

Literature review on the impacts of infrastructure on quality of life

A Rapid Evidence Assessment

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Executive Summary

The purpose of this report is to provide a review of academic evidence for links between economic infrastructure and quality of life. As a guide to existing evidence, it is based on a comprehensive search and review of published academic work, and attempts to synthesise these relations. In order to visualise these relations, a summary table and graphic is provided at the end of this executive summary.

This section provides a brief summary of the research. Our intent here is to provide guidance with respect to how strong the evidence is within particular areas and where gaps have been identified. We provide a short discussion first by infrastructure sector, then by quality of life theme.

State of the evidence and key findings

Our review found the most comprehensive evidence within the **transport** sector. This sector has the most coverage in terms of how infrastructure impacts quality of life in beneficial and adverse ways. Transport infrastructure is generally quite ‘visible’ and small changes can be measured through diverse research approaches. Some of the key findings related to transport include:

- Living within walkable neighbourhoods with good access to public transport is associated with increased levels of leisure time walking among older adults. In contrast, less walkable neighbourhoods are associated with overweight and/or obesity in adult populations. Evidence shows that walking and cycling have population-level health benefits.
- Investing in, and managing, the relationship between roads and the surrounding built environment can lead to positive health and wellbeing impacts. This includes, for example, design modifications to junctions (e.g., roundabouts), slowing traffic (e.g., 20 mph zones) and separating pedestrians from vehicles.
- Some research suggests that people who walk or cycle to work are generally more satisfied with their commute than those who travel by car and especially those who use public transport.
- Research demonstrates that long term exposure to air pollution, particularly related to traffic, is associated with deficiencies in lung function across all age groups.
- However, due to the heterogeneity across interventions, outcomes, and methods, it can be difficult to derive overall conclusions regarding the effectiveness of interventions in terms of improved air quality or health.

There is also a great deal of evidence within the **flood risk management** sector. However, the majority of research we reviewed centres on the absence or failure of flood infrastructure. Researchers have done a very good job studying the adverse impacts of flooding – on people’s physical and mental health, on home values and so on. With the exception of sustainable drainage systems (SuDS) and green infrastructure, less work has been done accounting for the quality of life benefits of flood infrastructure. Key findings include:

- There is significant evidence demonstrating the adverse impacts associated with flooding. These include robust evidence of the physical, mental and social challenges for those who experience flooding.
- Flood experiences will impact people differently, often reflecting levels of vulnerability or fragility.
- There is a gap in the evidence on the efficacy of flood management infrastructure to influence quality of life (with the exception of SuDS and green infrastructure).

Water supply and wastewater research was under-represented in our reviews. Our initial searches identified numerous studies detailing the importance of clean water and the value of infrastructure systems. Yet, these were almost exclusively located in the global south and developing contexts. We highlight the following key points from the review:

- Drought (particularly long-term periods of drought) has been shown to have adverse impacts on human health and wellbeing. In particular, evidence demonstrates significant and lasting mental health impacts among vulnerable individuals (e.g., those with pre-existing mental health conditions) who experience drought.
- Reductions in water consumption through conservation techniques could result in some adverse health impacts, particularly in households with lead piping.
- Living farther away from the nearest sewage treatment works is associated with higher levels of life satisfaction.

As might be expected, our **waste infrastructure** review identified some challenges for this sector including the negative impacts associated with landfill and incineration facilities. Positive impacts were identified in areas of new technology and innovation (e.g., waste-to-energy, vacuum waste collection). From this vantage point, it seems that the quality of life benefits associated with waste infrastructure is under-researched. Key findings within the waste chapter include:

- People who face health impacts associated with living near a landfill site are also likely to be experiencing multiple disadvantage.
- There are adverse health impacts related to e-waste exposure. However, further epidemiological data and longitudinal studies are needed to establish a definitive causal relation.

Within the **digital infrastructure** sector, we found evidence of the adverse impacts associated with digital exclusion (a lack/failure of infrastructure) and less about the positive quality of life impacts specifically associated with the physical infrastructure. This is somewhat surprising as digital connectivity has transformed work patterns and lifestyles, particularly in the last decade. Key findings from our review are that:

- Trends toward digitalisation may result in both digital and social exclusion for older people in rural and urban areas, and women and young people living in rural areas.
- Evidence suggests that people who are digitally excluded are also more likely to be excluded off-line in everyday life.

