisation and mortality risks from six pollutants (CO, NO_2, O_3, PM_{10}, $PM_{2.5}$, and SO_2)
- Hoek *et al*. (2013): a systematic review and meta-analysis of increased risk of cardiovascular and cardio-respiratory diseases from five pollutants (PM_{10}, $PM_{2.5}$, O_3, SO_2 and NO_2)

Both studies carry out meta-analyses with robust methodologies, expressing the results as dose-response coefficients which are amenable to quantitative analysis. Both studies emphasise especially particulates as a source of heightened health risk.

As well as being robust sources of evidence in themselves, the results are readily combined with available data (from Defra) on modelled point estimates of the above pollutants. These can be directly applied to the evidence above Given the slightly greater number of pollutants covered, we opt to use the Requia et al. (2018) estimates in the analysis in Section 5.3.

Other evidence (mostly about increased mortality) was judged of lower usefulness owing to either weaker methodological rigour (on the evidence side) or a stronger need for source-specific data (e.g. tailpipe emissions).

4.4 Limited access to green space, recreation and leisure

Green space is beneficial for physical and mental health

A number of hypotheses exist for the relationship between health and natural spaces, including the opportunities for physical exercise which, as already noted, provide health benefits, which are increased when exercise is undertaken in natural spaces; through the opportunities for social interaction, which improve wellbeing; through exposure to sunlight and vitamin D; and the 'old friends' hypothesis of exposure to bacteria, protozoa and helminths which boost the immune system and regulate inflammation (Twohig-Bennett & Jones, 2018).

The impact framework table for limited access to green space is shown as a sheet in the supplementary workbook, and summarises the evidence on impacts from the literature distinguishing, respectively, upstream causes (here, factors that affect access to green space) from downstream impacts (the consequences of changes in access. The tables also summarise the data that would be needed to model these impacts ('Data requirements') alongside our assessment of which data are currently available for the current purpose ('Available data'). Within the evidence shown, there are systematic reviews which cite multiple studies and coefficients that could be used for modelling.

The evidence largely concerns the link between usage and health/wellbeing

As the supplementary impact framework table shows, the downstream impacts of green space are extensive. As a health and wellbeing impact judged to have Tier 1 evidence (by our assessment framework), the stronger associations between green space exposure and health outcomes are suitable for quantitative modelling.

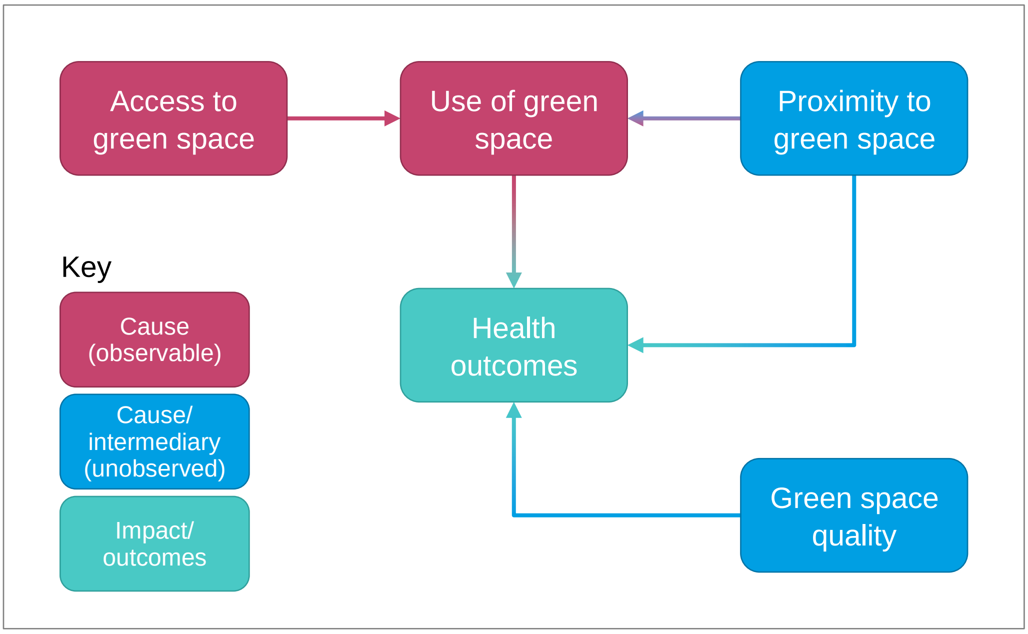
The evidence of health benefits from green space concerns three main channels: health outcomes derived from direct use, i.e. the benefits to people being in that green space; outcomes which are more passive, and which derive from proximity; and outcomes based on quality, such as 'greenness' or improvements to the green space. For transport interventions, which are likely to be more focused on improving access, modelling will mainly focus on benefits resulting from use, which will in turn be a function of access.

In some cases, proximity could serve as a surrogate for usage

The process of modelling the impacts depends on the causal channel (see Figure 4.1). Modelling proximity to health outcomes is simplest and, based on the evidence, can take one of two approaches:

- **Distance to green space**: For those measuring health impacts caused by green space being within a specified range of a dwelling, spatial data on green space combined with spatial data on household characteristics could be used. For example, a boundary representing the distance within which health impacts operate could be mapped around each green space polygon to assess health impacts of residences within that range.
- **Proportion of green space**: Some health outcomes arise due to proportions of nearby green space, for example, a quantified reduction in the risk of diabetes per percentage-point increase in green space within 1km of subjects' residences.

Figure 4.1: Causal chains of green space health impacts



The upstream data from Ordnance Survey on green space, combined with the data TfN provided on households at the MSOA level would in principle support both approaches.

Access could be inferred…

To model outcomes based on use of green space - for example, by using coefficients that show a larger impact of exercising in green space than in a gym – the focus would need to switch to modelling *access* to green space. This is likely to be a concern in modelling transport interventions. The Ordnance Survey green space spatial data include access points to the green space. This could be combined with TfN data both on major road networks and on household access to cars to get a picture of viable transport links to nearby green space at the household level.

Similarly, data on active mode networks, such as the cycle route network data (e.g. from Sustrans or Transport for Greater Manchester), would permit modelling of households' access to green space either on foot or by bicycle. The impact framework includes coefficients on people's relative likelihoods of walking, cycling, or driving to get to green space which could enrich such analysis.

…but converting this to usage remains challenging

After modelling access, however, a challenge will be in quantifying (or finding ways to proxy) usage. From our data assessment, there is no obvious dataset that measures such usage of green space. By extension, there are also no data on how usage might change in response to a transport or other intervention designed to improve access.

Appropriate quality measures represent a data gap at this time

Modelling quality-based impacts would require data on green space quality (however defined). Measurements used in the literature include the Normalised Difference Vegetation Index (NDVI) and proximity to greening interventions. However, we were unable to find such data as part of this exercise and this represents a data gap that TfN may wish to investigate further in the future.

Other challenges in relating the literature to factors of interest concern:

- finding measures of green space exposure and use that can be related to transport interventions, rather than simply proximity to green space
  - in the literature, such access metrics would ideally cover indicators such as walkable or drivable distance to green space
- the availability of corresponding data on health outcomes at a sufficiently detailed spatial level

Evidence for analysis

The strongest evidence on the health impacts of green space can be found in:

- Twohig-Bennett and Jones (2018): A systematic review and meta-analysis of green space exposure and health outcomes
- Yang (2021): An umbrella review - review of 40 systematic reviews – of green space and human health
- Public Health England (2020): A systematic review on improving access to green space.

There are several more strong pieces of evidence. Yet the challenge is noted in the initial evidence review of modelling, of assessing *access* to green space. There is also a challenge of translating access into use, for which we could not find any appropriate data.

Given these challenges, and the available data, we considered the options for GIS analysis to be related to proximity to green space (distance to green space) and green space in a neighbourhood (number of parks nearby, for example, or proportion of area that is green space).

The studies that were either in the evidence review or cited in the systematic reviews, and which both covered health outcomes of interest and which were amenable to this type of analysis were:

- Houlden *et al*. (2018): A systematic review of the positive association between green space and life satisfaction
- Astell-Burt *et al*. (2014): A study examining how the proportion of green space within 1 km of residents of an area is associated with diabetes
- Astell-Burt and Feng (2019): A study examining how the amount of green space within 1 km of an area's residents is associated with psychosocial distress

We chose Houlden *et al*. (2018) because it allowed a simple proximity measure to be used, and has the advantage of putting to the test UK and EU guidelines that individuals should have access to a green space within 300m of their home.

We chose the two Astell-Burt studies (2014 and 2019) because they relate to the proportion of nearby green space and because they cover both a well-known physical health outcome and a mental health outcome.

4.5 Noise pollution

Noise pollution can have an array of physical and mental health impacts

Noise pollution arising from traffic has been associated with a range of adverse physical health outcomes, such as hypertension, heart disease, breast cancer, and diabetes.

The impact framework table for noise pollution is shown as a sheet in the supplementary workbook, and summarises the evidence on impacts from the literature. Upstream impacts cover the factors likely to increase noise, whereas downstream impacts cover the effects on health of noise. The upstream table is much more sparsely populated which reflects the greater focus of the literature on the downstream. Upstream causes include volume and speed of local traffic, and proximity to rail lines and air routes, but predicting noise volumes from these is a specialist field – noise propagation modelling, which is a field of acoustics.

Noise beyond a threshold is associated with increasingly adverse health outcomes

The downstream impacts outlined in the supplementary tables all come from systematic reviews. They cover noise exposure from rail, road, and air noise and the aforementioned health impacts. One of the impacts considers the combination of noise from multiple sources. The evidence in this part of the impact framework is strong, with only mental health impacts seeming to still lack a strong body of evidence. The different pieces of evidence mostly share the same independent variable, decibels of noise exposure, and are thus amenable to mapping against data showing the spatial distribution of noise pollution. Most of the coefficients are continuous, describing increasingly adverse health outcomes with rising decibels, but some are discrete.

Modelling health outcomes is relatively straightforward

As with air pollution, the process of modelling impacts is relatively straightforward and would involve clipping spatial data to areas of interest and overlaying onto population data. Decibels can be translated into likelihoods of health outcomes using the coefficients from the impact framework, and population data could be overlaid onto the map to assess where these impacts fall most on the population of the North. The UK government provides data both on spatial mapping of noise, measured in decibels, and noise exposure data, with numbers of people affected by decibel levels of > 55db, > 60db, > 65db etc.

While the focus of the operational impact framework is on the effect that runs from noise (in decibels) to health impacts, we note that predicting the effects of interventions to manage noise would be more challenging e.g. a diversion of traffic intended to reduced traffic volume in noise hotspots. Specialist modelling (perhaps adapted from TfN's existing tools) would be needed to accurately forecast such effects before applying the downstream analysis here.

Aligning timespans of evidence and data is a consideration

The outcomes of this analysis are the heightened risk (i.e. the change in relation to the pre-existing risk). Were there more detailed data on pre-existing risks, it would be possible to see the overall impact on health risks.

We were unable to find data on noise pollution caused by aircraft, only that caused by road and rail. Further data searches could focus on this to be able to utilise some of the coefficients we found in the evidence. Another consideration in modelling noise impacts on health is aligning the timespans covered by the data with those used by researchers in the evidence. For example, finding data that is the average noise over 24 hours, if that is how the coefficient is measured in the literature.

Evidence for analysis

The strongest evidence on the health impacts of noise pollution can be found in:

- Van Kempen *et al.* (2018): A systematic review and meta-analysis of the effects of environmental noise and Cardiovascular and Metabolic Effects
- Basner and McGuire (2018): A Systematic Review on Environmental Noise and Effects on Sleep
- Munzel *et al.* (2018): A comprehensive review of the effects of noise exposure on oxidative stress and cardiovascular risk

All three pieces provide evidence amenable to modelling, and may be operationalised using the road and rail noise data from the UK government, which is detailed and comprehensive.

Given the broader coverage of health outcomes, and inclusion of coefficients for combined rail and road noise, we decided to use coefficients cited in the Munzel *et al*. (2018) study in the noise pollution analysis in Section 0, to better convey the range of modelling approaches that may be used. Of these, we found Babisch (2014), covering coronary heart disease from road noise; van Kempen *et al*. (2018) and Babisch (2012), covering hypertension from road noise; and Seidler *et al*. (2017), covering depression from road and rail noise, to be most useful in exemplifying the different approaches one might take to modelling noise pollution.

But the other studies are robust and highly amenable to modelling, and with scalable approaches being now demonstrated in the analysis section, could be used in analysis in the same way as we have done for these three studies.

4.6 Severance

Transport infrastructure can sever people from friends and family

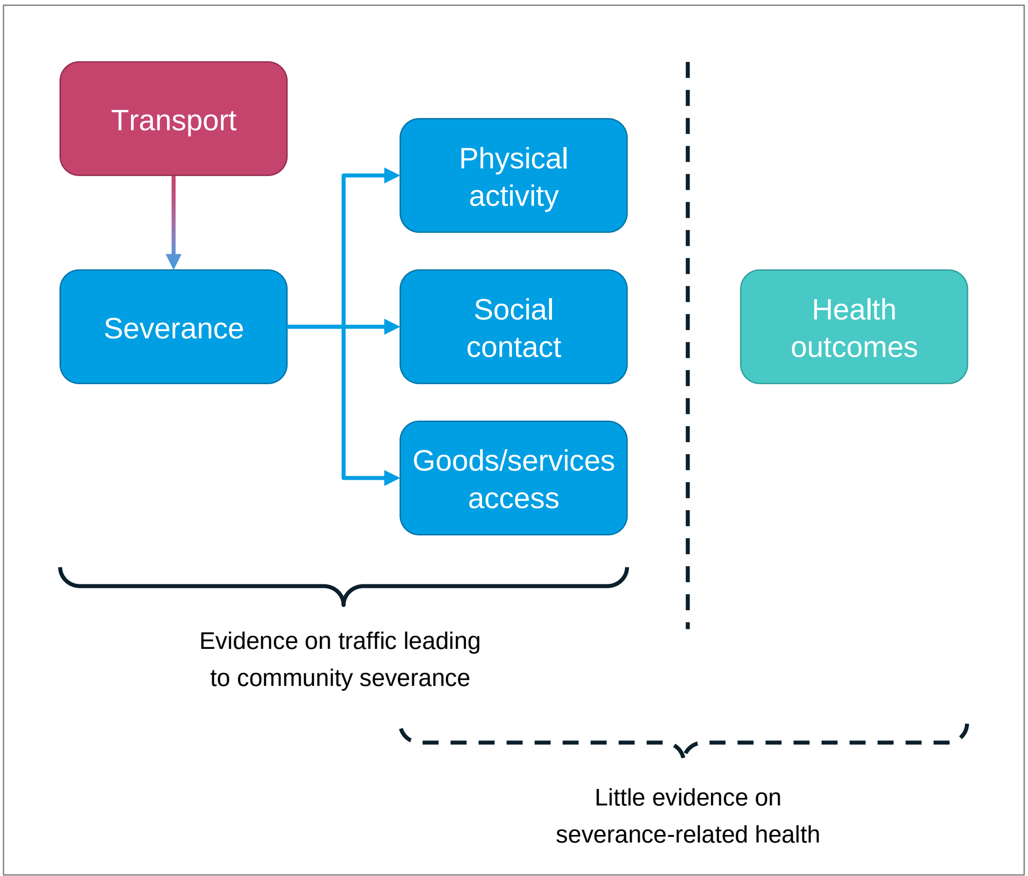
Severance concerns a range of effects and, following Mindell and Karlsen (2012), community severance describes barriers that can impede access to active travel or free movement of people to visit friends and family in their nearby areas. The barriers in question result from transport infrastructure, such as large motorways. Especially for older people or children, such barriers can be very challenging to cross and, if they lie across the routes between people, can disrupt people's social connections.

There is a lack of evidence linking transport to health outcomes due to severance

The impact framework table for severance is shown as a sheet in the supplementary workbook, and summarises, respectively, evidence for the upstream causes and downstream impacts of severance The upstream coefficients outline the ways that social connections and green space visitation may be affected by walkability, traffic volume, and perceptions of safety. The downstream impacts outline the ways in which social capital or social isolation can affect physical and mental health outcomes.

As an impact with tier 2 evidence by our assessment framework, there is some quantitative information on the effects of severance. However, there are also one or more gaps/limitations that limit the degree to which a robust quantitative assessment can be made. In this case, the problem is one of linking upstream (factors leading to severance) to downstream (health outcomes caused by such severance) (see Figure 4.2).

Figure 4.2: Logic of, and evidence for, health impacts of community severance



The evidence suggests that traffic volume and speed interfere with normal activities while other evidence suggests that reduced access to social contact and goods and services is detrimental to health. The link that has not been formally established (however likely it seems), is between community severance by roads and traffic directly and adversely affecting health and wellbeing in a direct manner (Mindell & Karlsen, 2012).

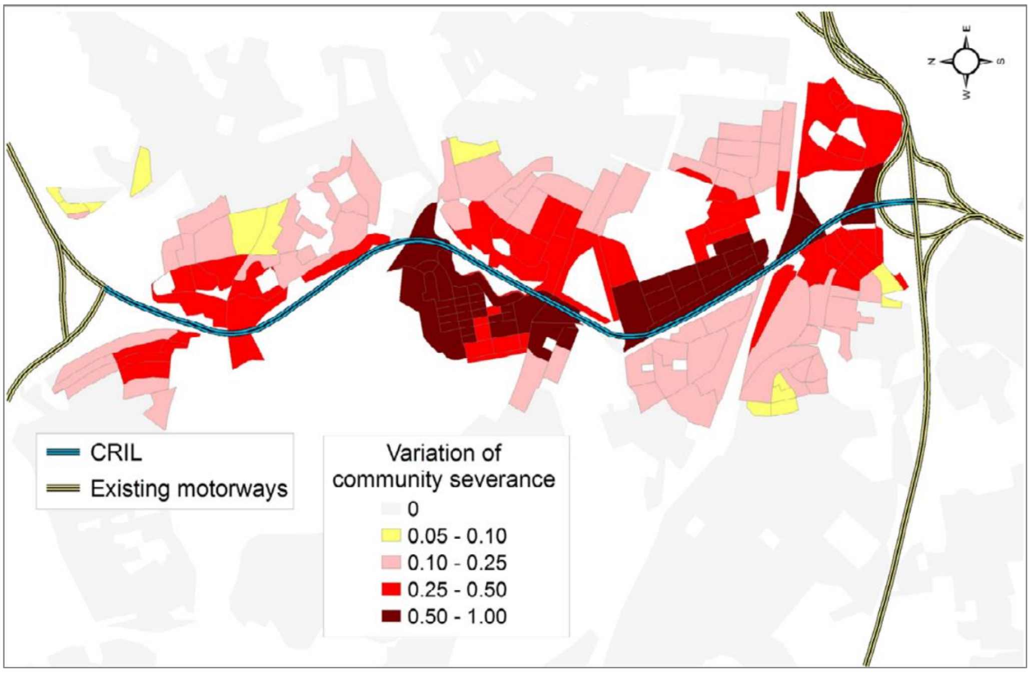
Modelling severance remains a challenge but there may be ways to infer social connectedness

While there is an evidence gap between transport and severance-related health impacts, TfN was keen to explore options for advancing the analysis all the same. One option for doing so would be to follow a method put forward by Anciaes (2013).[7] In that paper, Anciaes (2013) identifies all potential destinations in walking distance of a neighbourhood, assigning an attractiveness score to each weighted by population. Severance can then be assessed by identifying the destinations that lie beyond (are severed by) a road. Extensions of the method could then adjust for the severity of the barrier e.g. availability of crossing point, traffic speed, traffic volume etc. Carried out

[7] This paper uses the example of a ring road in Lisbon to demonstrate the approach.

on a neighbourhood-by-neighbourhood basis would yield a map such as Figure 4.3, showing how access to (in principle) walkable destinations may be impeded by a road.

Figure 4.3: Severance effects of a section of road



Source(s): (Anciaes, 2013).

Data gaps and challenges

The challenge of Anciaes's (2013) method is that it requires values for attractiveness (with population proposed as a proxy) and, in principle, methods for (numerically) specifying the severity of a barrier represented by a road. Currently, there seems to be relatively little in the way of evidence with which to derive such values e.g. to feature in a quantitative (maybe even cost-benefit) analysis. This would typically require new research to quantify non-monetary benefits e.g. from stated preference surveys to develop willingness-to-pay metrics.[8] Also, the problem would still remain of then translating that lost access to physical and mental health outcomes. Linking the outputs of such a method to the literature requires a common unit which is not straightforward or settled, as the supplementary impact framework table shows (in part because of the challenges of measuring the phenomena of interest).

A tentative approach

Nevertheless, and subject to various caveats, the style of analysis put forward by Anciaes (2013) may be possible in a simpler form, based purely on population data.

Using detailed population data (e.g. postcode-level data), and interpreting a postcode as a neighbourhood, it is possible to identify the population in walking distance of said postcode as a group of potential (rather than

[8] Anciaes (2016) does, however, cite a few other studies that show, for example, that land prices tend to be lower in areas next to elevated railways than areas next to underground ones (Lee and Sohn, 2014); and that land value premiums rose following the tearing down of a freeway and replacing it with a linear park (Kang and Cervero, 2009). However, another study found speed bumps to not significantly affect property prices (Bretherton et al, 2000). There is thus some suggestion of monetisable effects but this was beyond the scope of this current study.

actual/observed) social connections. If a road passes through this walkable area, the population can then be divided into two, giving a percentage of potential social connections severed. Were one willing to interpret these potential social connections as some crude measure of social capital, such higher severance could be thought of as being a risk factor for worse health outcomes.

We apply this method to a test case in Section 5.6, where we also discuss the relative merits in more detail.

> **Evidence for analysis**
>
> A recurring finding in the literature is that community severance cannot yet be effectively quantified. Boniface *et al*. (2015) also find that 'There are relations between severance and both social capital and social cohesion, but no quantifiable relations were identified'.
>
> Nor did the initial evidence review uncover quantitative evidence that is of direct use for modelling. As such, it was not possible to perform analysis for severance in the same way as was done for the preceding impacts.
>
> But, since this is an area of interest, we proceeded with testing an experimental approach outlined in Anciaes (2013), which articulates a methodology that transport planners might seek to develop. This approach was supported by data obtained on population and on local area geographical features (roads, neighbourhoods).
>
> A strong caveat should be noted that this approach is nascent, and would require substantial additional research and development before being ready to be operationalised in a meaningful way.

4.7 User experience

The experience of a mode of travel can have mental health impacts

The experience of travel can differ depending on the mode, and this in turn can affect the traveller's health and wellbeing.

User experience is classed as Tier 2 for its amenability for quantitative modelling, meaning either the data were insufficiently comprehensive, or econometric results were not strong enough, for this to be characterised as a robust result. In this case, evidence is sparse. The distinction between upstream and downstream for the obtained evidence is less clear, with stress shown as both a cause and effect of improved user experience in the system map in Appendix A.

The strongest quantitative evidence was found for active travel (walking and cycling) and psychological wellbeing

The downstream impacts include positive associations between active travel and wellbeing indicators. The strongest quantitative association was found between active travel and psychological wellbeing. Impacts on depression have conflicting evidence: in the systematic review cited, some studies found an effect and others did not, while in another systematic review, the strongest evidence was for effects on depression. Associations between travel by car and wellbeing were negative in one panel study.

Data on mode of travel and wellbeing may be challenging to obtain

The challenges in modelling user experience are manyfold. Firstly, the data we found on model of travel is at a fairly broad geographical level and does not have continuous data on time spent in particular forms, but rather discrete bins of travel time by type. Data on the outcome variables may be available from Fingertips or ONS but metrics such as wellbeing, the outcome for which the strongest associations were found, may be harder to find, particularly at a fine level of geographical detail.

Data requirements for future analysis

The literature found during the evidence review and the available data did not suggest that this impact would be conducive to modelling at this time: the evidence was weak to moderate in strength and the data on modes of transport was at an overly broad geographical scale.

Were stronger evidence to emerge, data acquisition efforts should focus on access to public transport, on modes of travel at a detailed (LSOA or lower) level, and on time spent in particular modes of travel.

4.8 Limited access to healthcare facilities

Variations in access to healthcare are likely to be associated with varying health outcomes

Variations exist in people's ability to access healthcare services, and this is likely to affect health outcomes. Access to healthcare is classed as tier 3 for its amenability for quantitative modelling, meaning that although evidence may exist, quantification is limited. The impact framework table for limited access to healthcare is shown as a sheet in the supplementary workbook, and summarises the evidence on impacts from the literature. Car availability and public transport provision are the two upstream causes for which we have evidence, but these are single studies, one of which is descriptive and of little use in modelling. These are included more to demonstrate the paucity of evidence than for their usefulness. The downstream evidence covers the differential access to health services and its estimated impact on heart disease and stroke mortality but does not contain usable coefficients.

Evidence and data are limited

Modelling access to healthcare will be challenging. The evidence does not link access to health services with health outcomes. A modeller could make the very reasonable assumption that access improves outcomes but could not quantify this based on the available evidence. Furthermore, modelling access could be challenging. Data is available on access to cars but we found less on public transport provision. Data on access to healthcare services are limited. The upstream evidence has only one quantitative coefficient, and this from a single study. The downstream evidence has none.

Data requirements for future analysis

The literature found during the evidence review and the available data did not suggest that this impact would be conducive to modelling at this time.

The single piece of evidence found was weak and thus not suitable for modelling. We did not find useable data on access to healthcare facilities.

Were stronger evidence to emerge along the lines of the existing evidence, data acquisition should focus on geographically detailed data on access to GP services, including distance, accessibility by different modes of transport, and ease of using the services. To assess differences in accessing services for particular ethnic groups, as in this study, or to compare differences in access along such lines, the population data would need to include information about ethnicity. This is not available at a very detailed geographical level.

4.9 Limited access to high-quality employment

Variations in access to employment are thought to have health outcomes, but this is not quantified

The evidence suggests that employment is beneficial for health. And where access to employment is limited by transport, this is a potential policy issue. However, at present, the evidence is insufficient to inform such interventions. Access to employment is classed as Tier 3 for its amenability for quantitative modelling, meaning that although evidence may exist, quantification is limited. Single study results are available for the upstream discussing how access to car or public transport can affect access to employment. While downstream evidence links employment to depression and mental health.

Evidence is insufficient for modelling

As already noted in the literature review, there are no reviews that look at the direct quantitative relations between transport-related access to employment and health outcomes. Robust, usable coefficients are thus unavailable.

Data requirements for future analysis

The literature found during the evidence review and the available data did not suggest that this impact would be conducive to modelling at this time: the supplementary tables show that evidence found during the review was rejected.

To model access to employment by car or public transport, data would be needed on access to cars, public transport availability, as well as, for a given neighbourhood of interest, the nearest locations of employment, which would include spatial data on business locations, the size of their workforces, and rates of hiring.

This could give a picture of the state of nearby labour markets and the strength of access. However, one should be aware of endogeneity issues in this approach: hiring activity is likely to be influenced by available applicants, and this will be influenced by access, if the hypothesis is correct. So comparisons with areas that have similar economies, but improved access, might be employed to overcome this.

If this were combined with data on unemployment and on the underlying health outcomes these (rejected) papers suggest are linked to employment, then a detailed picture could be drawn of where public transport interventions might have the most impact in increasing employment access and by addressing health problems in doing so.

4.10 Environment quality

There are good reasons to think the built environment affects health and wellbeing but the available evidence does not (currently) support quantification

It is reasonable to assume that features of the built environment, such as walkability residential density; land-use mix; presence of shops; access to services; walking and cycling facilities would influence health outcomes. Yet as noted in the literature review, this has not been quantified. Environment quality is thus classed as Tier 3 for its amenability for quantitative modelling. We did not find upstream evidence for environment quality. Downstream impacts of the built environment concern in particular how it encourages physical activity. This is a separate issue, discussed earlier in this impact framework, and for which plentiful evidence and data exists. But not health outcomes are quantified. Given this, it would not be possible to model health outcomes due to environment quality using currently available evidence.

Data requirements for future analysis

The combination of the evidence uncovered in the systematic review of evidence and the available data did not show itself to be conducive to modelling. The two pieces of evidence were rated as 1 out of 5 for usefulness in modelling. The evidence did not cite quantitative coefficients that one could link to a particular data requirement.

Stronger evidence would be needed on this impact to support modelling and would need to have clear quantitative coefficients to identify a data requirement.

5 Analysis

This chapter presents the analysis and results of the geospatial modelling

This chapter presents the analysis and the results of the geospatial modelling, considering both the upstream and downstream health impacts set out in the previous chapters.

The analysis focuses the six impacts considered feasible for further quantitative analysis:

1 physical inactivity

2 incidents and safety

3 air pollution

4 limited access to green space, recreation and leisure

5 noise pollution

6 severance

In approach, the analysis takes upstream factors identified in the impact framework (where there are suitable data) and applies coefficients from the available evidence to first assess the spatial distribution of health effects e.g. areas in which air pollution is high, translating to heightened health risks. As appropriate, health impacts are then estimated by overlaying the above with data on the spatial distribution of the population. For example, while there may be equally high air pollution in two areas (a similar *effect*), the *impact* will be greater in whichever area has the greater population.

Population impacts for noise pollution, greenspace (wellbeing) and physical inactivity are calculated using the LSOA population in 2019. In cases in which the effects are defined by area, the analysis tries to estimate the portions of the area (and thus population) affected under the assumption of a uniformly distributed population within an LSOA. For air pollution, severance and greenspace (other health outcomes), more detailed postcode-level population impacts are assessed, tied to data ultimately rooted in the 2011 census.

5.1 Physical inactivity

Our analysis of physical inactivity concerns proximity to walking and cycling routes, and parks (for exercise)

In this section, we present our analysis of the impacts of transport infrastructure on the health risk of physical inactivity. This analysis models the upstream segments of the theorised causal chain, linking transport to physical activity (which is itself a determinant of health outcomes, not a health outcome). We had insufficient data to model the downstream impacts because the increases in physical activity associated with walking and cycling routes and urban parks are relatively modest. This increase in physical activity is too modest to link to most health outcomes, which depend on receiving a sufficiently high dose of physical activity to change.

Proximity to walking and cycling paths

A 2014 study of residents in three municipalities of the UK found that living within 1 km of a newly-built mixed walking and cycling route was associated with greater levels of physical activity two years after the route was built

(Goodman *et al*., 2014). Table 5.1 lists the increased average level of combined walking and cycling activity per resident associated with living near such a development, by distance from the route.

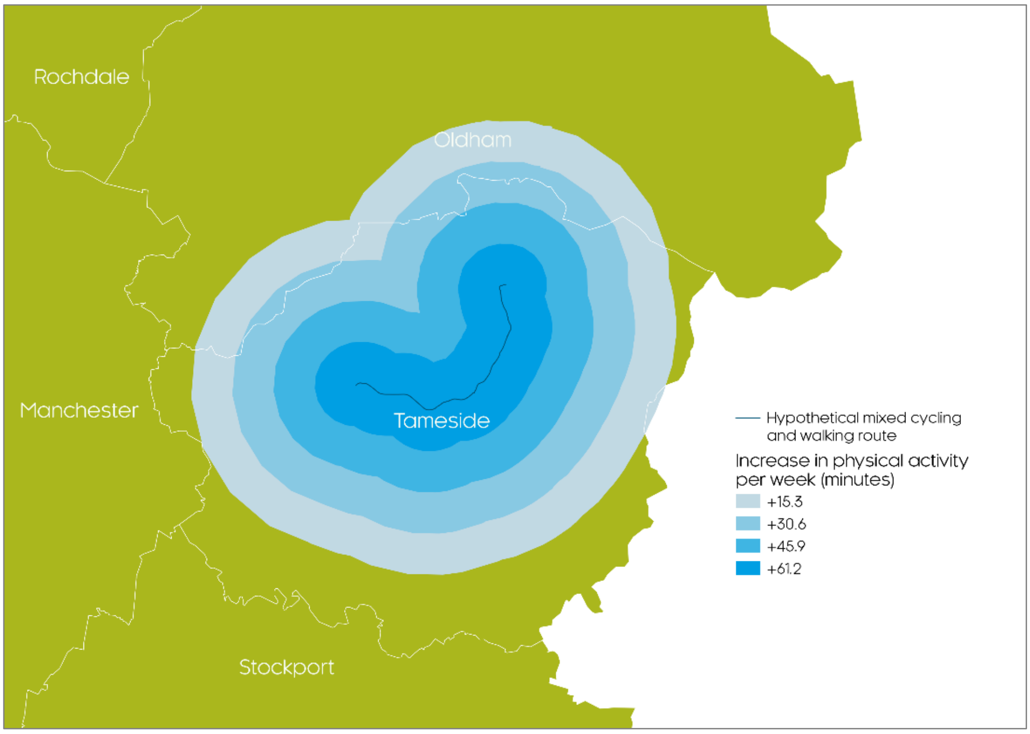
Table 5.1: Increased average walking and cycling activity by proximity to route

Distance of residence from route (km)	Increased average walking and cycling activity per week (minutes)
0-1	61.2
1-2	45.9
2-3	30.6
3-4	15.3

Note(s): Only routes within 4 km are considered
Source(s): Goodman *et al*. (2014).

As an illustration of the approach before applying it to actual data for the North, Figure 5.1 depicts these physical activity benefits on a map with a hypothetical newly-built mixed walking and cycling route in the Tameside borough of Greater Manchester.

Figure 5.1: Increase in physical activity associated with hypothetical mixed walking and cycling route relative to reference (>4 km away from mixed cycling and walking route)

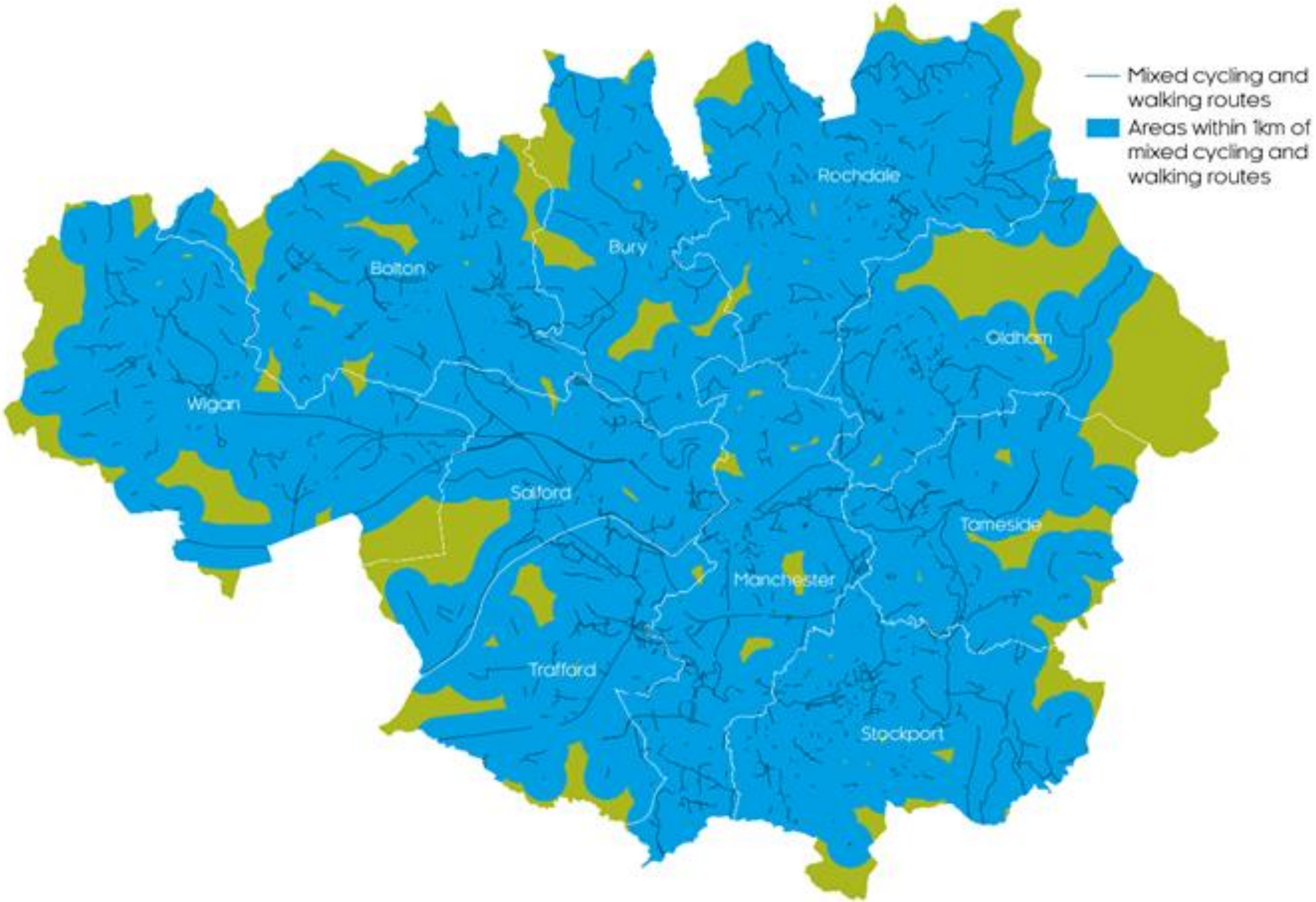


Source(s): Goodman *et al*. (2014); Cambridge Econometrics analysis.

The majority of land area in Greater Manchester is within 1 km of existing cycling infrastructure

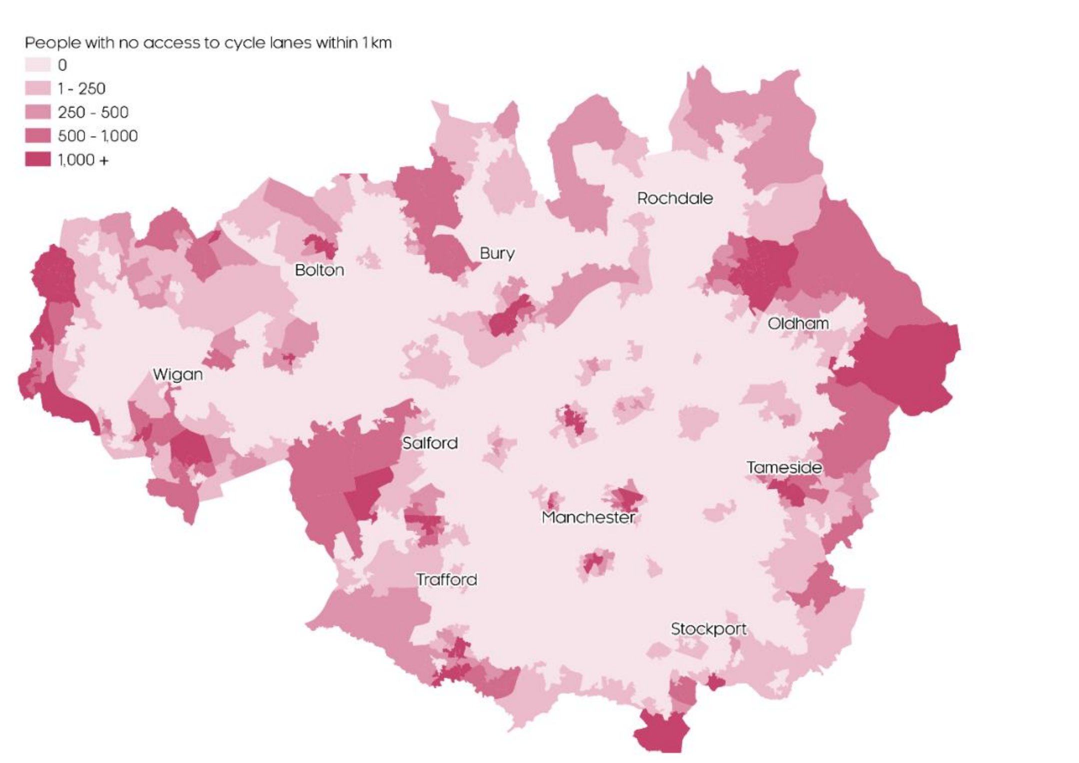
However, a relatively large urban centre like Greater Manchester has an existing network of walking and cycling routes that extends throughout the region. Thus, the marginal benefits of building new cycling infrastructure are harder to know, given the spread of existing infrastructure. Figure 5.2 displays the walking and cycling route network for Greater Manchester and the geographic area that lies within 1 km of any given section of this network. This map shows that a large majority of land area within Greater Manchester is within 1 km of existing cycling infrastructure.

Figure 5.2: Areas within 1 km of mixed cycling and walking routes in Greater Manchester



Source(s): Goodman *et al*. (2014); Cambridge Econometrics analysis.

Figure 5.3: Access to walking and cycling routes by LSOA in Greater Manchester



Source(s): Goodman *et al*. (2014); Office for National Statistics; Cambridge econometrics analysis.

Figure 5.3 shows the population of Greater Manchester by Lower Layer Super Output Area (LSOA) that does not live within 1 km of an existing mixed walking and cycling route. Over Greater Manchester, over 2.6m people have access to a cycle lane within 1 km of their home. Nevertheless, the map below also identifies 163,000 people with no nearby access (on distance alone). These areas are concentrated on the edges of the region, particularly around Bolton and Wigan. There are also a series of pockets with little or no access to cycling routes in the centre of the area. For example, over 5,000 people are more than 1 km from a cycling route in the Manchester 058B, Manchester 058D and Salford 016D LSOAs.

Our analysis of cycling and walking routes and their relationship to physical activity presumes that all infrastructure is of the same quality. However, the quality of existing routes in a city like Manchester varies depending on the type, age, location, etc. of the route. These details were not available in the geospatial data used in this analysis and are not well addressed by the literature linking built environment infrastructure to physical activity. Further information on quality and infrastructure usage could provide additional nuance to this analysis.

Proximity to parks

A 2016 study of individuals across 14 different global cities found that the density of parks near residences in urban areas is linearly associated with an increase in moderate to vigorous physical activity (MVPA) (Sallis *et al.*, 2016). Table 5.2 lists the increased physical activity associated with the number of parks within 0.5 km of a place of residence. Sallis *et al.* (2016) found this relationship to hold regardless of the size or quality of park(s).

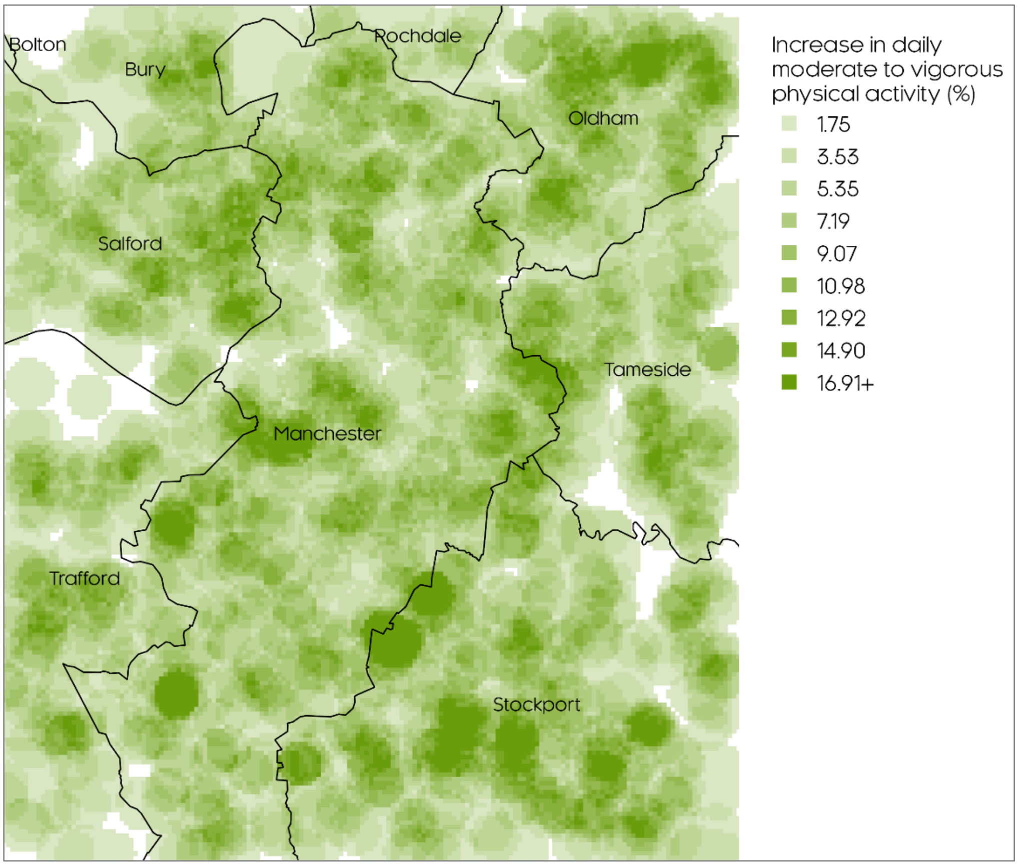
Table 5.2: Increased MVPA relative to the reference category (0 parks within 0.5 km)

Number of parks within 0.5 km buffer	Increase in daily MVPA (%)
1	1.75
2	3.53
3	5.35
4	7.19
5	9.07
6	10.98
7	12.92
8	14.90
9+	16.91+

Source(s): Sallis *et al.* (2016); Cambridge Econometrics analysis.