Finally, our review of **energy** research highlights evidence related to fuel poverty (e.g., affordability) as well as perceptions related to renewable systems and impacts on local environments. Research clearly identifying positive quality of life impacts from energy is under-represented in our review. Key findings identified in the evidence include:

- Eliminating and/or replacing biomass energy systems can lead to improvements in air quality and reduced mortality rates.
- There is a value in connecting people to their energy systems and ensuring they feel empowered as active agents in how local systems are developed and deployed.
- Reducing fuel poverty can lead to a range of physical and mental health benefits. However, further empirical study and attention to health outcomes are needed, particularly across population subgroups.

Our review suggests that, at least in developed countries, the success of infrastructure systems can render them ‘invisible’ and possibly, less prevalent within academic study. Much of the scholarship identified is concerned with specific breakdowns or areas of infrastructure deficit (e.g., flooding). With the exception of newer forms of infrastructure (e.g., green infrastructure) or where priorities have shifted (e.g., away from the automobile and towards active travel), there tends to be an absence of evidence regarding the efficacy of infrastructure to support quality of life in contemporary, developed contexts. This invisibility is reflected in our searches and in the evidence reviewed.

Considering the evidence by quality of life theme

Our objective was to understand the evidence on infrastructure and the associated quality of life impacts. We organised our analysis through the key themes of quality of life the National Infrastructure Commission identified in the scoping documents. This meant identifying relations between infrastructure and ‘five key themes of quality of life’. More detail on this is provided in the report’s introduction section. A brief discussion of our findings is outlined below, where we highlight areas of strength and weakness within each quality of life theme.

Quality of Life Theme: Impacts of infrastructure on physical and mental health

By far, most of the evidence included in our review falls into the category of physical and mental health. The relationship between infrastructure and health is richly studied. This includes studies of how infrastructure might adversely impact individuals and communities (e.g., where someone lives near a wastewater plant or a landfill), how the ‘lack’ of infrastructure, or its failure results in negative health outcomes (e.g., as in the case of flooding or drought), and how infrastructure supports positive impacts to wellbeing. This final category represents a minority of studies in the evidence we reviewed. Scholarship has done a thorough job investigating infrastructural failures and inadequacies. We found less thorough evidence of the positive impacts associated with the presence of infrastructure. An outlier here is within some of the newer infrastructure sectors (and/or approaches) such as green infrastructure or renewable energy where a case is often made for innovation through cost-benefit analysis and other forms of evaluation. The benefits of these infrastructures are often pitched in contrast to conventional systems and approaches.

Quality of Life Theme: Impact of infrastructure on the natural and local environment

All infrastructure has some form of impact on the natural and local environment. Much of the research reviewed indicates a relationship between the two. Yet, the direct evidencing of this impact is less prevalent. In some sectors, this is discussed through perception and subjective criteria. For example, we found evidence that 'place' and the emotional bonds people have to their neighbourhoods and towns can have a significant impact on the way they interpret the impacts of large infrastructure systems (e.g., wind farms). Again, the green infrastructure scholarship more commonly shows how infrastructure investments create value through the construction of new amenity spaces (e.g., parks as well as flood management areas). Nevertheless, much of the scholarship reviewed here narrates the adverse impacts of infrastructure (or its lack) on local environments.

Quality of Life Theme: Connectivity and accessibility

The research reviewed includes evidence about the connectivity and accessibility provided by infrastructure. This is particularly evident within the transport literature where access to a personal automobile or living in a walkable neighbourhood directly impacts quality of life. Further, there is evidence that green infrastructure approaches can contribute the creation of walkable environments in addition to their role in flood management. As might be expected, the role of broadband and digital infrastructure is important for quality of life. Connectivity and access issues were identified, particularly in rural contexts.

Quality of Life Theme: Affordability of infrastructure

Affordability themes were less prevalent in the research we reviewed. In part, this reflects our focus on infrastructure delivery rather than its operation. For example, our searches excluded literature which focused exclusively on the 'service provider' (e.g., the cost of a train ticket) as opposed to the infrastructure. Affordability was identified as a quality of life theme within the digital infrastructure as well as energy. In both of these cases, the costs of access (e.g., to broadband) limited use which then impacted on other quality of life themes.