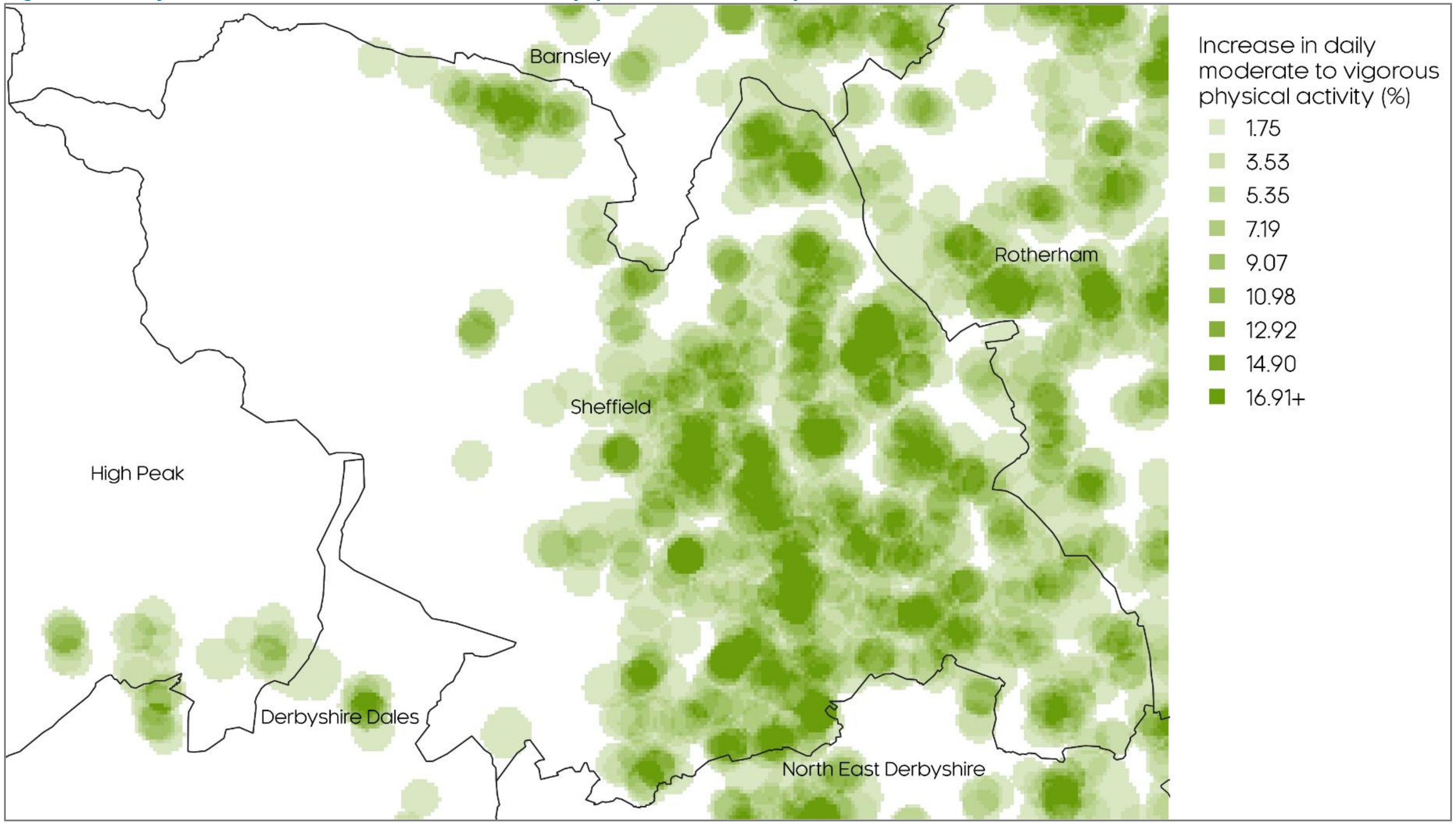
Using the values above, Figure 5.4 (Manchester) and Figure 5.5 (Sheffield) show, for two urban areas, how proximity to parks could increase daily MVPA. This is relative to areas with no parks within 0.5 km of the place of residence.

Figure 5.4: Daily increase in MVPA relative to reference (0 parks within 0.5 km), Manchester



Source(s): Sallis *et al*. (2016); Cambridge Econometrics analysis.

Figure 5.5: Daily increase in MVPA relative to reference (0 parks within 0.5 km), Sheffield



Source(s): Sallis *et al.* (2016); Cambridge Econometrics analysis.

In both maps, white spaces represent areas that are more than 0.5 km from any park and thus not expected to benefit (on the basis of the evidence used). Relative to Sheffield, Manchester has a higher density of urban parks, though there are certain parts of Sheffield area with access to many nearby parks. Note that Sallis *et al.* (2016) focused on parks in urban areas but that the white area to the west of Sheffield includes the Peak District, which would also be expected to confer health benefits. These are not assessed in this current piece of analysis.

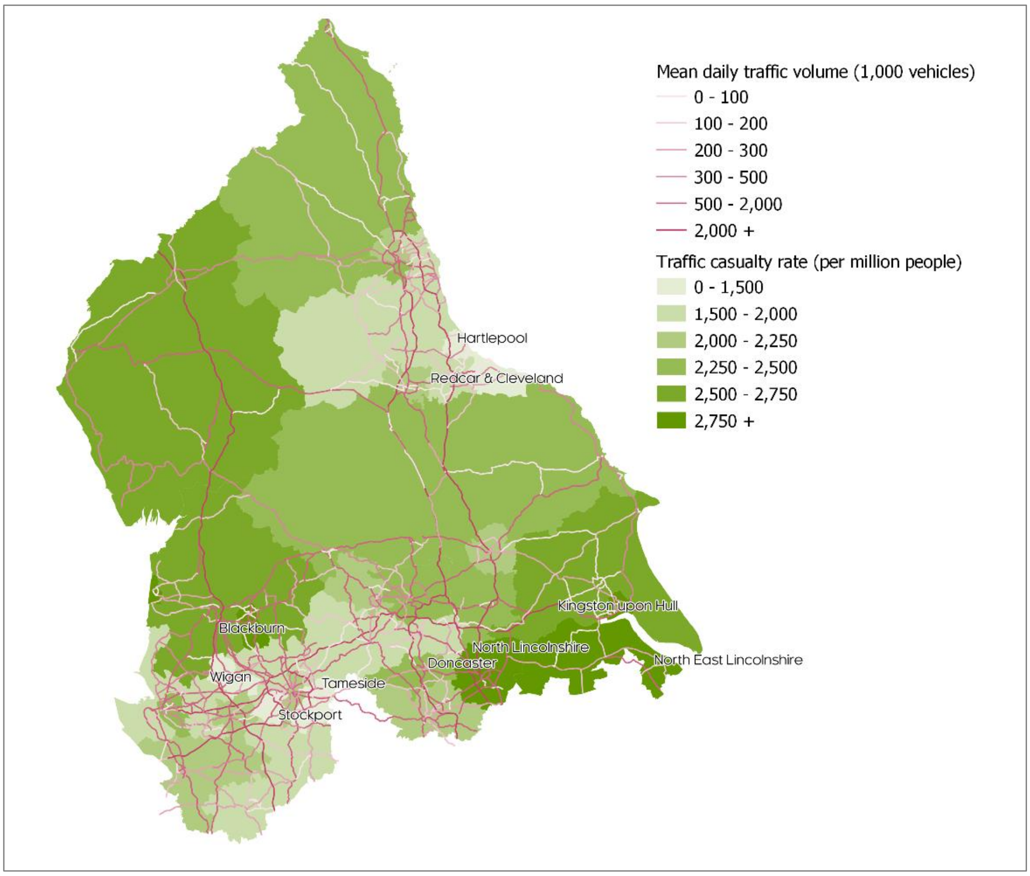
5.2 Incidents and safety

There were 1,752 road deaths recorded in the UK in 2019. At 26.4 deaths per million people, the UK's road death rate that year was 4 times lower than that of the US (36,096 deaths in a population of 332m people), and 2.5 times lower than New Zealand's (318 deaths; 5m people). This rate was slightly higher than that of Switzerland and the Nordic countries. Despite the UK's low rate by international standards, there is room for improvement, and there can be differences between regions.

There is great variation in the incidence rate across countries and, as the evidence below suggests, the occurrence of road traffic incidents is likely highly context specific.

In 2019, the North of England recorded 459 of the above deaths. This is proportionally more than the North's share of the UK population, implying a slightly higher death rate, of 30.8 per million people. Traffic incident and casualty data are available at the local authority level from the Department for Transport. Figure 5.6 presents the casualty rate per million inhabitants and shows areas of high/low traffic incident rates.

Figure 5.6: Casualty rates in the North of England



Note(s): The same rate is applied to all LADs where the data are only available at county level (Cumbria, Lancashire and North Yorkshire).
Source(s): Department for Transport 'Road traffic statistics' and 'Accidents by local authority'; Cambridge Econometrics analysis.

Table 5.3 presents road incident statistics for the four areas with the highest and lowest casualty rates. The highest casualty rate is found in Kingston upon Hull, followed by North East, and then North, Lincolnshire.

Table 5.3: Road incident statistics for selected areas

Geography	Casualty rate (per million people)	Casualties	KSI	Fatalities
Kingston upon Hull (highest)	3,603	936	149	7
North East Lincolnshire	3,259	520	77	3
North Lincolnshire	3,152	543	90	13
Blackburn	3,013	451	116	4
Hartlepool	1,377	129	30	1
Stockport	1,346	395	59	8
Redcar & Cleveland	1,342	184	51	5
Wigan (lowest)	1,244	409	112	15

Note(s): KSI - Killed or Seriously Injured.
Source(s): Department for Transport 'Accidents by local authority'.

Serious incidents (not shown), follow the population distribution, with Leeds, Sheffield and Liverpool on top.[9] The high traffic volume in those three areas is in line with the evidence of a link between traffic volume and incident occurrence. Figure 5.6 also suggests some relationship between traffic volume and the casualty rate, with areas like Cumbria and Lancashire having heavy traffic and high casualty rates. On the other hand there are notable exceptions with Wigan, Stockport, Kirklees and Calderdale all showing high traffic volume but low casualty rates. More granular incident data would be needed for further analysis.

Roshandel et al. (2015) discuss the factors that matter in the probability of an incident taking place. Table 5.4 below shows the statistically significant factors affecting the odds ratio of a traffic incident taking place.

Table 5.4: Factors affecting traffic incident occurrences

	Change in odds ratio of a traffic incident per unit increase (%)
Average speed	-4.8
Traffic volume	0.1
Speed variation	22.5
Speed difference	3.2

Source(s): Roshandel *et al*. (2015).

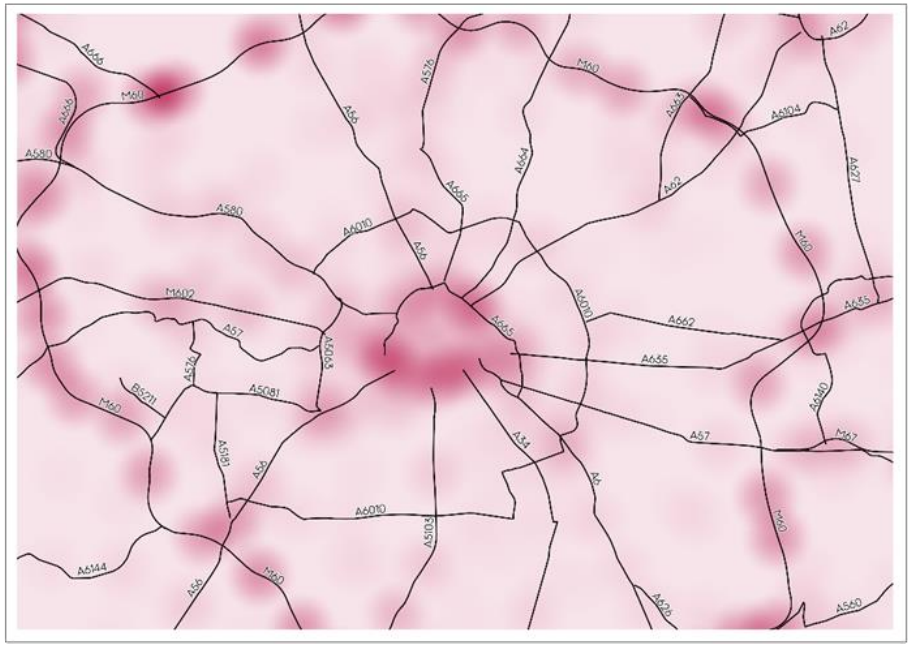
Average speed is the only factor with a negative impact on the probability of an incident. As Roshandel *et al*. (2015) point out, 'this result is not surprising because stop and go driving conditions are associated with lower average speeds, and the outcome being assessed is crash occurrence and not severity'.

- then highlight locations and coincidence or otherwise with traffic volumes

[9] These figures exclude the three counties analysed – North Yorkshire, Lancashire and Cumbria.

To examine the hypothetical coincidence of traffic incidents with volumes, data for the exact location of traffic incidents is available for Greater Manchester (see Figure 5.7 and Figure 5.8).

Figure 5.7: Traffic volume in Greater Manchester



Note(s): Individual traffic counts are weighted by their volume before creating the heatmap.

Source(s): Department for Transport 'Road traffic statistics'; Department for Transport; Cambridge Econometrics analysis.

Figure 5.8: Traffic incidents in Greater Manchester

Note(s): Individual incidents are weighted by the severity index that accompanies the dataset.
Contains Transport for Greater Manchester data. Contains OS data © Crown copyright and database right 2021.

Source(s): Transport for Greater Manchester 'GM Road Casualty Accidents'; Department for Transport; Cambridge Econometrics analysis.

Figure 5.8 shows how casualties are concentrated around junctions and roads with lower speed limits in city centres. This highlights how low- and medium-speed roads have higher casualty rates and are thus incident hotspots. This is also reflected in the casualty rate per road, which is ten times lower for motorways when compared to A roads (as shown in the DfT data). This may explain the relatively low number of incidents around the M60 in Manchester, despite high traffic volume.

As data are available at relatively limited geographical detail, any relationship between traffic volume and the casualty rate in the North is not clearly visible. This may also be partly because varying incident rates by road type can cloud this relationship. The analysis shows the lowest incident rates on Motorways , at 58 per billion miles. This is followed by ‘A Roads’ (347) and ‘Other Roads’ (440). Smaller roads can therefore lead to more accidents, even when they have less traffic. This is supported by the literature, which suggests that speed (which is related to the road type) is negatively correlated with the probability of a traffic incident. Other variables that have significant explanatory power in the literature include speed variation, which would be interesting to gather data on.

5.3 Air pollution

Air pollution increases the risk of hospitalisation and mortality

Our analysis of air pollution concerns the health effects of six pollutants (see Table 5.5) for which (modelled) data are available from Defra as annual means. By Requia, Adams, *et al* (2018), these pollutants can be translated from measured concentrations into the following (increases in) health risk:

- hospital admissions
- mortality

Table 5.5: Air pollutants and their main sources

Pollutant	Main source(s)
Carbon monoxide (CO)	Cars, industrial furnaces
Nitrogen dioxide (NO_2)	Fossil fuels, cars
Sulphur dioxide (SO_2)	Fossil fuels, mineral ore smelting
Particles <10 μm in diameter (PM_{10})	Dust, pollen, mould, tire and brake wear
Particles <2.5 μm in diameter ($PM_{2.5}$)	Combustion, organic compounds, metals
Ozone (O_3)	Indirectly from NOx

The analysis that follows presents figures for 2019, as the last year of pre-pandemic data i.e. before movement restrictions.

Table 5.6 summarises the range of (increased) health risks across the North for five of the six pollutants, calculated from the Defra emissions data for 2019.[10]

[10] Because the Defra data report ozone different, as number of days on which a threshold was passed (120 μg/m^3), we treat this separately in the analysis that follows.

Table 5.6: Increased health risks from air pollution (per 100,000)

	Hospital admissions		Mortality	
	Mean	Maximum	Mean	Maximum
Carbon monoxide (CO)	4	5	-	-
Nitrogen dioxide (NO_2)	1,325	6,445	1,115	5,427
Sulphur dioxide (SO_2)	202	1,935	61	589
Particles <10 µm in diameter (PM_{10})	1,713	3,447	1,178	2,370
Particles <2.5 µm in diameter ($PM_{2.5}$)	1,051	1.937	1,511	2,784

Note(s): Risk estimates calculated from Requia, Adams *et al*. (2018), who did not find a link between carbon monoxide and mortality.
Source(s): Defra 'Modelled background pollution data', Requia, Adams *et al* (2018); Cambridge Econometrics analysis.

All prevalence observed in 2019 is below the UK government guidance for mean annual concentrations. These limits are 40 µg/m^3 for NO_2 and PM_{10}, and 25 µg/m^3 for $PM_{2.5}$, while the maximum prevalence observed is 34, 22 and 12 µg/m^3 respectively.[11] Table 5.7 below shows the distribution of the impacts of the three most harmful pollutants across the population of the north.

Table 5.7: Population affected by impacts tied to air pollution

Health impact: increased risk of mortality	Population affected ('000s)	Proportion of affected population in lowest IMD decile (%)
Nitrogen dioxide		
High impact (over 2.33%)	5,880	30
Medium impact	5,540	14
Low impact (up to 1.58%)	4,411	6
Particulate Matter 2.5		
High impact (over 2.0%)	5,850	28
Medium impact	5,150	14
Low impact (up to 1.68%)	4,540	10
Particulate Matter 10		
High impact (over 1.50%)	5,640	26
Medium impact	5,320	16
Low impact (up to 1.27%)	4,570	10

Note(s): Totals may not be equal across impacts due to rounding error.
Risk brackets for 'low', 'medium' and 'high' divide the population into equal thirds.
Across the north, 18% of the population find themselves in the lowest IMD decile.
Population impacts are calculated at a postcode level and then grouped by IMD LSOA when reporting deprivation.
Source(s): UK Data Service 'UK 2011 census Postcode Headcounts'; Cambridge Econometrics analysis.

A clear pattern emerges from the table above, with the areas of 'high' increase risk of mortality from air pollution having a larger proportion of population in the lowest IMD decile (26 – 30%). For reference, an average of 18% of the population of the north find themselves in the lowest IMD decile so this 26-30% means worse-off people are disproportionately represented in these high

[11] Defra, 'UK Air Quality Limits' Air_Quality_Objectives_Update.pdf (defra.gov.uk), Cambridge Econometrics Analysis

impact areas. On the other hand, in areas of 'low' risk only 6 - 10% of the population are within the lowest IMD decile. This suggests a strong association between pollution and deprivation. We also note the tendency for people living in these deprived areas to be younger. It was beyond the scope of this work to consider causal factors.

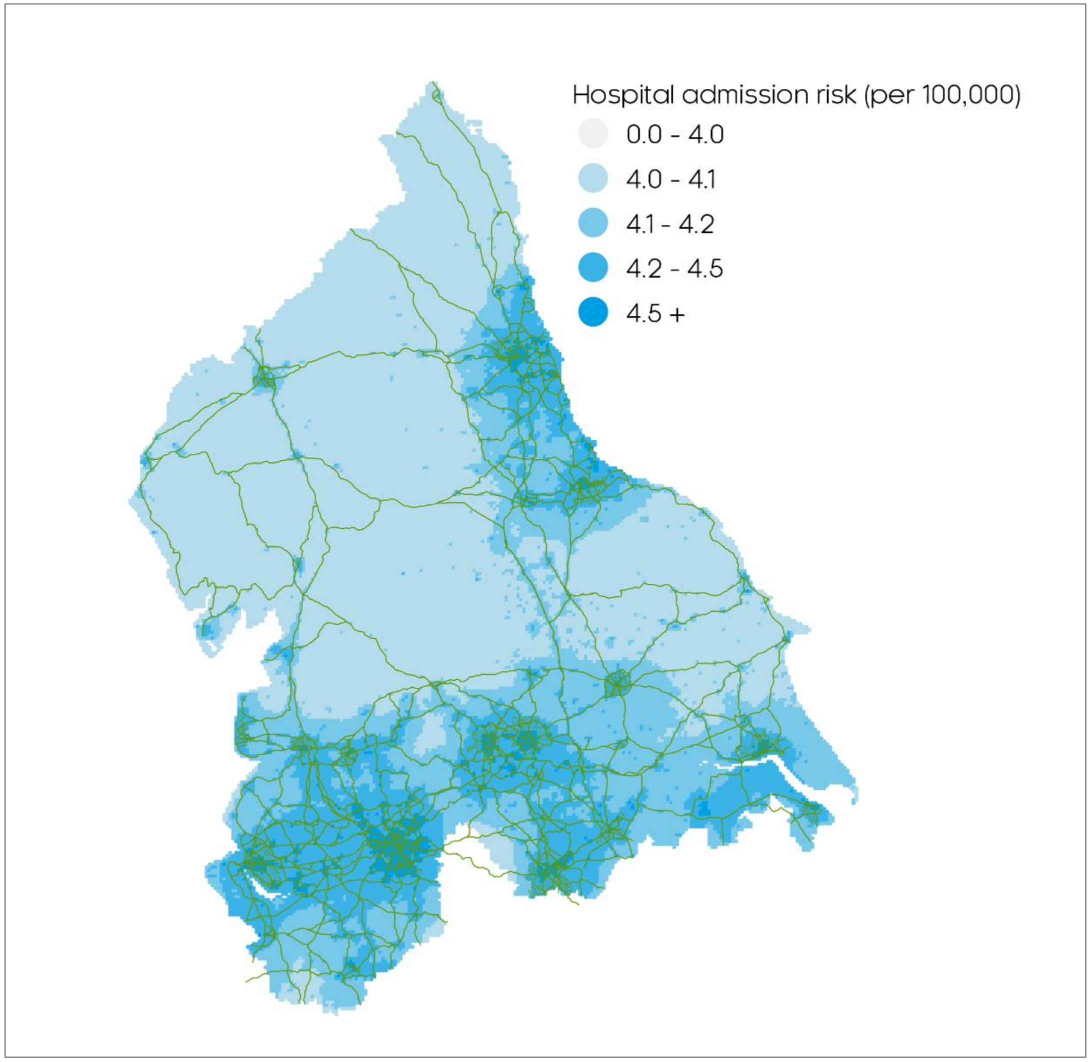
Carbon monoxide

Carbon monoxide arises mainly from internal combustion of fossil fuels (most commonly road transport) and industrial processes. Higher concentrations are thus found around residential areas and major roads; and industrial zones. Consequently, heightened risks of hospital admissions are in these same places, and especially the more densely populated residential areas (see Figure 5.9).

When compared to the other pollutants considered, the risk of such admissions is relatively low for carbon monoxide. Even in areas with high concentrations, the annual estimated admissions risk rises by, at most, 5 people per 100,000 in the most built-up urban areas. This rate is three orders of magnitude smaller than, for example, nitrogen dioxide (as below).

Requia, Adams, *et al* (2018) did not find any clear relationship between carbon monoxide exposure and mortality.

Figure 5.9: Increased hospital annual admission risk from carbon monoxide



Note(s): Risk estimates calculated from Requia, Adams *et al* (2018).

Source(s): Defra 'Modelled background pollution data', Requia, Adams *et al* (2018); Cambridge Econometrics analysis.

Nitrogen dioxide

Nitrogen dioxide exposure substantially increases hospitalisation and mortality risk

Nitrogen dioxide (NO_2) is mainly formed from cars and combustion of fossil fuels. We therefore see a similar spatial distribution as for carbon monoxide (see Figure 5.11).

However, the associated health risks are significantly higher for NO_2 than carbon monoxide, increasing the risk of hospital admission by as much as 6,445 people per 100,000. This compares to a rate of 36 people per 100,000 for carbon monoxide (as above).

The associated risk of mortality is also high from NO_2 exposure, increasing the risk by as much as 5,427 people per 100,000 in the highest-emissions areas.

Given the source of these emissions, the health risks are concentrated in densely populated areas and therefore have significant public health implications.

PM_{10} and $PM_{2.5}$

Health impacts arise more from $PM_{2.5}$ (in residential areas) than PM_{10} (along major roads)

Particulate matter refers to any non-gas substance in the air and so can come from a variety of sources. From transport, coarser PM_{10} is associated with trace metals emitted during vehicle motion as well as tire and brake wear (Defra, 2005). Finer particulate matter ($PM_{2.5}$) is associated with exhaust emissions from diesel vehicles, and also tire and brake wear (Defra, 2012). However, there is no data available on the emissions by source and pollutant, therefore the analysis cannot isolate pollution linked exclusively to transport.

Increased risk of mortality associated with $PM_{2.5}$ is concentrated in densely populated areas. In contrast, heightened mortality risk associated with PM_{10} is more clearly concentrated around major roads (see Figure 5.12). The health impacts of particulates are thus more consequential for $PM_{2.5}$ given the location of the population of the north.

Although both sizes of particle arise from road traffic, the evidence suggests that, while $PM_{2.5}$ concentrations are high within 1 metre of the kerb, these particulates are quick to disperse, with limited concentrations past that distance (Defra, 2012). PM_{10} is slower to disperse, leading to a wider spread around the road network. This is visible in Figure 5.12.

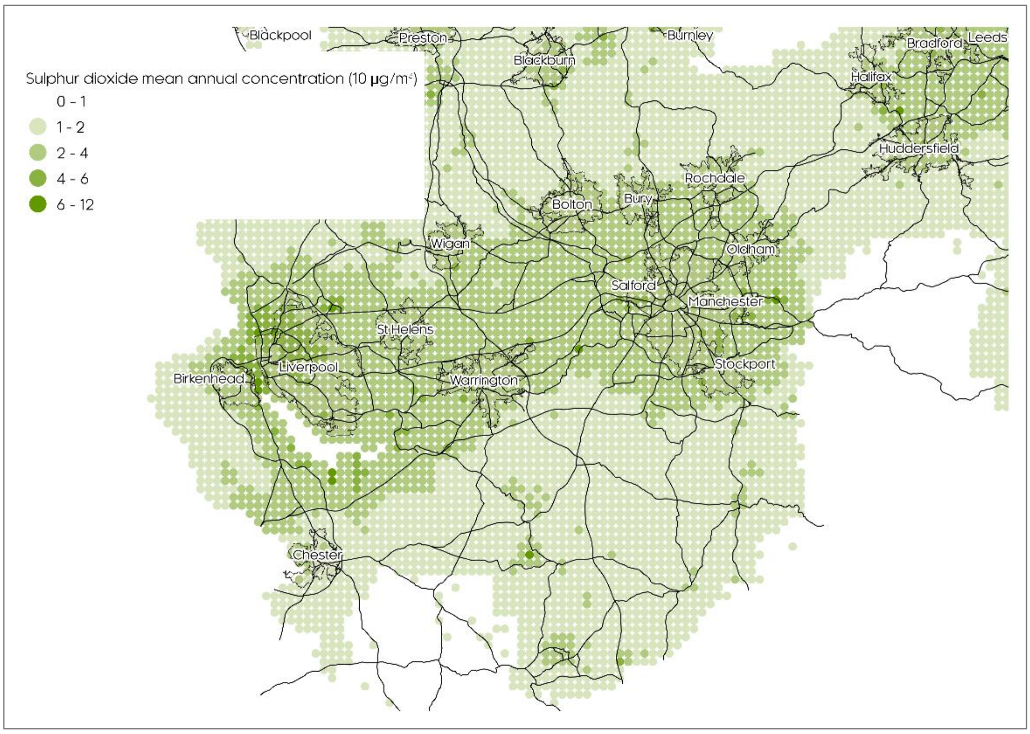
Sulphur dioxide

Health impacts from sulphur dioxide also cluster around population centres

The main source of sulphur dioxide emissions is fossil fuel combustion. Again, this leads to the pollutant concentrating around population centres and industrial areas. Sulphur dioxide is more of an industrial than a transport pollutant. As such, concentrations of sulphur dioxide follow the road network less clearly compared with carbon monoxide and nitrogen dioxide. The estimated increase in mortality risk ranges from 61 to 589 per 100,000 people, and is concentrated around densely populated areas.

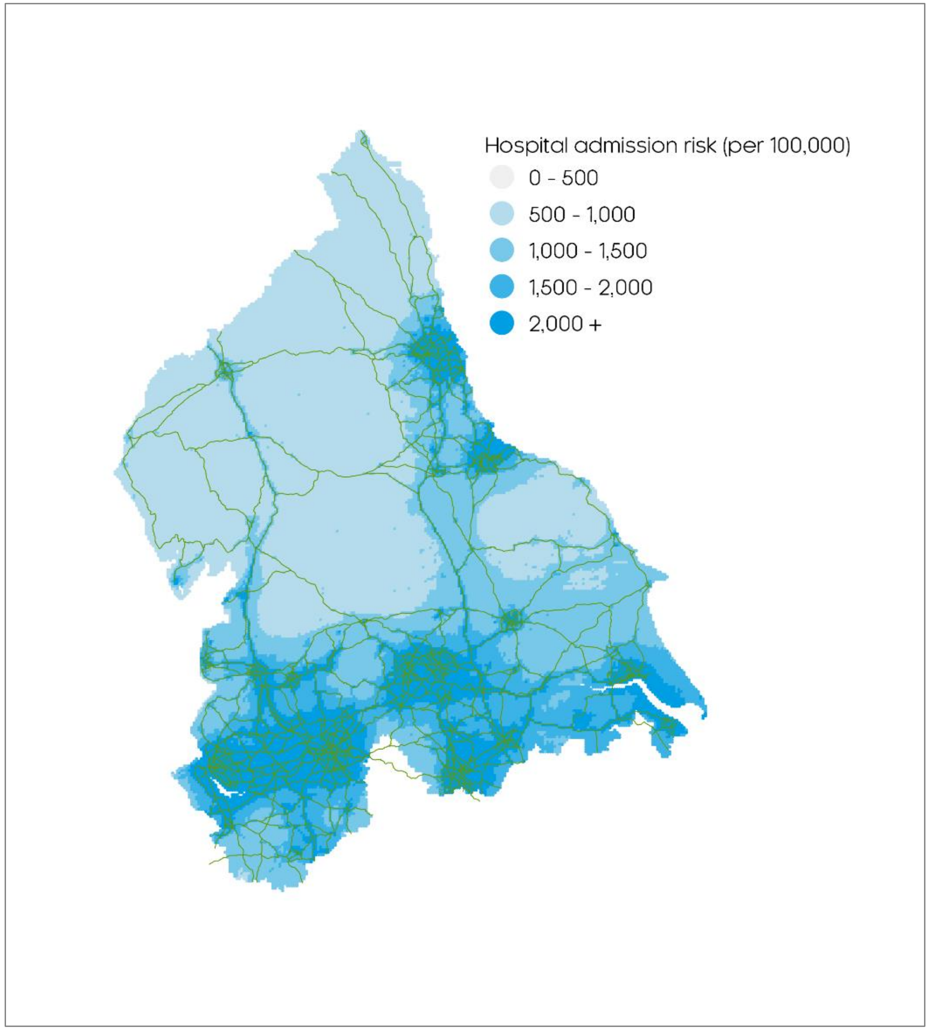
The associated increases in hospital admission risk are wider, ranging from 202 to 1,935 people per 100,000, by virtue of the larger coefficients. The highest concentrations are not clustered around major road networks and thus are more likely to be industry- rather than transport-related.

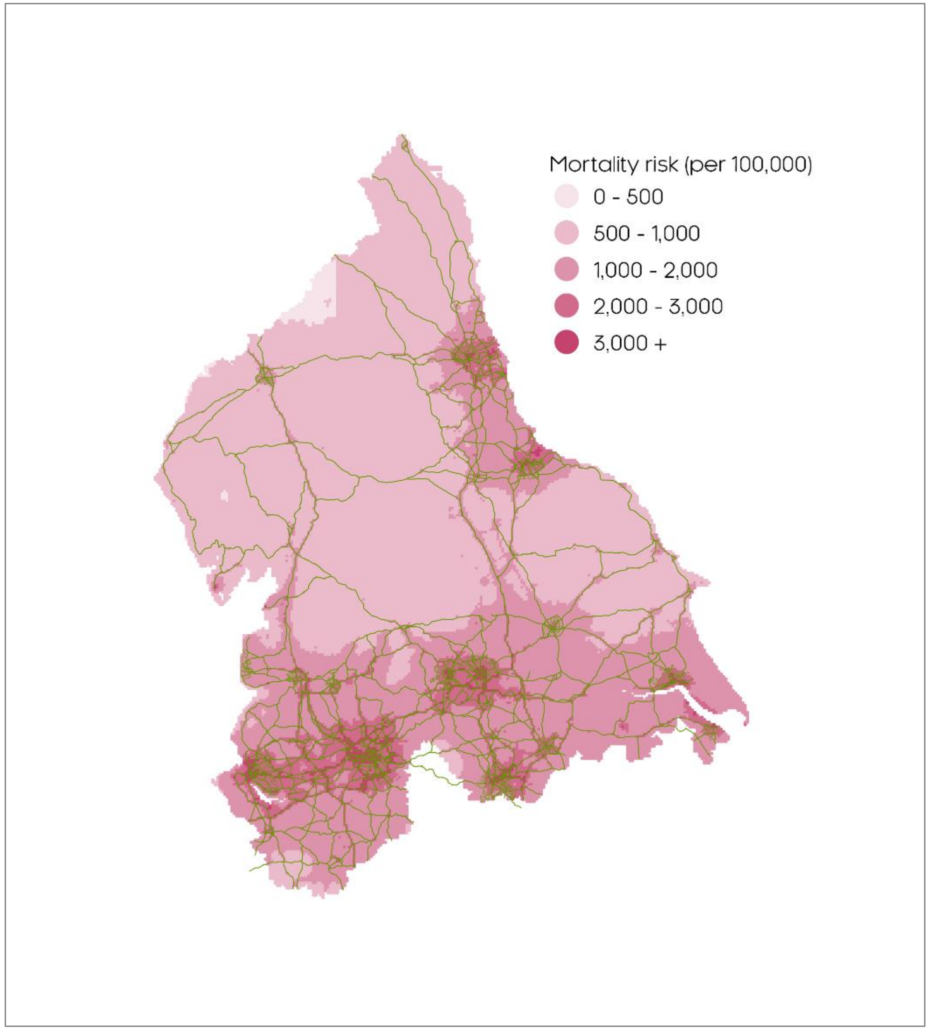
Figure 5.10: Concentrations of SO_2 around Manchester and Liverpool



Source(s): Defra 'Modelled background pollution data'.

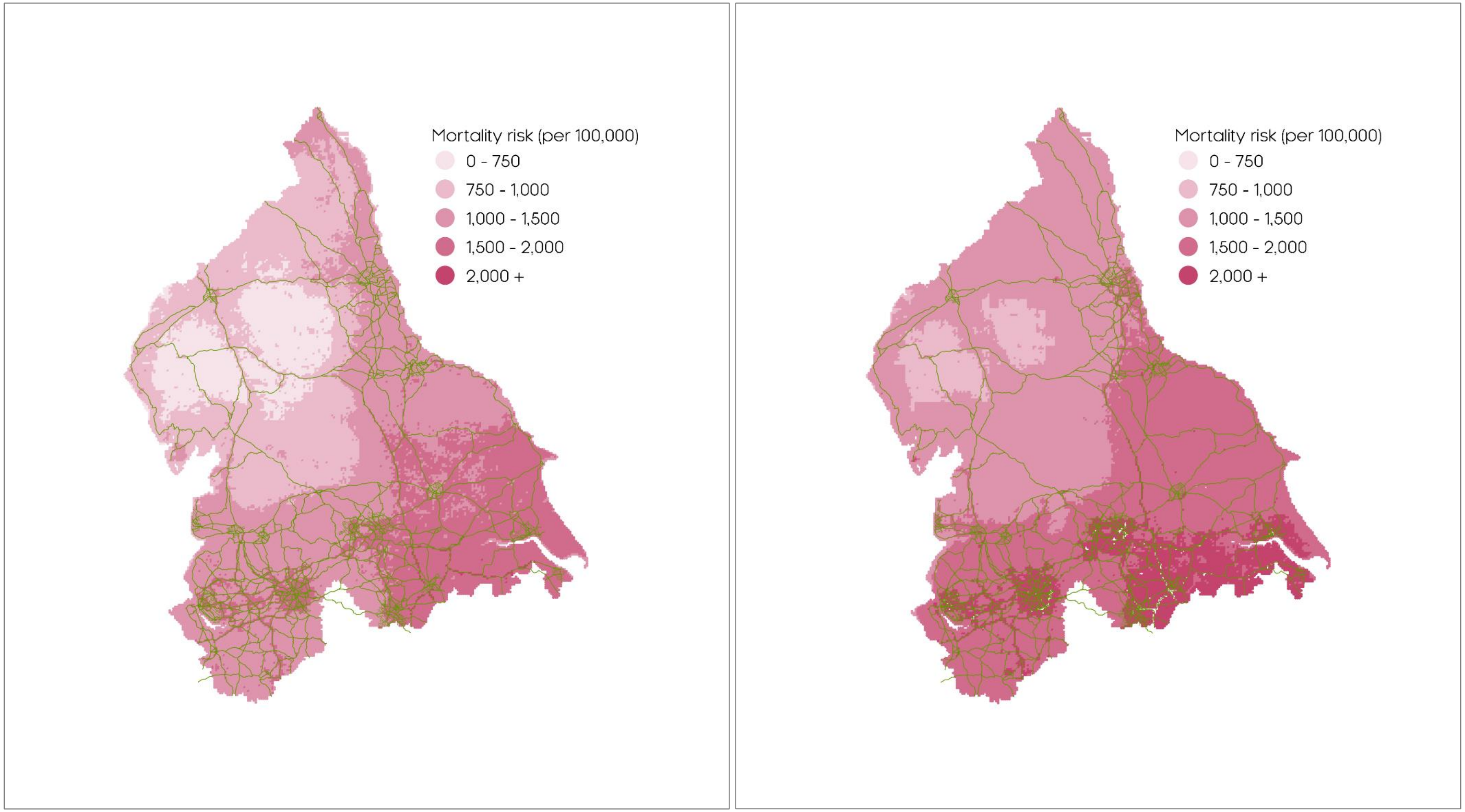
Figure 5.11: Increased health risks from nitrogen dioxide





Note(s): Risk estimates calculated from Requia, Adams *et al* (2018).
Source(s): Defra 'Modelled background pollution data', Requia, Adams *et al* (2018); Cambridge Econometrics analysis.

Figure 5.12: Increased mortality risk from PM_{10} (left) and $PM_{2.5}$ (right)



Note(s): Risk estimates calculated from Requia, Adams *et al* (2018).
Source(s): Defra 'Modelled background pollution data', Requia, Adams *et al* (2018); Cambridge Econometrics analysis.

Ozone

Ozone is a powerful oxidant that causes damage to mucous and respiratory tissues in animals, as well as plant tissues. Low level (tropospheric) ozone is the product of two anthropogenic pollutants, forming when nitrogen oxides react with volatile organic compounds (VOCs). Sources of VOCs include chemical plants and oil-based paints. Ozone can take hours or days to form and may reach maximum concentrations many miles downwind of these original sources.[12]

European guidance sets an air quality standard for ozone by which concentrations should not exceed 120 μg/m^3 (the maximum daily eight-hour mean) on more than 25 days each year (averaged over three years).[13]

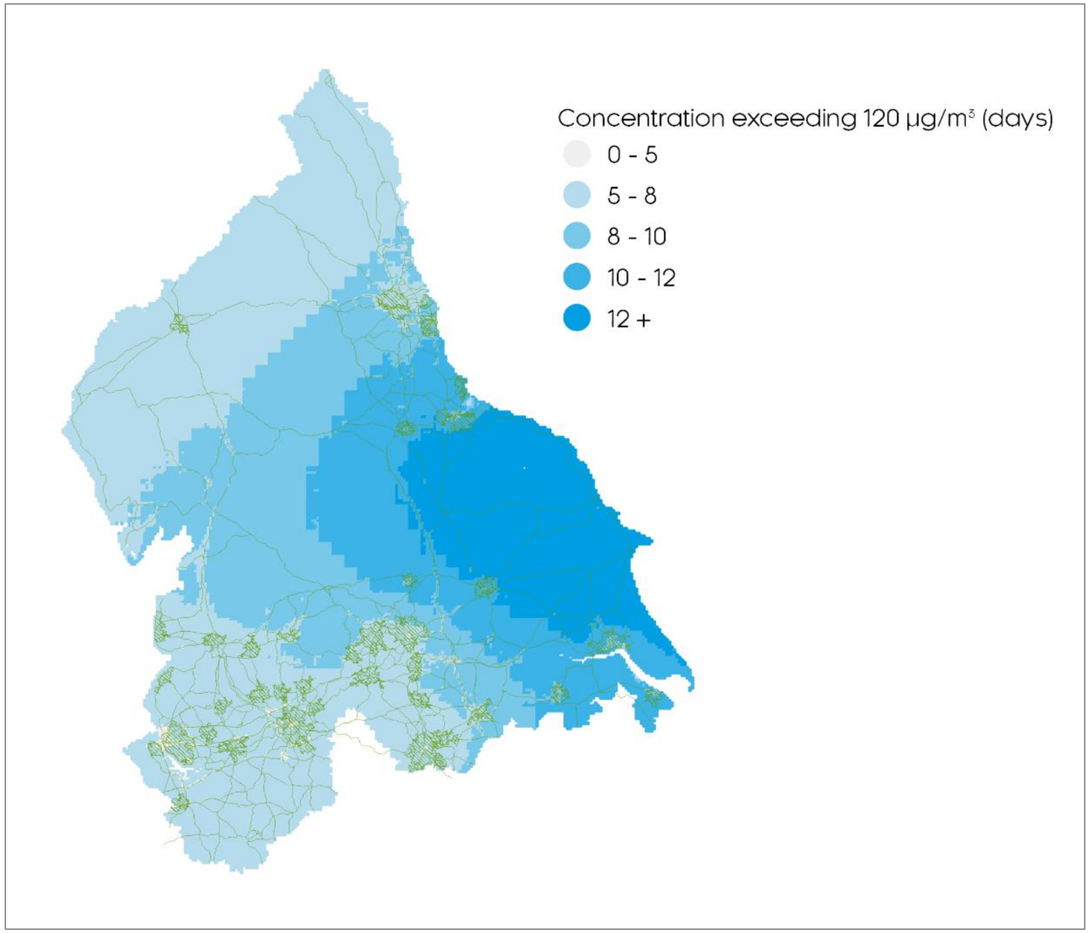
Compared to other pollutants considered in this analysis, the health risks from ozone exposure are relatively low. Even if an area were to exceed these concentrations every day of the year, hospitalisation and mortality risks would increase by just 19 and 8 people per 100,000, respectively.

Figure 5.13 shows the number of days on which ozone concentrations exceeded the above threshold in 2019. The map shows the highest exposure is quite far from population centres in the north, suggesting quite limited impacts (especially given the comparatively smaller increases in health risks).

[12] UK Air Pollution Information System: Ozone: http://www.apis.ac.uk/overview/pollutants/overview_o3.htm

[13] European Commission 'Air quality standards': https://ec.europa.eu/environment/air/quality/standards.htm

Figure 5.13: Areas of high annual ozone exposure



Note(s): Risk estimates calculated from Requia, Adams *et al* (2018).

Source(s): Defra ‘Modelled background pollution data’, Requia, Adams *et al* (2018); Cambridge Econometrics analysis.

5.4 Limited access to green space, recreation and leisure

The association between proximity to green space and human health has been long established by the literature. With increasing urbanisation, the lack of green space in cities has been noted as a risk factor for a range of physiological and psychological conditions. Green space is thought to affect health in many indirect ways, such as by increasing opportunities for physical activity, social interaction, cleaner air, sun exposure, and exposure to micro-organisms within the natural environment. All of these can be linked to better health outcomes.

The North of England is filled with broadly-defined green space, especially in more remote or rural areas of the region. Our analysis examines the relationship between residential proximity to green space (including areas with tree cover, open green/grassy areas [excluding farmland], and areas with other low-lying vegetation) and the following health outcomes:[14]

- wellbeing, focusing on Manchester and Newcastle, owing to the urban focus of the underlying evidence
- diabetes
- psychosocial distress
- self-rated general health

The wellbeing analysis suggests that around half of the population of Manchester does not live within 300 metres of green space of sufficient size to confer wellbeing benefits. The benefits for those in proximity to green space are relatively mild, though, increasing wellbeing scores by no more than 0.5%.

The reduced risk of type 2 diabetes due to proximity to green space is most concentrated in areas that are less populated, with urban areas, especially those in the corridor from Sheffield and Leeds to Newcastle and the southeast area around Lincolnshire, most at risk from type 2 diabetes as a result of limited access to green space.

The reduced risk of psychosocial distress is most widespread across the region, as this health outcome is dependent upon a lower threshold of proximate green space as well as a broader definition of green space compared to self-report general health (as below; by including tree canopy coverage).

The risk reduction in self-reported fair or poor general health (a negative health outcome) is the most diffuse, as this health outcome is dependent on tree canopy coverage, which makes up a smaller proportion of the green space in the North of England.

Overall, the region could be defined as one in which the health risks due to lack of green space are most acute in urban areas, though there are many rural/remote areas with green space near those major cities.

[14] For the purposes of our analysis, green space is defined as deciduous woodland, coniferous woodland, improved grassland, neutral grassland, calcareous grassland, acid grassland, heather, and heather grassland, as per the UK Centre for Ecology and Hydrology (UKCEH) land use categorisation.

Tree canopy is defined as deciduous or coniferous woodland, per the UKCEH land use categorisation.

Wellbeing

Our analysis of the wellbeing benefits of green space uses the indicators defined in the Annual Population Survey (APS). Looking at green space in terms of its wellbeing impacts is only applicable in urban settings, as most rural places will have access to abundant natural green space or fields within 300 metres. The results of a study by Houlden *et al*. (2018) for London are applied to the Manchester area, as the largest urban area in the North and thus closest to London in size. Given the city focus of the evidence we do not apply the approach to the entire North. The paper's results could be applied to other large urban areas but not in towns or rural areas because of the nature of the underlying evidence and the greater abundance of green space.

Table 5.8 shows that the benefits of being near green space (within 300 metres: around a five-minute walk) depend on the size (area) of that green space. The analysis maps proximity to such green space and the associated wellbeing benefits by area.

Table 5.8: Wellbeing benefits of green space

	Increase in the wellbeing indicator per km^2 of green space within 300 metres (%)	p-value
Life satisfaction	0.8034	< 0.001
Worthwhile	0.7398	< 0.001
Happiness	0.5208	< 0.001

Note(s): Life satisfaction - Very high rating of satisfaction with their lives overall.
Worthwhile - Very high rating of how worthwhile the things they do are.
Happiness - Rated their happiness yesterday as very high.
The percentages above refer to the change in the score, measured on a five-point scale.

Source(s): Houlden *et al*. (2018).

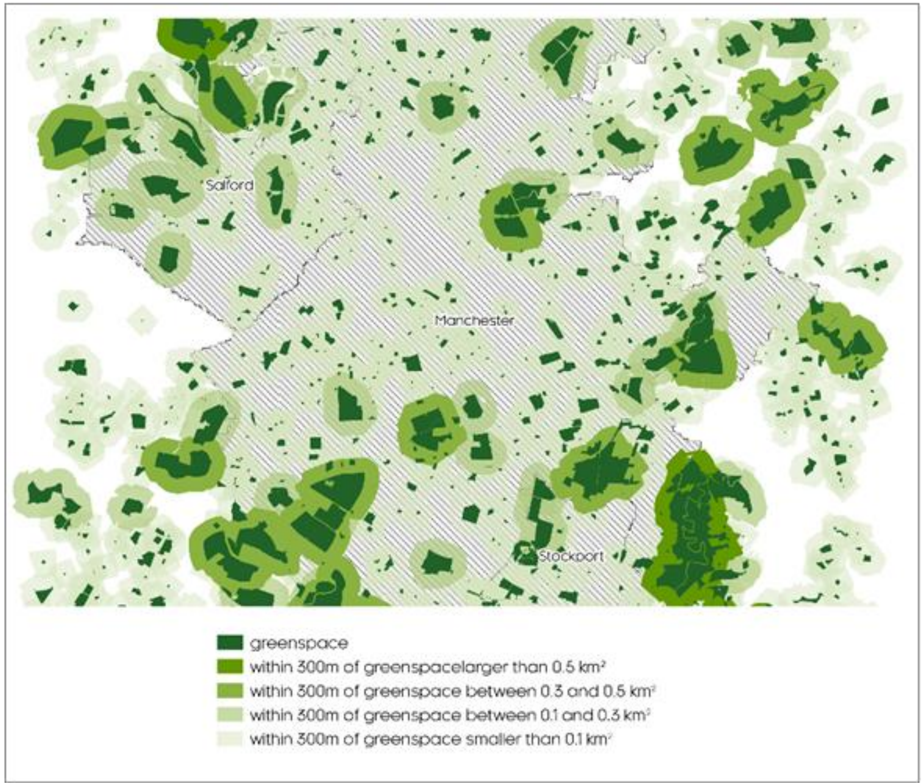
Figure 5.14 shows green space for the Manchester area. Each green space area is surrounded by a 300-metre buffer to proxy access. The buffers are coloured according to the size of the green space, to show the size of the associated wellbeing benefits.

Visibly grey areas are not within 300 metres of any (identified) green space and, by our approach, do not benefit from increased wellbeing. People living within 300 metres of parks larger than 0.5 km^2 are estimated to have improved life satisfaction by at least 0.4%, with their sense of how worthwhile their activities are, and happiness also increasing by at least 0.37% and 0.26%, respectively. Those near parks with an area of 0.3 km^2 would benefit from increased life satisfaction, sense of worth and happiness by 0.24%, 0.22% and 0.16%, respectively.

Young people in Manchester benefit the least from existing green space

Of note is that the least green LSOAs also have the lowest median age (see Figure 5.15). This suggests that, in terms of wellbeing, younger people benefit the least from existing green space.

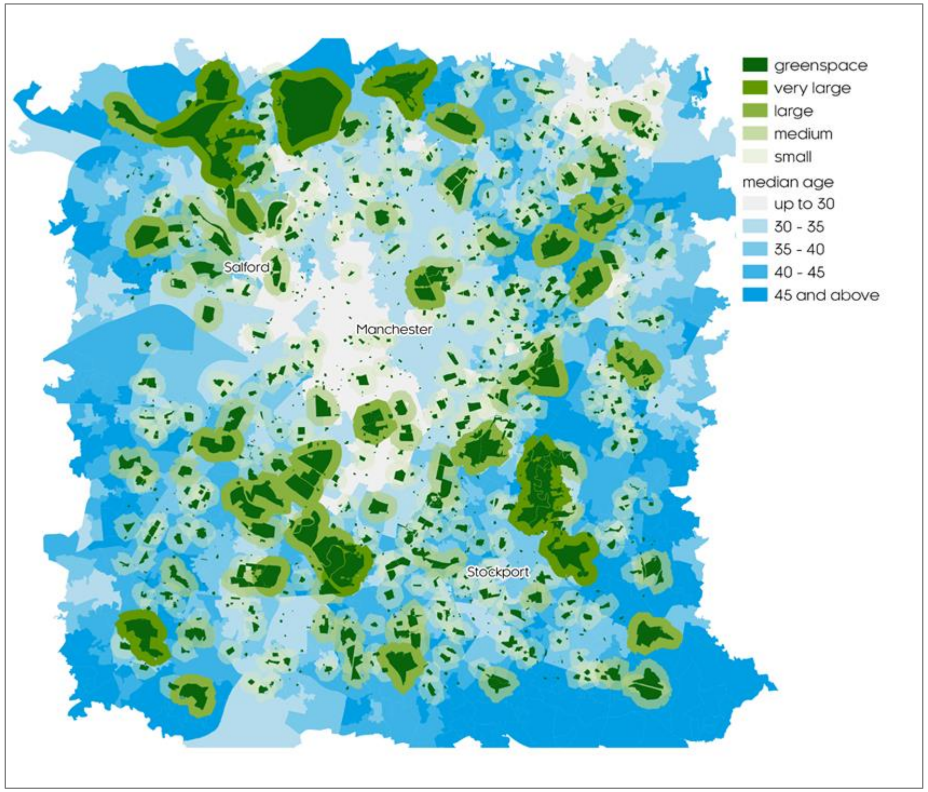
Figure 5.14: Green space around Manchester



Note(s): Some parks appear as multiple areas (rather than a single area), reflecting their representation in the underlying data.

Source(s): Ordnance Survey ‘Open Greenspace’; Cambridge Econometrics analysis.

Figure 5.15: Green space and median age around Manchester



Note(s): Some parks appear as multiple areas (rather than a single area), reflecting their representation in the underlying data.
Green spaces are classified as very large (larger than 0.5 km^2), large (between 0.3 and 0.5 km^2), medium (between 0.1 and 0.3 km^2) and small (between 0.01 and 0.1 km^2). Very small green space (smaller than 0.01 km^2 or 1 hectare) is excluded because of its minimal estimated wellbeing impacts.

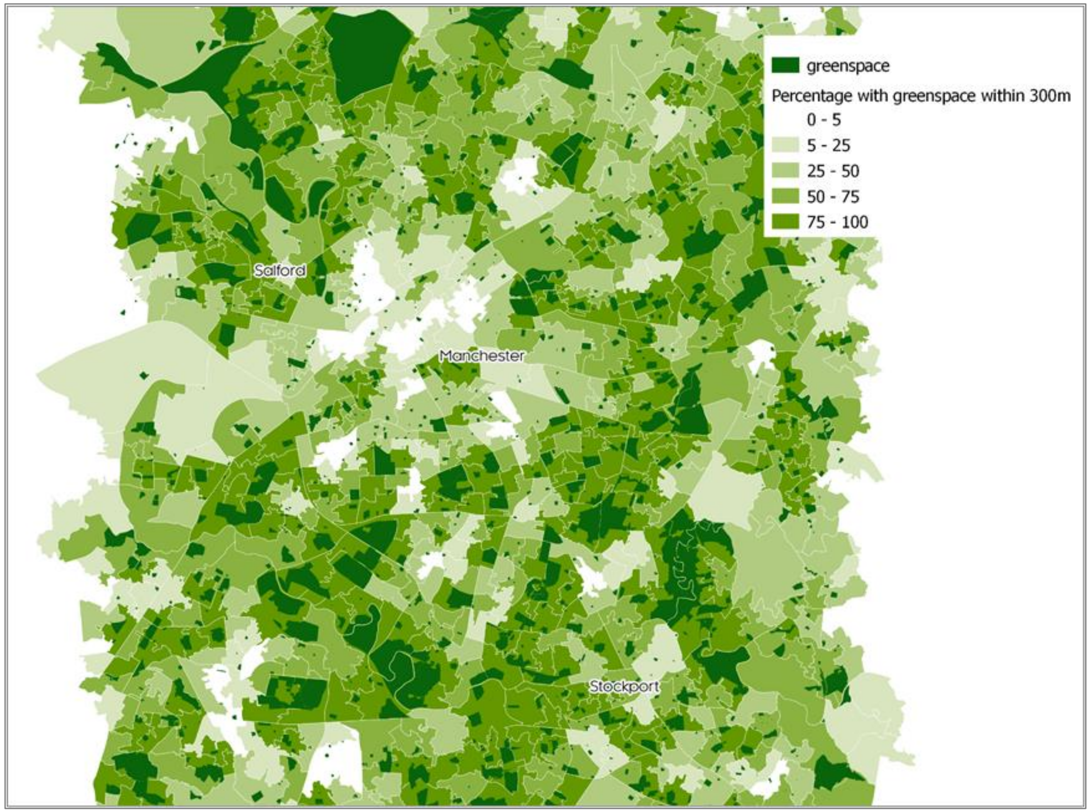
Source(s): Ordnance Survey ‘Open Greenspace’, ONS ‘Lower layer Super Output Area population estimates’; Cambridge Econometrics analysis.

The magnitude of the wellbeing impacts quickly diminishes with decreasing park size. Densely populated areas in the centre of Manchester do not have easy access to large green space. This means that the potential wellbeing benefits of creating a new green space there would be significant and reach a large part of the population.

Assuming constant population density within each LSOA, we estimate that 800,000 people in the Manchester area have no green space larger than a hectare within 300 metres of their home. That is equivalent to 51% of the area's population.

Figure 5.16 identifies the percentage of people in each LSOA who have access to green space within 300 metres of their homes. In white and light-green areas, less than 25% of the population has access to green space larger than a hectare within 300 metres of their home.

Figure 5.16: Share of population in Manchester with green space within 300m of their homes



Note(s): Very small green space (smaller than 0.01 km^2 or 1 hectare) is excluded because of its minimal estimated wellbeing impacts.

Source(s): Ordnance Survey 'Open Greenspace', ONS 'Lower layer Super Output Area population estimates'; Cambridge Econometrics analysis.

Applying the same method to Newcastle shows quite different results. In the area examined, 324,645 people (69% of the population) are estimated to have access to green space within 300 metres of their home, whereas 146,631 (the remaining 31%) have not. In 20 LSOAs, **less than a quarter of the population** has nearby access to green space. In contrast, in 211 LSOAs, **more than half the population** is estimated to have access to greenspace. Two LSOAs (totalling 5,835 people) have no nearby access to greenspace: 006F (Salters Road, north of Nuns Moor) and 023H (near Newcastle train station).

Figure 5.17: Share of population in Newcastle with green space within 300m of their homes

Note(s): Very small green space (smaller than 0.01 km^2 or 1 hectare) is excluded because of its minimal estimated wellbeing impacts.

Source(s): Ordnance Survey 'Open Greenspace', ONS 'Lower layer Super Output Area population estimates'; Cambridge Econometrics analysis.

Diabetes

A study (Astell-Burt *et al*., 2014) of more than 250,000 people in Australia found that living in an area where more than 40% of the land in a 1 km radius is green space is associated with a significantly reduced risk of developing type 2 diabetes. Table 5.9 lists the reduced risk of developing type 2 diabetes associated with living in an area with specific increments of green space within a 1 km radius.

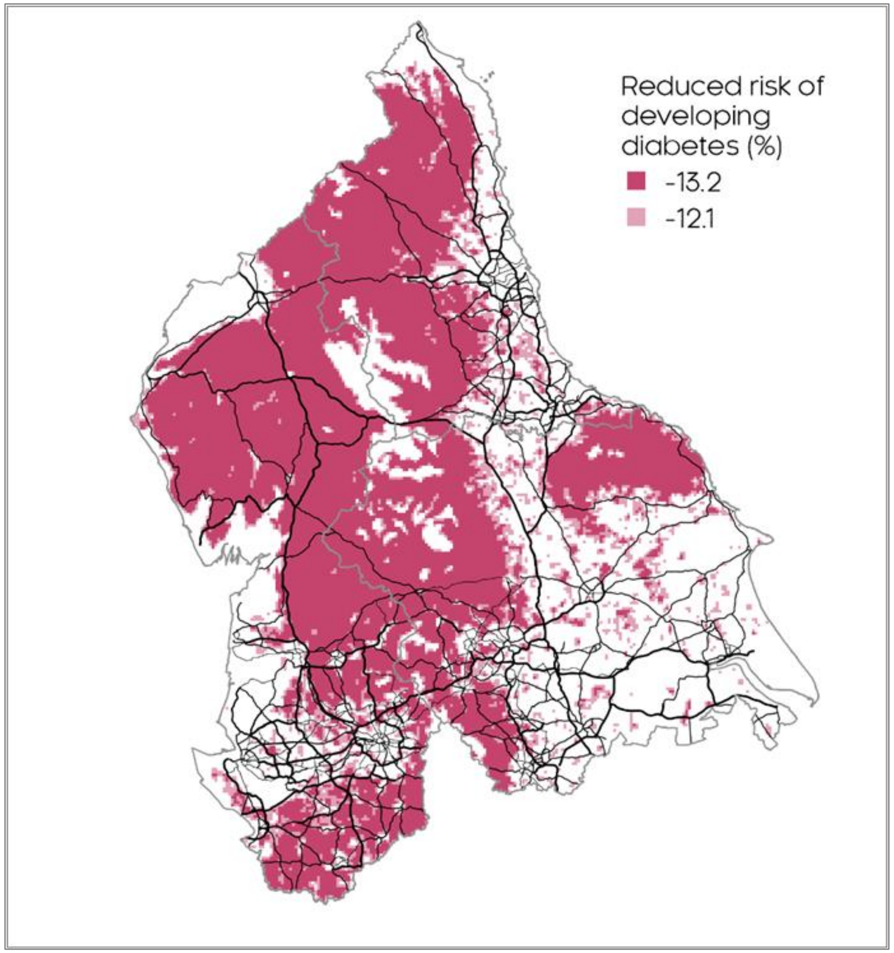
Figure 5.18 shows the spatial distribution of that reduced risk, highlighting the areas away from / around major cities. White areas on the map correspond to areas that have a lower density of green space within a 1 km radius (less than 40% of the surrounding area is covered by health-enhancing green space). The predominant land use in these areas is mostly urban, suburban, and farmland as well as rock- or sand-covered spaces in coastal areas.

Table 5.9: Reduced risk of type 2 diabetes relative to reference category (<40% within 1 km radius)

Green space increment (% within 1km radius)	Change in risk (%)
41-60	-12.1
60+	-13.2

Source(s): Astell-Burt *et al*. (2014).

Figure 5.18: Reduced risk of type 2 diabetes from proximity to green space



Source(s): Astell-Burt *et al*. (2014); Department for Transport (2020); UK Centre for Ecology & Hydrology; Cambridge Econometrics analysis.

Psychosocial distress

A study (Astell-Burt and Feng, 2019) of more than 45,000 people in Australia found that living in an area where more than 5% of the land in a 1-mile (1.6 km) radius is green space is associated with a significantly reduced risk of psychosocial distress. Table 5.10 reports the reduced risk of psychosocial distress associated with living in an area with specific increments of green space within a 1-mile radius.

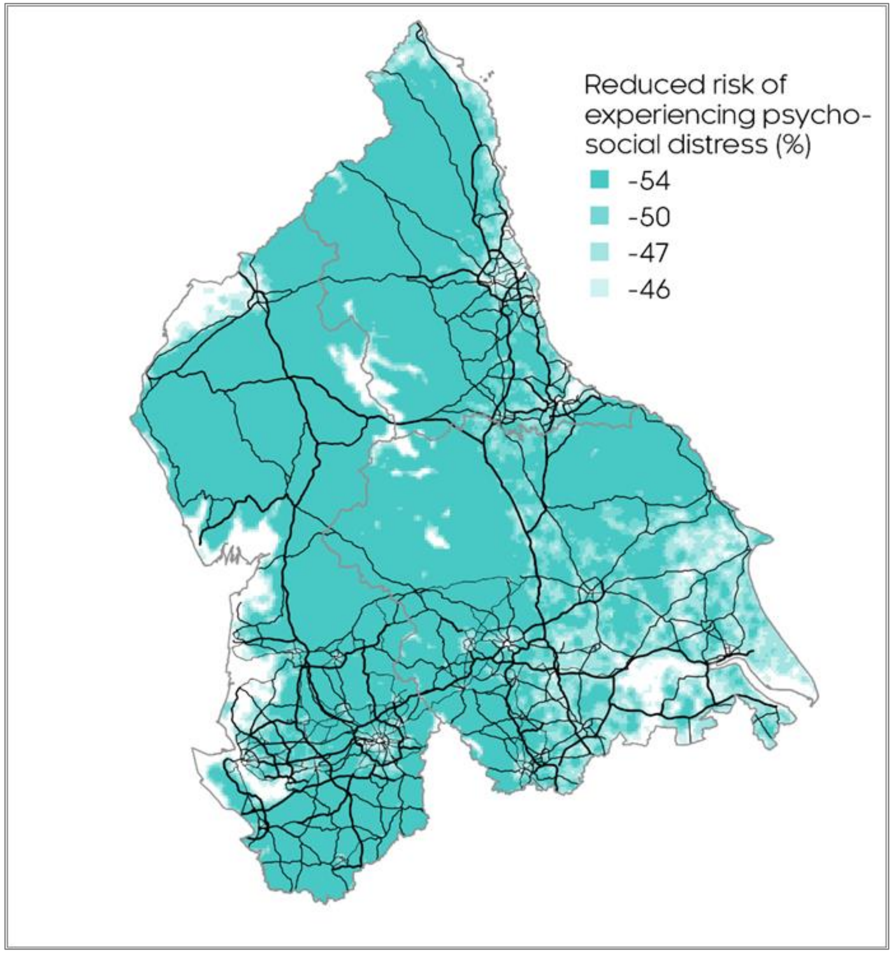
Figure 5.18 shows the spatial distribution of that risk reduction to be much more wide-ranging than for type 2 diabetes risk (as above) owing to the lower threshold identified for health benefits. The white space on this map corresponds to areas that have less than 5% of land within a 1-mile radius as green space. This lower threshold (especially compared with the diabetes analysis) translates to a large impact area across the region of the North.

Table 5.10: Reduced risk of psychosocial distress relative to reference category (<5% within 1-mile radius)

Green space increment (% within 1-mile radius)	Change in risk (%)
5-9	-46
10-19	-47
20-29	-50
30+	-54

Source(s): Astell-Burt and Feng (2019).

Figure 5.19: Reduced risk of psychosocial distress from proximity to green space



Source(s): Astell-Burt and Feng (2019); Department for Transport (2020); UK Centre for Ecology & Hydrology; Cambridge Econometrics analysis.

Self-rated general health

A study (Astell-Burt and Feng, 2019; as for psychosocial distress) of more than 45,000 people in Australia found that living in an area where more than 10% of the land in a 1-mile (1.6km) radius is tree canopy is associated with a significantly reduced risk of self-rated fair or poor general health. Table 5.11 lists the reduced risk of self-rated fair or poor general health associated with living in an area with specific increments of tree canopy within a 1-mile radius.

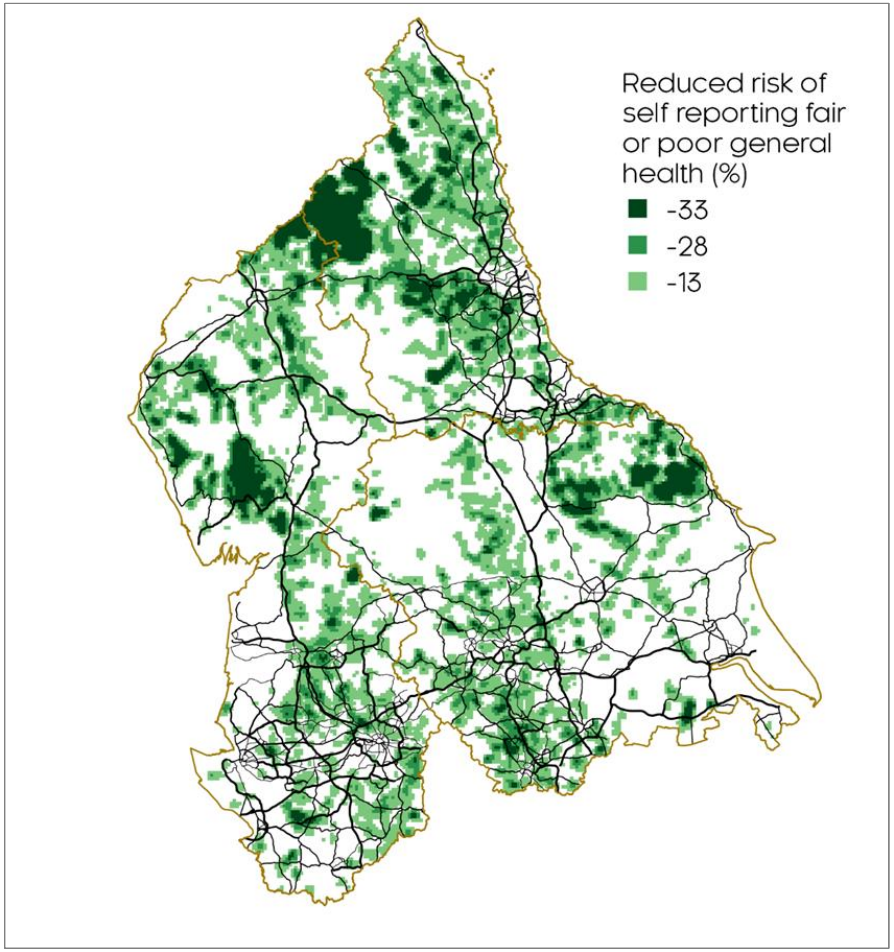
Figure 5.20 shows the spatial distribution of that risk reduction, with at least some areas in and around cities in the North. White spaces on this map correspond to areas with less than 10% of land within a 1-mile radius covered by tree canopy. According to Astell-Burth and Feng, people living there would be more likely to report poor general health, all other things constant. Relative to more broadly-defined green space, areas with sufficiently dense tree canopy are rarer in the North. The areas enjoying the greatest benefits of proximity to tree canopy are more concentrated in the northern half of the region, around Northumberland and Lake District National Parks. The North York Moors near Scarborough also offer good tree coverage.

Table 5.11: Reduced risk of self-rated fair or poor general health relative to reference category (<10% within 1-mile radius)

Tree canopy increment (% within 1-mile radius)	Reduced risk (%)
10-19	-13
20-29	-28
30+	-33

Source(s): Astell-Burt and Feng (2019).

Figure 5.20: Spatial risk of self-rated fair or poor general health from proximity to tree canopy in the North of England



Source(s): Astell-Burt and Feng (2019); Department for Transport (2020); UK Centre for Ecology & Hydrology; Cambridge Econometrics analysis.

Areas with the greatest health benefits from proximity to green space are less likely to be deprived areas

The 2011 census (the basis for our postcode-level analysis) reports 14.9m people living in the North of England, with the 2020 population estimates from Nomis reporting a more recent figure of 15.6m. From our (2011-based) analysis, some 5.2m people live in areas that benefit from lower risk of diabetes, 14.7m people live in areas that benefit from lower risk of psychosocial distress, and 9.1m people live in areas that benefit from a lower risk of self-rated fair to poor general health in the North. Table 5.12 lists the numbers of people in the North affected by each of these impacts. For diabetes and self-rated general health, those that live in the areas of highest risk were also more likely to be in the lowest decile of the 2015 English Indices of Multiple Deprivation (IMD). For psychosocial distress, few people (around 200,000) live in areas with the highest risk (receiving no estimated benefit from green space).

There is evidence of a steeper social gradient, with over one-third of people receiving the smallest benefit also living in the most deprived areas; while the rate falls to just over one in eight for areas seeing the highest benefit. In all cases, the areas enjoying the greatest health benefits from proximity to green space were least likely to have populations in the lowest IMD decile. This finding suggests that the health benefits of green space are unevenly distributed in the North, favouring wealthier or less deprived areas.

Table 5.12: Population affected by impacts tied to proximity to green space

Impact	Population affected ('000s)	Proportion of affected population in lowest IMD decile (%)
Diabetes		
Highest risk (0% risk reduction)	9,720	23.6
12.1% risk reduction	2,900	13.2
13.2% risk reduction	2,270	5.0
Psychosocial distress		
Highest risk (0% risk reduction)	200	16.7
46% risk reduction	490	34.9
47% risk reduction	1,920	30.9
50% risk reduction	2,970	23.8
54% risk reduction	9,310	13.8
Fair to poor general health		
Highest risk (0% risk reduction)	5,750	22.8
13% risk reduction	6,230	18.1
28% risk reduction	2,310	13.3
33% risk reduction	600	7.0

Note(s): Population totals (middle column) may not be equal across impacts due to rounding.
Source(s): Cambridge Econometrics analysis.

5.5 Noise pollution

Traffic noise has both physical and mental health impacts

Noise in the environment is a stressor that can trigger physiological and psychological responses in the body. Chronic noise exposure is a risk factor for a range of non-communicable health conditions, including heart disease (Münzel *et al*., 2018) and depression (Seidler *et al*., 2017).

This analysis focuses on the relationships between:

- road traffic noise and physical health: coronary heart disease (drawing on a meta-analysis by Babisch, 2014) and hypertension (van Kempen and Babisch, 2012)
- road and rail traffic noise, and mental health: depression (Seidler *et al*., 2017)

A meta-analysis by Babisch (2014) considered 24 studies on the relationship between road traffic noise and coronary heart disease and found an odds ratio of 1.08 for each increment of 10 decibels (dB) from 55 to 75 dB.

For hypertension, van Kempen and Babisch (2012) considered 27 studies in their meta-analysis of the relationship with road traffic noise and found an odds ratio of 1.034 for each increment of 5 dB from 45 to 75dB.

Table 5.13 lists the increases in the risks of coronary heart disease and hypertension associated with living in an area with road traffic noise.[15] The table begins at 55 dB to match the measurements in the accompanying traffic noise data from Defra.

Table 5.13: Increased physical health risks from road traffic noise

	Increase in health risk (%)	
Increase in noise (dB)	Coronary heart disease	Hypertension
55.0 - 59.9	8.0	6.9
60.0 - 64.9	8.0	10.6
65.0 - 69.9	16.6	14.3
70.0 - 74.9	16.6	18.2
75.0+	26.0	22.2

Source(s): Coronary heart disease: Babisch (2014).
Hypertension: van Kempen and Babisch (2012).

Both road and rail traffic noise increase depression risk, but rail impacts are less certain at high noise levels

Seidler *et al*. (2017) considered the association, in Germany, between both road and rail traffic noise, and depression. This study found a strong, positive relationship between road traffic noise in one's place of residence and the risk of experiencing depression. The authors also found that rail traffic noise does increase the risk of experiencing depression, but this effect was not significant at higher levels of noise, likely because of fewer observations at close proximity to the rail network. Table 5.14 lists the increase in risk of depression associated with living in an area with road and rail traffic noise.

[15] Measured as the average noise level in decibels over a 16-hour period between 07:00 and 23:00.

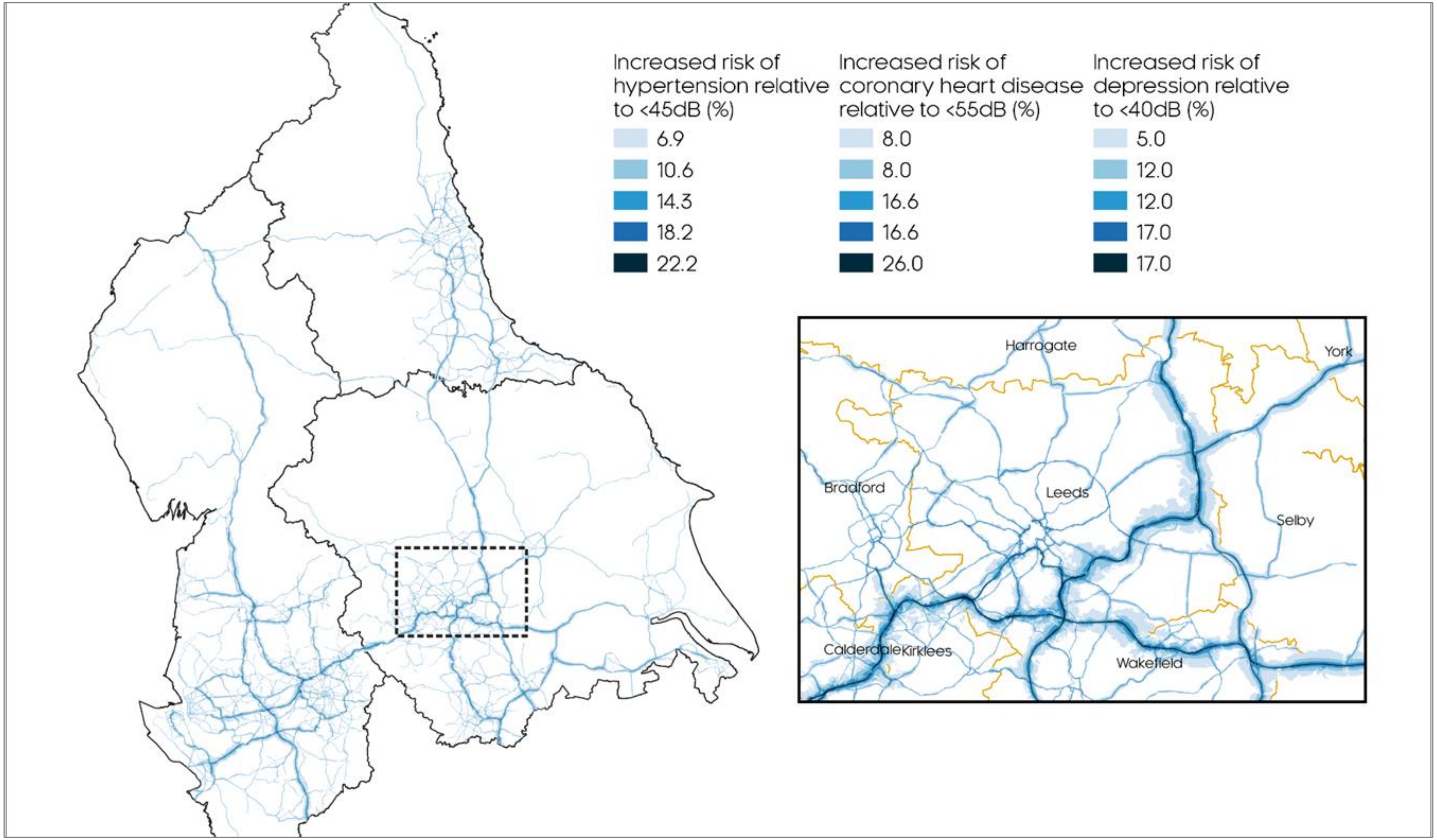
Table 5.14: Increased mental health risks from road and rail traffic noise

	Increase in depression risk (%)	
Increase in noise (dB)	Road	Rail
55.0 - 59.9	5.0	6.0
60.0 - 64.9	12.0	15.0
65.0 - 69.9	12.0	7.0*
70.0 - 74.9	17.0	-7.0*
75.0+	17.0	-7.0*

Note(s): * denotes estimates that are uncertain and not statistically significant at the 5% level. This is likely due to small sample sizes in close proximity to rail
Source(s): Seidler *et al*. (2017).

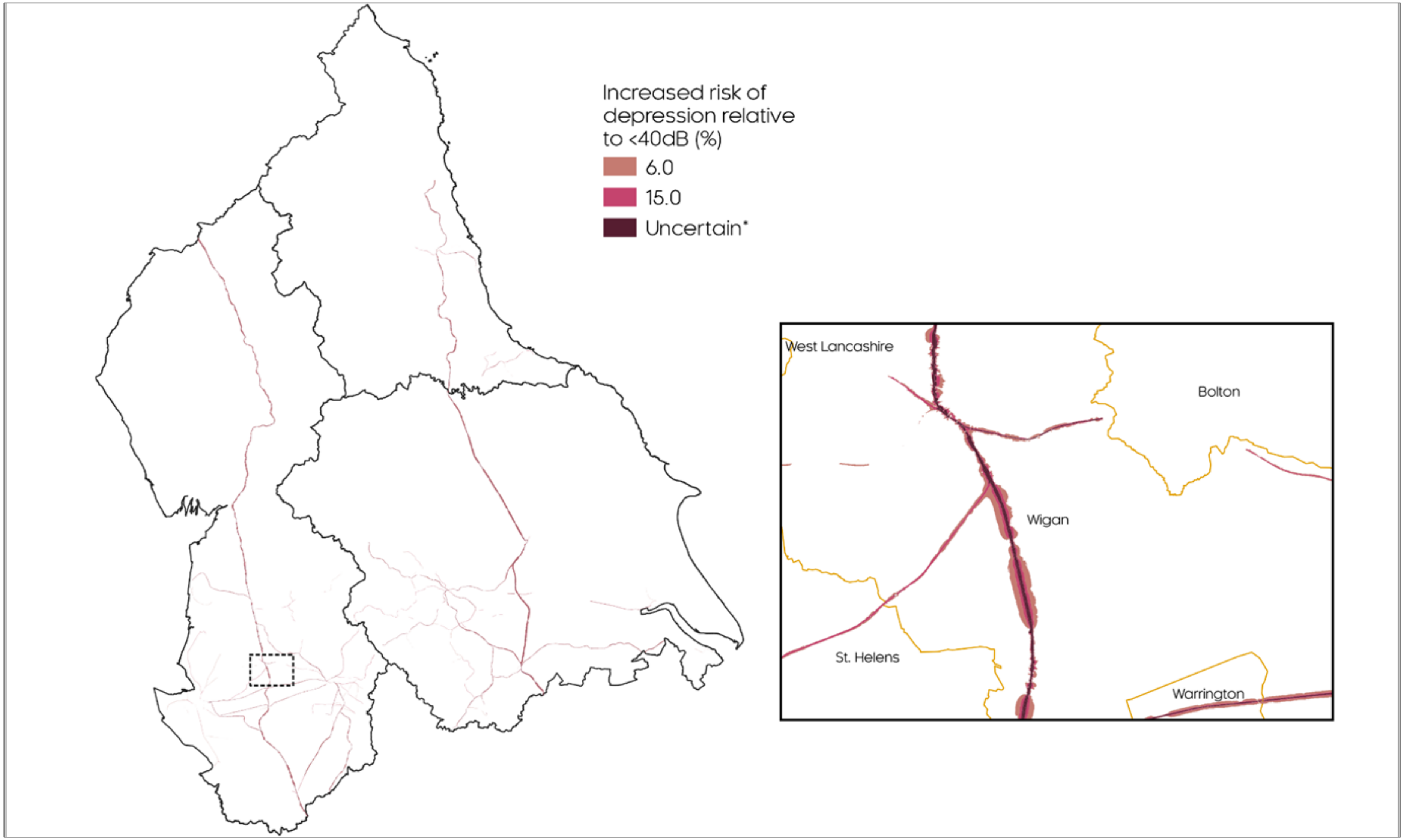
Figure 5.21 shows that the areas with the highest risk of health impacts due to road traffic noise are concentrated around major motorways, including more densely-populated urban areas around Manchester, Liverpool, Leeds, and Newcastle. The risk of depression due to rail traffic noise is much more diffuse, though there are areas of higher risk concentrated around two major north-south rail lines: one leading to Glasgow in the west and the other heading to Edinburgh in the east (see Figure 5.22). Both are electric, therefore noise differences may be due to the frequency rather than type of service. Generally, areas of high rail traffic noise do not extend as far from rail tracks as road traffic noise does from major roads and even more so for motorways, suggesting rail transport contributes much less to the burden of disease than does road transport.

Figure 5.21: Increased health risks from road traffic noise



Source(s): Babisch (2014), van Kempen and Babisch (2012), Seidler et al. (2017); Defra; Cambridge Econometrics analysis.

Figure 5.22: Increased mental health risks from rail traffic noise



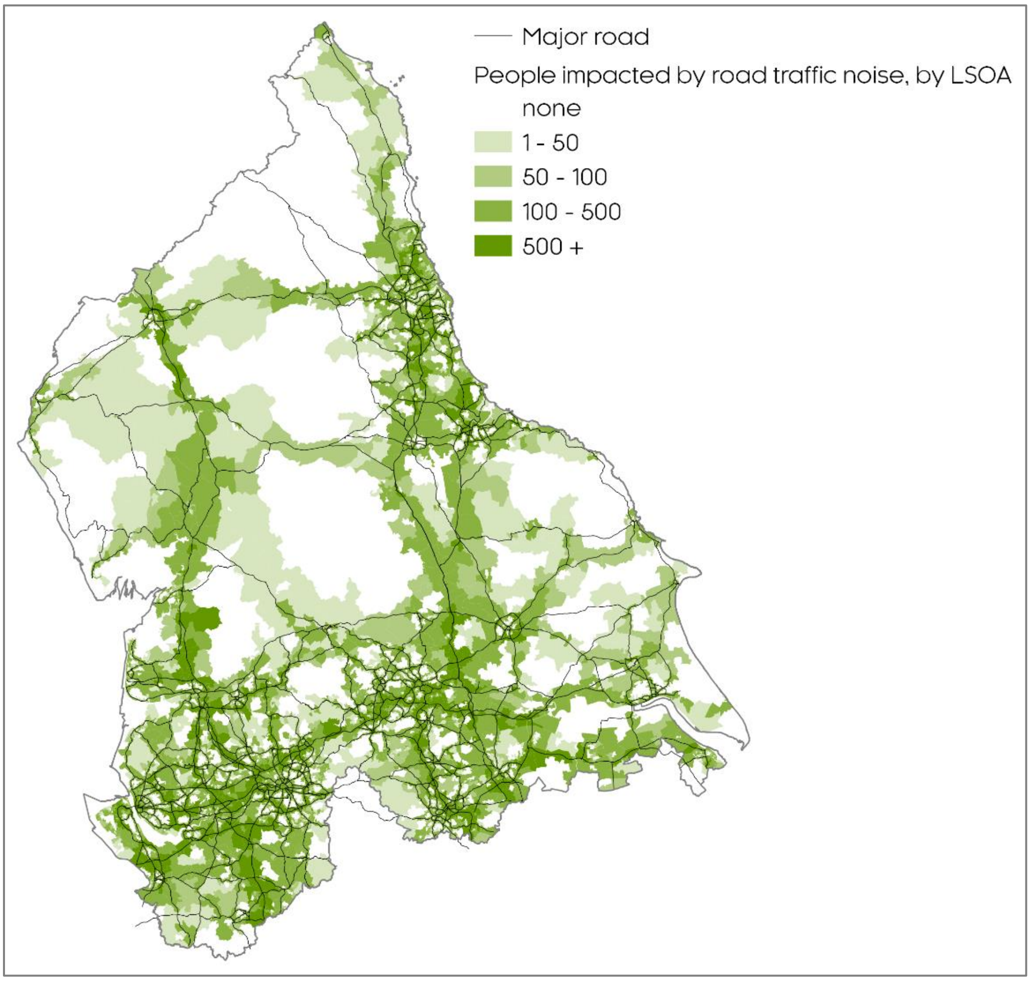
Source(s): Seidler *et al*. (2017); Defra; Cambridge Econometrics analysis.

Over 2.5m people are affected by road traffic noise in the North

Figure 5.23 illustrates the estimated impact that road traffic noise has on the population of the North, by LSOA. Over 2.5m people are affected by traffic noise from roads in the North. In percentage terms, this represents 18% of people in the North West, 15% in Yorkshire and the Humber, and just under 15% in the North East. The high percentage affected in the North West is likely to be linked to large urban centres such as Manchester and Liverpool. The impacts are most concentrated in and near the most densely-populated cities and towns. The human impact of road traffic noise in sparsely populated areas is minimal.

One caveat of the analysis is that impacts on sparsely-populated LSOAs is likely underestimated. This is because the method assumes that people are evenly spread within an LSOA. In reality, LSOAs have an uneven population distribution and residences are likely to be concentrated near major roads. Our estimate is therefore likely smaller than the real figure.

Figure 5.23: People impacted by road traffic noise in the North, by LSOA



Source(s): Seidler *et al*. (2017); Defra; Office for National Statistics; Cambridge Econometrics analysis.

5.6 Severance

This section presents an example application of a method proposed by Anciaes (2013)

Approaches to modelling community severance in relation to transport are still not fully developed. This is because community severance cannot yet be quantified effectively (Mindell & Karlsen, 2012). Nevertheless, impacts resulting from what can be identified as severance are outlined as part of the impact framework (see Section 4.6).

This section presents an application of the method put forward by Anciaes (2013) to measure (potential) severance caused by a road. We present it as a proof-of-concept which TfN may wish to explore further.

Anciaes's (2013) proposed method considers how destinations are separated by a road and how this restricts a neighbourhood's access to those destinations.[16] A resident's potential destinations are all other population centres within walking distance of their neighbourhood. This captures both households where friends and family reside, and facilities and services, such as shops and town centres, which are also population centres.

Severance can be thought of as separating populations ('connections') in walking distance of each other

The calculation of severance involves:

- the number of people affected: the population of the neighbourhood in question
- the attractiveness of each candidate destination: proxied by the population of that destination i.e. as a weight
- the severance value of the road: how difficult it is to cross and how much of a detour must be taken to reach its crossings

Destinations are classed as population centres within straight line walking distance, and two walking distance bands are chosen based on the 'Streets for Life' urban design concept by Oxford Brookes University (Burton & Mitchell, 2006), at 0-500 and 500-800 metres. Destinations between 500-800m have their attractiveness score halved.

The severance value of the road depends on how significant a barrier it represents to those wishing to cross it, which is discussed in more detail below.

Adapting Anciaes (2013), the severance effect of a road on all neighbourhoods can then be calculated as:[17]

$$Total\ Severance = \sum_{n \in N} Pop_n \cdot \sum_{d \in D} A.I_d \cdot RSI$$

where:

- n = a neighbourhood within 800m of the road
- N = all such neighbourhoods

[16] The method could feasibly be used for rail or any other infrastructure that imposes a barrier between two places.

[17] Anciaes (2013) does not articulate a formula, but sets out, descriptively, the input variables.

- Pop = The population of a neighbourhood
- A.I = Attractiveness index of a destination, proxied by its population
- d = a destination of neighbourhood n that has been severed by the road
- D = all such destinations
- RSI = Road Severance Index

As mentioned in Section 4.6, the unknowns (which must be defined and then measured) are the attractiveness index and the road severance index. Anciaes (2013) proposes population density as a convenient (and real-world) proxy for attractiveness and, as we suggest above, this could be interpreted as a measure of potential social connections. However, the road severance index remains problematic as a concept. We revisit this below, after presenting our example analysis.

Example: A dual carriageway in Liverpool

The A580 is a dual carriageway that goes through densely populated areas of Liverpool, including Norris Green, northwest of Liverpool city centre. A section of it is shown in Figure 5.24.

Figure 5.24: Severance imposed by Road A580 on Postcode L11 7AS

Source(s): Ordnance Survey 'OpenMap Local', UK Data Service 'UK 2011 census Postcode Headcounts'; Cambridge Econometrics analysis.

Walkable distance both defines and weights the neighbourhoods of interest

Figure 5.24 shows the severance impact of the A580 on the people living in a single neighbourhood, as measured by a postcode, L11 7AS, shown as the red dot at the centre of the concentric rings. The impact on this neighbourhood of the A580 road is measured in terms of lost connections, adjusted for distance.[18] The 62 people living in L11 7AS now have to cross a road to get to any of the pink highlighted neighbourhoods (north of the road). The total population of the neighbourhoods within 500m of L11 7AS (the inner concentric circle), and on the other side of this road is 1,807. The total population of the neighbourhoods 500-800m away (the outer concentric circle) and on the other side of the A580 is 807.

A weighted (attractiveness) score for these separated connections combines those potential connections within 500m (1,807) and those within 500-800m (807 halved = 403). This score is 2,210 (1,807 + 403).

The above gives a severance impact on the postcode of:

$$Severance_{\text{L11 7AS}} = \text{Pop}_{\text{L11 7AS}} \sum_{d \in D} A.I_d \cdot RSI$$

which translates to:

$$Severance_{\text{L11 7AS}} = 62 \cdot 2{,}210 \cdot RSI = 137{,}020 \cdot \text{RSI}$$

Were we to follow Anciaes (2013) at this point, we would then need to quantify the road severance index (RSI) of the A580 for this community.[19] With no consensus on what this index should be (nor any straightforward way to interpret it), we opt not to calculate this term and, instead, focus on the number of (weighted) potential connections severed: 2,210.

The value of 2,210 compares to a total weighted value (i.e. the entire population in the vicinity, not just north of the road) of 7,837 such that 28% of the potential connections are separated by the A580. While not necessarily inaccessible, 28% of the connections could only be reached by crossing the road. The deterrent effect, whether physical or psychological, *may* represent potentially weaker social connectedness/capital.

The approach only identifies potential connections severed…

This population-based analysis could be taken to represent the number of (weighted/equivalent) social connections separated by a road. If one were willing to make this assumption, then this represents a proxy for social capital/connectedness which could then be interpreted in the light of the literature as greater risk of physical and mental ill-health. Were there evidence to link to severance, these would be applied at this point e.g. some change in health or some heightened risk of ill-health in response to more severance. As discussed previously, the lack of evidence precludes this final step, even if the analysis above might help in giving some indication of hotspots.

At best, however, the above is only a risk factor: we cannot observe the connections themselves (e.g. whether these people would necessarily have been connected in the absence of a road) nor can we know what the

[18] Following Anciaes (2013), people living between 500m and 800m from the origin are given half the weight of those within 500m, as they are further away. Those living more than 800m from the origin neighbourhood are excluded.

[19] The discussion in Anciaes (2013) goes further to consider how different road characteristics might affect severance in terms of road features but also ability to cross and other physical/psychological factors which may have a bearing.

behavioural response might be (e.g. if people are more willing to walk a little further in other directions away from the road to compensate).

The configuration of walking routes may also be relevant. Here, we consider straight-line distance rather than, say, distance by walking paths. How this might change the results is, however, beyond the scope of this analysis; as is any consideration of other transport options.

Other aspects of the method that may warrant future investigation include:

- the definition of a neighbourhood (here, taken to be the population living in a given postcode) and, by extension, the boundary around which the 800m radius can be drawn
- what is a reasonable walking distance. We use 0-500m and 500-800m here after Burton & Mitchell (2006) but this may vary over time and by neighbourhood
- whether demographic factors can be incorporated e.g. to consider the likely greater physical and psychological impact on children and the elderly

Extended example: The A1 in Newcastle

…but may be useful to highlight risks of reduced social connectedness / capital

As an example, this approach could, in principle, thus be applied across an area to understand severance as a function of population density and road configuration. While the analysis still cannot take the step from severance to health, the approach, rooted in population distribution, may help to shed light on potential reductions in connectedness.

Taking the example further, we now apply the approach to a section of the A1 going through west Newcastle. The busy road crosses the edge of the Newcastle metropolitan area, with residential areas on either side. The population of the square area examined is 146,881. Severance, as calculated here, is not affected by any characteristics of the road, such as speed limit or number of lanes, since the methodology used does not have the means to account for these. It is therefore a function only of the sizes of the populations separated by the road. Also, we will only consider connections within 500 metres for (computational) simplicity, although different definitions of an area could be applied.

Figure 5.25 below shows a section of the A1 crossing a densely populated area in Newcastle.

Figure 5.25: Severance imposed by the A1 in Newcastle

Note(s): Connection severed defined as the percentage of total connections within 500 metres of a postcode interrupted by a major road.
For clarity, only postcodes with at least some (potential) severance are shown.
Source(s): Ordnance Survey 'OpenMap Local', UK Data Service 'UK 2011 census Postcode Headcounts'; Cambridge Econometrics analysis.

In total, 524,660 potential connections within 500 metres are on the other side of a major road in the area examined. These are concentrated in areas where both sides of the road are densely populated. Because the map only shows postcodes with at least some (i.e. non-zero) severance, while there is a populated area near the A1 in the south-east part of the map, there is no estimated severance risk here, because the population is entirely located to the south with no-one living north of the road. Some postcodes are more affected, with a higher proportion of their connections severed (up to a maximum of 83%). Higher proportions are observed in postcodes with major roads on multiple sides (see both roundabouts) and bends in the road.

The total number of connections severed should be interpreted with caution, because of significant double counting. A single postcode might lose connection to multiple (n) other postcodes within 500 metres. In that case, its population will be counted as 'severed' n times. For reference, the area examined has a total population of 146,881 people.

An adaptation of this approach could be used to compare the severance value of various road configurations in the same area.

6 Conclusion

6.1 Summary

This report considers the impacts of transport on health and wellbeing in the North of England

This project considered the impacts of transport on health and wellbeing in the North of England, with the aim of improving how such effects might be quantified to inform: the further development of TfN's Strategic Transport Plan (STP), TfN's Decarbonisation Strategy, and TfN's capacity to analyse the impacts of transport in the North.

We divided the work into:

1 an evidence review (a review of reviews) to see how strongly identified various the links for ten impacts were, and to assess their amenability for subsequent modelling

- expert interviews helped with this process, to augment both the causal representation (the system map, as in Appendix A) and the body of evidence reviewed

2 the development of an impact framework to operationalise the evidence (where such evidence were suitably robust) in a way that could then be applied to questions of transport, health and wellbeing

- a spreadsheet accompanies this report, setting out the various evidence, links and data requirements (and availability)
- our analysis (in Chapter 5) shows how to apply the analysis and datasets we have developed as part of this work

6.2 Impact framework

Through the evidence review we identified three tiers of evidence

Through the evidence review, we identified three tiers of evidence according to the robustness of the quantitative findings and their amenability for further analysis. By this system, we categorised the ten types of impact as follows:

- Tier 1: Evidence from the literature and expert interviews supported by sufficient quantitative data and robust analysis for it to be possible to characterise the identified relations with high levels of confidence.
  - Physical inactivity
  - Incidents and safety
  - Air pollution
  - Limited access to green space, recreation and leisure
- Tier 2: Evidence from the literature and expert interviews is supported by sufficient quantitative data to estimate the strength of the relationship. However, either the data were insufficiently comprehensive, or econometric results were not strong enough, for this to be characterised as a robust result.
  - Noise pollution
  - Severance
  - User experience
- Tier 3: Evidence from the literature review and export interviews provides insight as to the direction, approximate scale, and nature of the

relationship between two or more variables; however no attempt to quantify this has yet been made.

- Limited access to healthcare facilities
- Limited access to high-quality employment
- Environment quality

Some impacts are amenable to analysis…

By this categorisation, Tier 1 impacts are in principle amenable to quantitative analysis of transport. This is reflected in the impact framework and, moreover, these are also aspects in which there tend to be good data on the necessary parts of the causal chain to carry out analysis.

but others face various analytical challenges

Tier 2 impacts present more of a challenge for quantitative analysis because of some (related) combination of:

- weaker or less conclusive quantitative evidence
- more complex chains of causation, possibly with evidence gaps (or unobservables) that make it difficult to operationalise the framework
- limited data availability to combine with the above

While this does not necessarily preclude quantitative analysis, depending on the impact, the degree of feasibility varies from broadly assessable (as in noise pollution) to tentatively, with caveats (as in our test case of severance) to not modellable (user experience).

The remaining impacts (Tier 3) tend to represent more in the way of hypothesised pathways that link transport to specific health outcomes, with little or no supporting quantitative evidence.

The impact framework thus identifies:

- five impacts for which there are sufficient evidence and appropriate geospatial datasets some form of analysis of health impacts (as presented in Chapter 5)
- one impact, severance, for which we carried out some test analysis of how a measure based on population density/proximity might help signal risks of social disconnectedness
- four impacts for which quantitative analysis is not currently possible, with some discussion of the gaps and how they might be filled

6.3 Analysis

Our summary findings from the analysis (in Chapter 5) are as follows.

Four of the six impacts analysed in this report considered the whole of the North of England. The two remaining impacts (physical inactivity and severance) were evaluated at smaller scales due to the complexity of the analysis and/or the availability of data. Where possible, we analysed not only the spatial distribution of health risks but also how these risks are distributed among the population of the North. Table 6.1 summarises the estimated number of people at risk from the health impacts analysed in Chapter 5.

The data (shapefiles) that informed this analysis accompany this report, both as analyses in their own right but also as examples of how such analysis could be carried out in the future.

Table 6.1: Summary of the estimated number of people at risk, by transport-related health impact and geography

Impact category	Impact	Geography analysed	Estimated number of people at risk in geography ('000s)
Physical inactivity	Lower walking and cycling activity	Greater Manchester	163
Incidents and safety	Number of traffic casualties	The North	33*
Air pollution	Higher risk of mortality from nitrogen dioxide		5,880
	Higher risk of mortality from PM_{10}		5,850
	Higher risk of mortality from $PM_{2.5}$		5,640
Limited access to green space, recreation and leisure	Higher risk of type 2 diabetes		9,720
	Higher risk of psychosocial distress		200
	Lower self-rated general health		5,750
Noise pollution	Higher risk of hypertension		2,500
	Higher risk of coronary heart disease		2,500
	Higher risk of depression		2,500

Note(s): * This number does not represent those at risk of traffic incidents but the number of traffic casualties in the North for 2019.
We did not calculate the number of people at risk for physical activity and subjective wellbeing from proximity to parks and severance.
For air pollution, only the three most harmful pollutants were considered.
Source(s): Cambridge Econometrics analysis.

Physical inactivity

The analysis of physical inactivity suggests that:

- in Greater Manchester, more than 2.6m people have access to a cycle path within 1 km of their home, translating to 61.2 additional minutes of physical activity per week relative to those who live more than 4 km from a cycle path
- parks in urban areas within 0.5 km of one's place of residence are associated with a 1.86% increase in a measure of physical activity per park in range, which we demonstrated as suggesting benefits to residents of Sheffield and Greater Manchester

The evidence points to the value of built environment interventions such as cycle routes and urban parks as ways to stimulate physical activity for those nearby. Insofar as built environment interventions increase access and use of features that promote physical activity within a community, healthier populations should result. However, we note that some of these effects may be quite small in scale, possibly limiting the degree of health improvement.

The principal limitations of the analysis concern the needs to:

- consider the quality of the infrastructure and whether/how it drives physical activity, especially given the finding that, in principle, much of the population of Greater Manchester is in reasonable proximity to a route
- consider access in a more nuanced way beyond straight-line distance i.e. to capture features of the environment and what it really means for travel routes and times/distances

Incidents and safety

Various features of roads and vehicle traffic patterns are associated with the number and severity of vehicle collisions and casualties. For example, average speed, traffic volume, speed variation, and speed difference are all factors shown to affect the occurrence of traffic incidents. Our analysis considered the rate of traffic incidents by local authority and daily traffic volume of major roads in metropolitan districts.

Our deeper analysis of Greater Manchester showed that, while traffic volume was high on major motorways, such as the M60, the bulk of incidents were concentrated on A roads, especially near the urban core of the area. Further, the casualty rate per distanced travelled is ten times lower for motorways when compared to A roads.

The risk of a road traffic incident is highly context-specific, meaning it can be hard to model the risk without a detailed representation of local factors. Further data with a measure of traffic density might be helpful in modelling the risk of traffic incidents. Additional data that identify incidents by point on the map may also be helpful in broadening the analysis.

Air pollution

Air pollutants, some of which are directly attributable to transport, are related to many negative health outcomes that can result in hospitalisation and/or mortality. We analysed six pollutants in the Northern regions to estimate the expected increase in risk of hospital admissions and mortality:

- most of the increased risk of hospitalisation and mortality comes from NO_2, $PM_{2.5}$, and PM_{10} emissions. Of these, NO_2 and $PM_{2.5}$ are highly localised, with maximum effects near the kerb, with implications for road design and pedestrian crossings

- NO_2 concentrations are much higher during the morning and evening rush hours: higher uptake of public transport commuting may thus added health benefits through cleaner air

Increased use of public transportation, especially low-emissions forms of public transportation, could be a means of alleviating the burden of transport-related air pollution.

As well as encouraging modal shift, policies that reduce pollution from motor vehicles or that encourage uptake of vehicles that pollute less (e.g. electric vehicles) could thus benefit human health by reducing emissions. However, pollutants such as PM_{10} can result from tire and brake wear, which would likely persist if such vehicle use were to continue.

Limited access to green space, recreation and leisure

Proximity to green space and proportion of green space nearby were analysed relative to subjectively and objectively measured health outcomes:

- the amount of green space within 300 metres of one's place of residence has a relationship with improved subjective wellbeing measures
  - focusing on the Manchester area, the urban core of the city has relatively lower access to public green space
  - the population of this core tends to be younger, suggesting that they are benefitting less from enhanced wellbeing
  - However, the analysis of Newcastle showed a very different story, with over two-thirds of the population estimated to live within 300m of greenspace.
- the proportion of green space near to one's place of residence is also associated with improved health outcomes, including lower risks of type 2 diabetes, psychosocial distress, and self-rated general health. When looking at the North:
  - the benefits of decreased risk of diabetes from green space were spread across the region, concentrated in more rural areas and lowest in the southeast corner of the region
  - the benefits of reduced risk of psychosocial distress from green space were wide-ranging through the region, including in urban areas
  - the benefits of reduced risk of self-rated fair or poor general health were most diffuse, concentrated in pockets of forested areas in the northern half of the region

The health benefits of proximity to green space in the North are unevenly distributed. Areas with lowest risks of negative health outcomes are less likely to have populations in the lowest IMD decile.

The North of England is fortunate to have an abundance of green space within its borders, including both urban parks and more rural areas of open or forested green space. Urban areas tend to be at higher risk of having more limited access to green space, so transportation options to increase access would be expected to improve health.

Further analysis on access to mountainous or coastal areas (not defined as green space in this analysis) could be useful, as these natural features most likely also provide access to recreation and leisure that could accrue health benefits to the population of the North.

Noise pollution

Noise resulting from transport traffic from roads and railways is related to several physical and mental health outcomes, including coronary heart disease, hypertension, and depression. With data on the extent of road and rail traffic noise in the North, the resulting health impacts were modelled for the whole region. We conservatively estimate that over 2.5m people in the North are affected to some degree by road traffic noise, concentrated in the more urbanised southern half of the region and along the major motorway routes. These populations face higher risks of hypertension, coronary heart disease, and depression, relative to areas with low levels of traffic noise.

While road traffic noise pollution does not penetrate into areas very far from major roads, this does affect large segments of the population, as residences and populated areas tend to be found near major roads. Interventions to help reduce noise pollution in residential areas, especially those near major motorways, would be expected to improve health outcomes. The risks due to railway traffic noise are much less widespread.

Further analysis could also look at air traffic noise pollution and consider the interaction of the noise pollution from the three sources, which may point to areas at particular risk.

Severance

TfN was also keen to consider if there might be some way to advance some understanding of the health impacts of severance. Here, the causal evidence chain is broken in the sense that there is some understanding that road traffic can lead to severance and that a lack of connectedness can be detrimental to health; however, the evidence on specifically severance-related health impacts is limited.

In this report, we have carried out small pieces of example analyses that look at how roads might limit how one neighbourhood can reach the people in another within a defined radius (of walkable distance) for both Liverpool and Newcastle. The total population within this radius represents one measure of *potential* social connections and, taking this as one possible proxy for social connectedness/capital, the extent to which the accessible population might be at risk of negative health impacts as a consequence.

Given the limited evidence in the literature, such analysis should be taken as indicative of the health impacts only, but it may be a promising route to better understand the spatial distribution of risk.

6.4 Directions for future work

There are various directions to expand the currently feasible analysis

In terms of how this work might be extended in the future, we identify three main themes:

1. the challenges of identifying access and usage, rather than just proximity (which is only a surrogate for access/usage): this concerns in particular physical inactivity and green space
2. context-specificity as a challenge to identifying appropriate upstream effects, which is most pertinent to incidents and safety

3 identified gaps in the evidence for impacts (in Tiers 2 and 3) thought to be of importance in understanding the role of transport in health and wellbeing

Indicators of, or insight into, usage would be valuable

As stated in this report, there is a lack of data on usage of infrastructure and green space and, in turn, the determinants of that usage. This is a challenge because, as the cycling routes analysis shows, in principle, large proportions of urban populations are reasonably close to these paths and understanding who makes use of them (and why) and not (and why not) is vital to understanding both the performance of the intervention itself, but also the health outcomes.

In the analysis (and, indeed, in the evidence), proximity is taken as a surrogate indicator of use/access such that being located closer to such infrastructure is associated with improved health, acknowledging that this effect must be mediated by usage.

As such, a fruitful area of further research would be to understand, perhaps in a consumer choice manner, what affects usage of routes and space, to gain a more nuanced understanding of whether and how an intervention might be effective.

Context-specific phenomena likely require expanded models upstream of the health analysis

In the case of road traffic incidents, we also noted the context-specific nature of certain effects. While there may be ways to crudely estimate the upstream causes (in this case, the likelihood of incidents, of varying severity), the challenges of prediction in order to then calculate the consequences has precluded more detailed analysis. Given the complexities, it may be that more sophisticated transport analysis is required before feeding into the health outcomes work.

Gaps in the impact framework may concern impacts of high importance

Finally, the clearest gaps in the impact framework concern those impacts for which both evidence and data are too limited. The following are perhaps most pertinent given the intuition / *a priori* expectation that they are material/important:

- severance, which is an issue of much concern and, as our example analysis suggests, it may be possible to begin advancing work on the social connectedness of populations (albeit under various caveats and assumptions)
- from a wellbeing perspective, user experience (which the evidence shows differs greatly by mode of transport) seems ripe for deeper exploration, not least from a behavioural perspective and in the context of efforts to encourage modal shift – understanding, for example, what is preventing people from switching to lower-stress transport options
- the benefits of access to healthcare tend to be taken as given in the literature, with the presumption that closer is better – while a reasonable assumption, from a strategic transport perspective, understanding the patterns of impact in quantitative manner, rather than simply the (likely) direction of impact, would be useful to prioritise investments
- access to employment, which is increasingly recognised as an important social determinant of health, would also be critical to understand in concert with other economic analyses for the North (not least given the devolution

agenda and recent interest in levelling up). Here, there are challenges to do with identifying data on access and travel (the routing) but also in appreciating the spatial variation in labour supply and demand (e.g. skills/occupational mismatch)

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Appendices

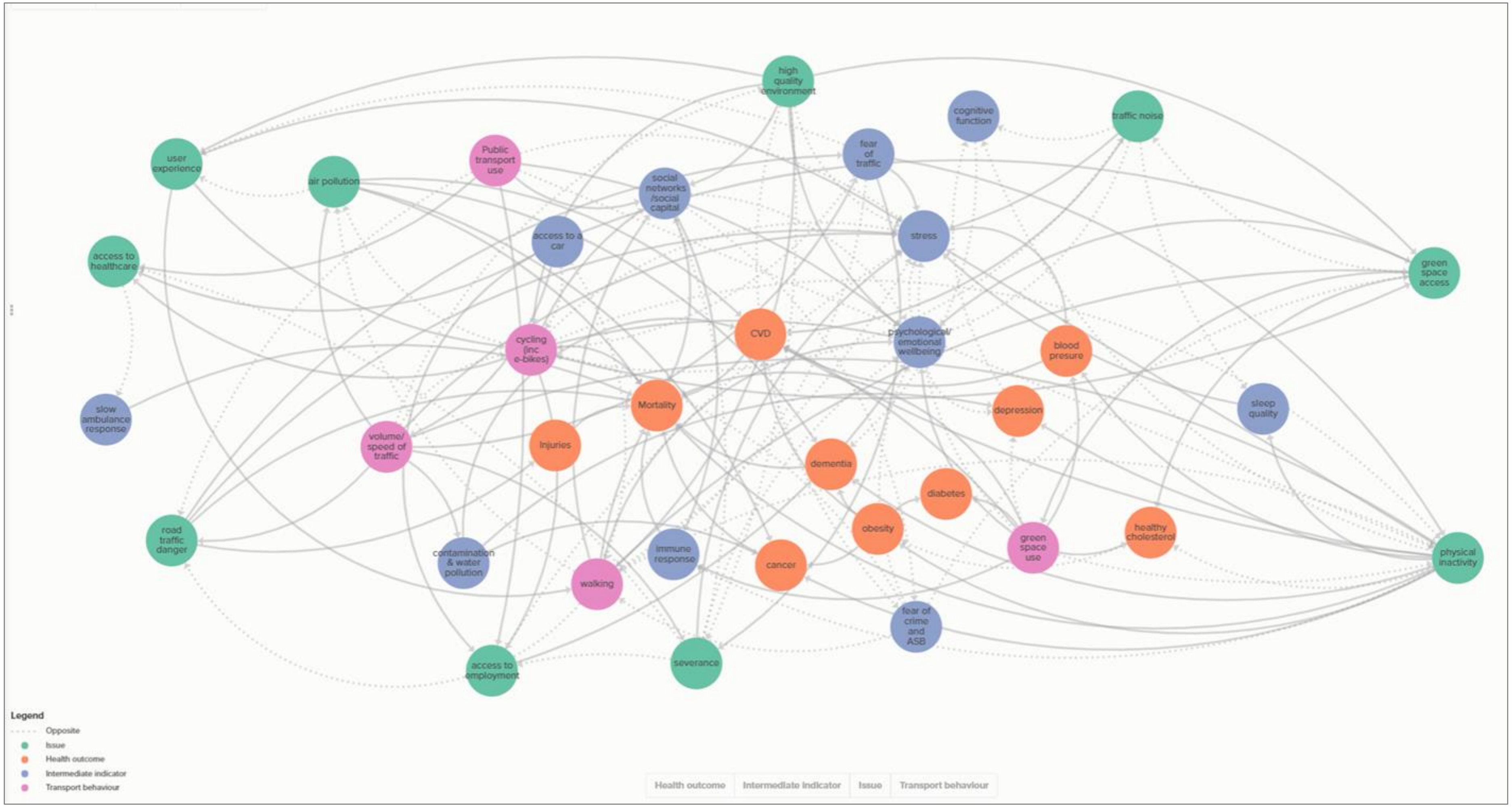
Appendix A System maps

The following pages present the full system map before showing, in sequence:

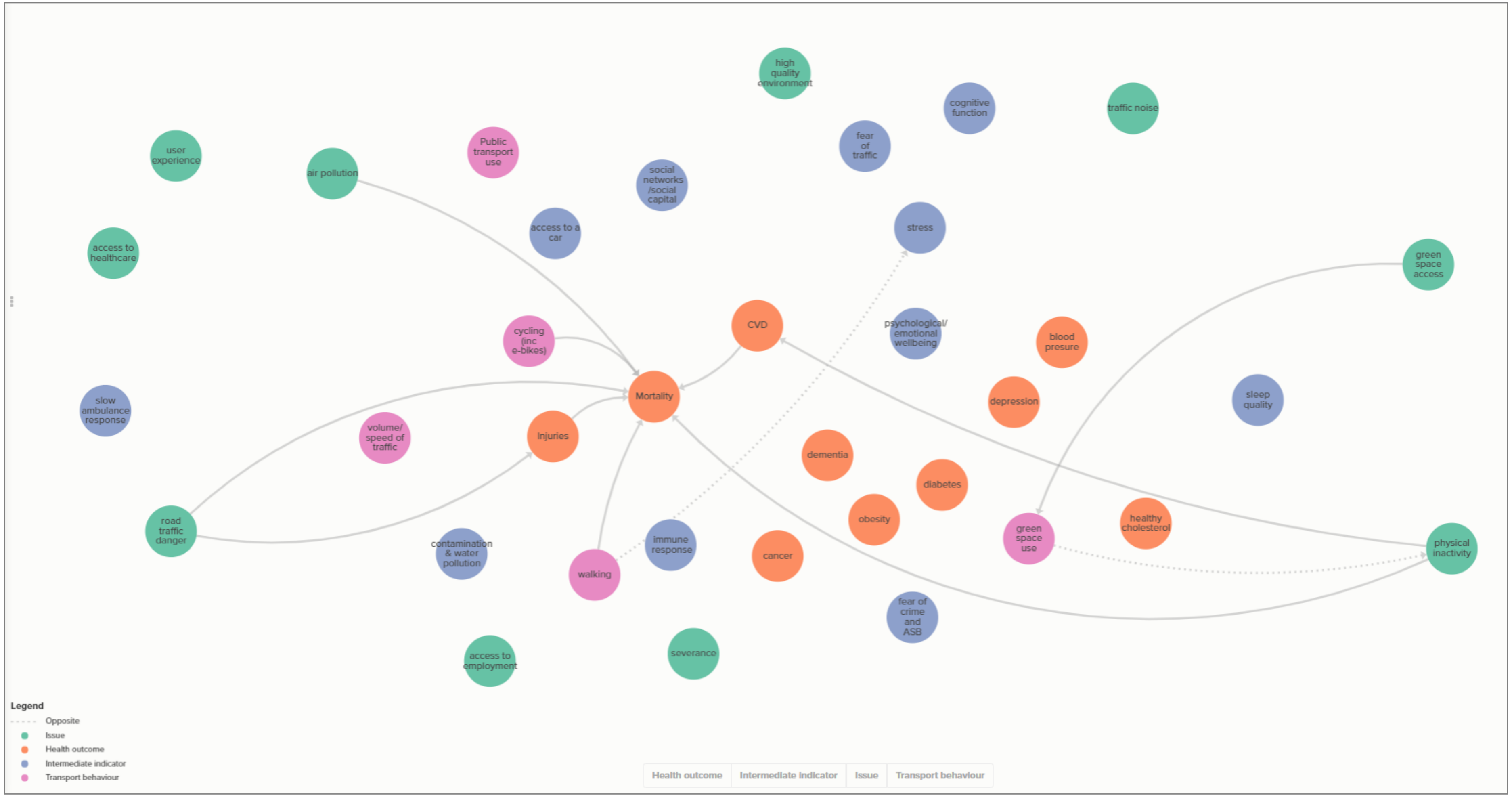
- links from Tier 1 evidence
- links from Tier 1 and 2 evidence
- links from Tier 1, 2 and 3 evidence

Interactive versions of the system maps are available from:
https://nickcavill.kumu.io/transport-for-the-north-transport-and-health

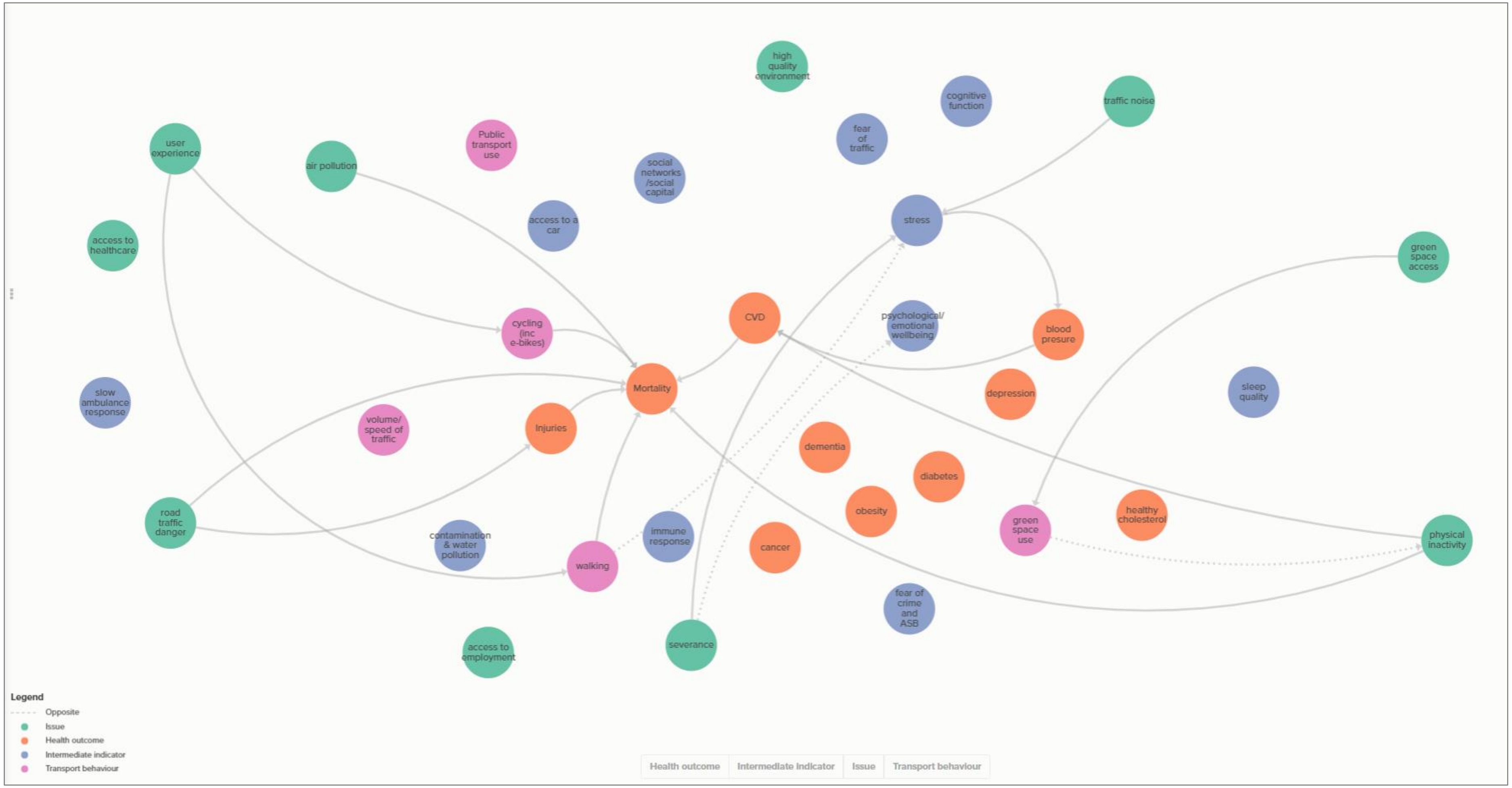
Appendix Figure A.1: Complete system map



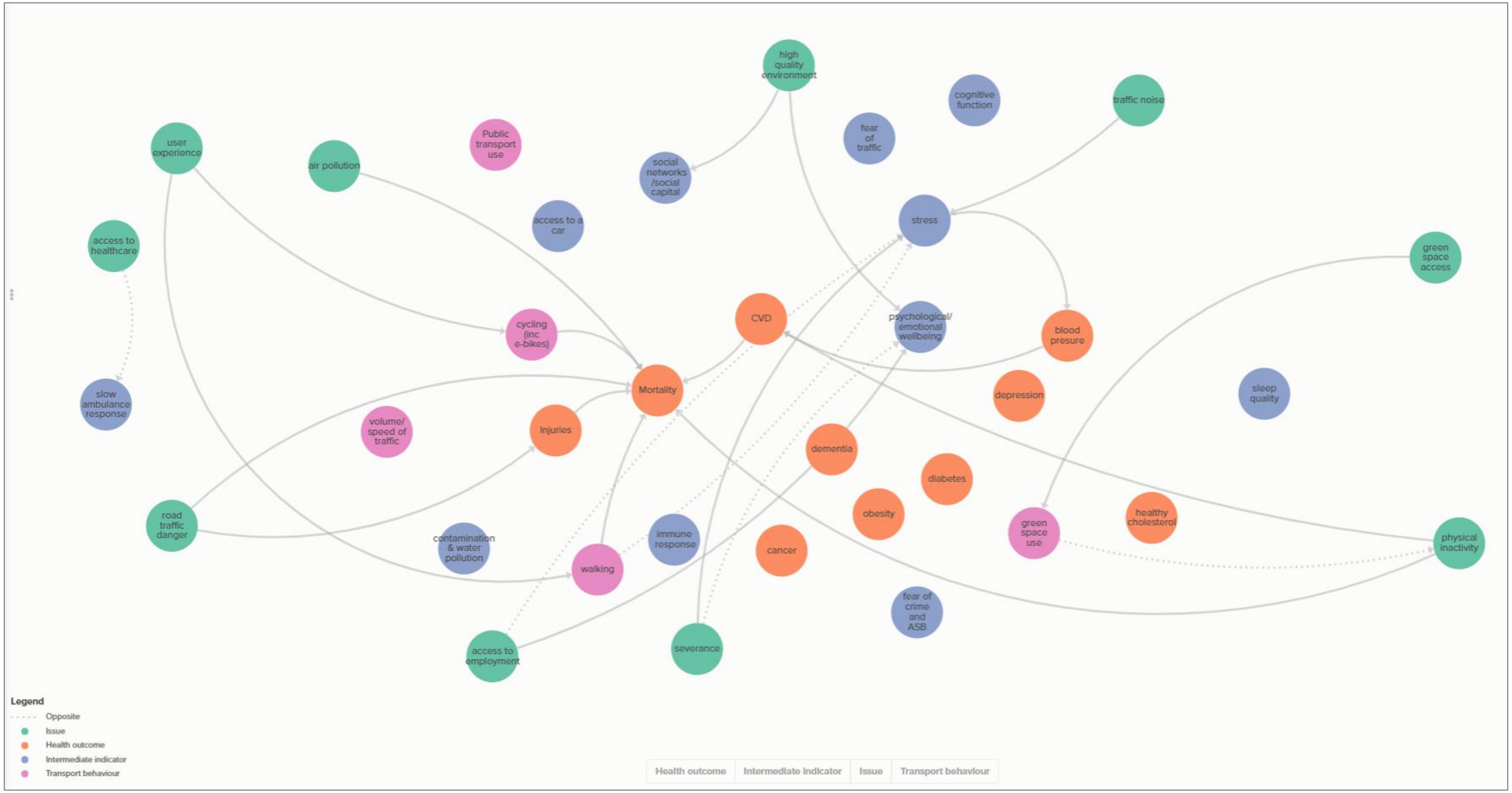
Appendix Figure A.2: System map for Tier 1 evidence



Appendix Figure A.3: System map for Tier 1 and 2 evidence



Appendix Figure A.4: System map for Tier 1, 2 and 3 evidence



Appendix B Expert consultations

Appendix Table B.1 below summarises the key discussion points from each expert interview, including (in the two rightmost columns) how the exchange informed an augmented evidence base and system map.

Appendix Table B.1: Transport and health expert consultations

Name	Organisation	Primary expertise	Topics discussed	Additional evidence cited	Amendments to system map
Dr Andy Cope	Sustrans Research and Monitoring Unit	• Active travel • Local monitoring and data collection	• Land use planning, as a significant determinant of transport patterns • 20-minute neighbourhoods • Inequalities • Use of green space • Physical activity • Importance of WHO HEAT tool • Growing importance of e-bikes • Mental health and the needs of different transport users • Loneliness and isolation • Potential for local data collection	-	• Link environment to public transport • Added micro-mobility e.g. scooters • Link walking and cycling to social networks

Name	Organisation	Primary expertise	Topics discussed	Additional evidence cited	Amendments to system map
Dr Christian Brand	Transport Studies Unit, University of Oxford	• CO_2 • Air quality • Active travel	• Public transport • Air pollution • Differences in wellbeing during an episode (i.e. journey) and how this varies by mode • Argued for the inclusion of carbon emissions in the model • Social capital • Access to healthcare • Fuel/transport poverty (as a cause of stress and ill-health)	PASTA (Physical activity through sustainable transport approaches) project	• Added public transport • Added multiple links especially to wellbeing • Link cardiovascular fitness to cardiovascular disease
Prof Adrian Davis	Transport Research Institute, Edinburgh Napier University	• All	• Spatial mismatch: people living away from destinations they need • Environmental quality: lack of evidence on this issue • Electric vehicles • Physical activity and immune response (highlighted by the Covid pandemic)	-	• Added numerous links • Added immune response and links to physical activity and social networks/capital • Links to obesity (cancer etc.) • Link car use to fear of traffic
Prof Jenny Mindell	Department of Epidemiology & Public Health, UCL	• Severance	• Quantifying severance • Use of community severance indices • Community severance costing tool • Health impact assessment • Physical activity	UCL Street Mobility Project Toolkit (see Appendix Section C.5)	• Additional links from severance

Name	Organisation	Primary expertise	Topics discussed	Additional evidence cited	Amendments to system map
Dr Francesca Racioppi	Head of the WHO European Centre for Environment and Health	• All	• Walking • Cycling • Economic assessment • Access to education • Cognitive function	Various WHO and other modelling tools (see Appendix C)	• Added numerous links, notably to walking and cycling • Made the case for 'access to education' as a separate issue • Added carbon emissions • Suggested specific outcome of 'cognitive function'
Prof Karen Lucas	School of Environment, Education and Development, University of Manchester	• Access	• Access to health services • Journey quality • Severance	-	• Some additional links from severance
Prof Charlie Foster	School for Policy Studies, University of Bristol	• Physical activity	• Physical activity and links to disease outcomes • Green space (both access and use)	-	• Added more links to physical activity, notably direct link from walking and cycling to mortality
Prof Nicola Christie	Faculty of Engineering Science, UCL	• Safety	• Inequalities in road traffic casualties • Proposed that deprivation should be included on the map • Psychological wellbeing (and links to deprivation) • Links between cars and crime	-	• Added fear of crime • Added links to social inclusion • Added links public transport and casualties
Dr Kiron Chaterjee	University of the West of England	• Access	• Commuting and wellbeing • Stress during travel	Transport reviews: commuting and wellbeing	• Added links to employment

Name	Organisation	Primary expertise	Topics discussed	Additional evidence cited	Amendments to system map
Prof Mark J Nieuwenhuijsen	Barcelona Institute for Global Health	• Health impact assessment • Air quality	• Pathways to health impacts, as in Glazener *et al*. (2021) • Importance of socioeconomic status for health • Accessibility • Green space • The importance of physical activity in most health impact assessments • Noise (and the challenges of quantifying) • Urban heat islands • Use of urban land for transportation	Glazener *et al*. (2021)	• Additional links especially to noise • Potentially additional topics, as per Glazener *et al*. (2021)
Prof Catherine Ward-Thompson	University of Edinburgh	• Environment	• Links between environment and walking and cycling • Green space and health • Engagement with nature • Safety and walking/cycling	-	• Amended to 'high quality environment' • Added links to walking and cycling • Links to emotional wellbeing
Prof Andy Jones	University of East Anglia	• Walking • Green space	• Green space access • Evidence for links to health outcomes (from his meta-analysis) • Physical activity as the main pathway for health benefits (i.e., being active in green spaces), and also factors such as microbiome	-	• Added green space use (in addition to access)
Dr Sally Cairns	Institute for Transport Studies, University of Leeds	• Access	• Health benefits of employment • Absenteeism • Evidence on access to employment	-	• Added links to employment • Suggested absenteeism as pathway

Appendix C Other tools for economic assessment

C.1 WHO Health Economic Assessment Tool (HEAT) for walking and cycling

WHO Health Economic Assessment Tool (HEAT) is designed to enable users without expertise in impact assessment to conduct economic assessments of the health impacts of walking or cycling. HEAT estimates the value of reduced mortality that results from specified amounts of walking or cycling, answering the following question:

> *If x people regularly walk or cycle an amount y, what are the health impacts on premature mortality and their economic value?*

As well as the health benefits from physical activity, HEAT can also take into account the mortality effects of exposure to air pollution and traffic crashes while walking or cycling. HEAT can further assess the effects on carbon emissions from shifting travel by motorised modes to walking or cycling.

URL: https://www.heatwalkingcycling.org

C.2 GreenUr: The Green Urban spaces and health tool

GreenUr is a plug-in for QGIS, a free and open-source desktop geographic information system (GIS). GreenUr offers the possibility to measure availability and accessibility of green space in cities. It accommodates algorithms to calculate potential direct health effects of green space, for example, on mental health, and indirect impacts, for example, through ecosystem services.

URL: https://www.euro.who.int/en/health-topics/environment-and-health/urban-health/activities/greenur-the-green-urban-spaces-and-health-tool

C.3 AirQ+: software tool for health risk assessment of air pollution

AirQ+ estimates:

- the effects of short-term changes in air pollution (based on risk estimates from time-series studies)
- the effects of long-term exposures (using life-tables approach and based on risk estimates from cohort studies).

URL: https://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/airq-software-tool-for-health-risk-assessment-of-air-pollution

C.4 Carbon Reduction Benefits on Health (CaRBonH)

The Carbon Reduction Benefits on Health (CaRBonH) calculation tool allows quantification of the physical and economic consequences for human health achieved through improvements in country-level air quality from domestic carbon reductions, specifically policy mitigation actions and measures as reported in the NDCs submitted by the Conference of the Parties to the UNFCCC in support of the objectives as set out in Article 2 of the Convention.

URL: https://www.euro.who.int/en/health-topics/environment-and-health/Climate-change/publications/2018/achieving-health-benefits-from-carbon-reductions-manual-for-carbonh-calculation-tool-2018

C.5 UCL Street Mobility Project Toolkit

The UCL Street Mobility Project Toolkit contains various tools developed by the UCL Street Mobility & Network Accessibility project team to support assessments of community severance in local areas.

URL: https://www.ucl.ac.uk/epidemiology-health-care/research/epidemiology-and-public-health/research/health-and-social-surveys-research-group/toolkit