Quality of Life Theme: Safety and reliability of infrastructure

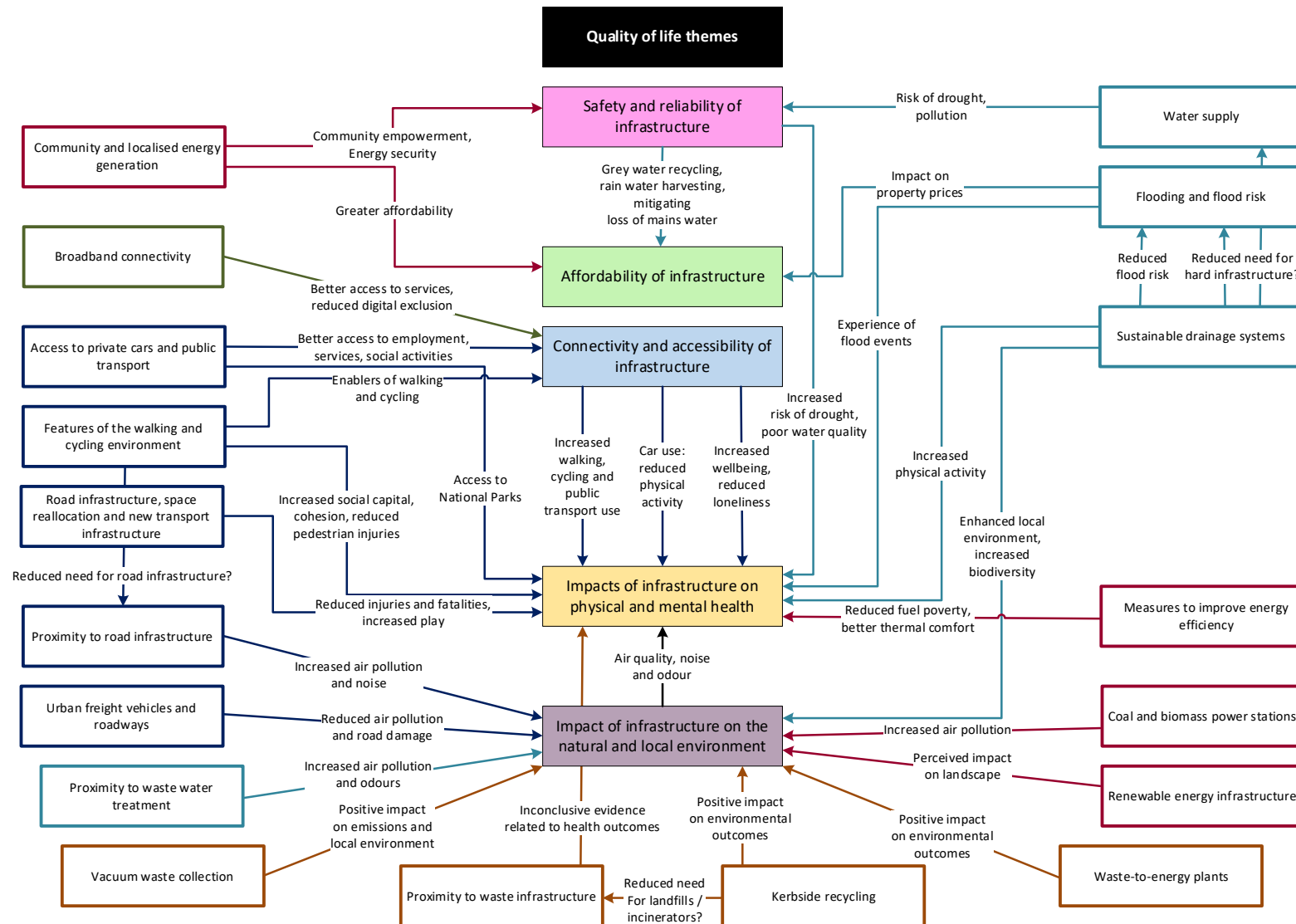
This theme did not feature prominently in our review. While this may reflect our interpretation of the evidence, it also possibly reflects the broad reliability of large-scale infrastructures we reviewed in a UK context. We found discussions of this theme within areas of new technology and innovation (e.g., autonomous vehicles, digital/broadband) as well as in areas where the potential for hazards are evident such as flooding and drought.

The following summary table and diagram summarises these associations.

Summary table of quality of life themes and pathways

Quality of Life Theme	Pathway	Type of infrastructure
<i>Connectivity and accessibility</i>	Better access to services, reduced digital exclusion	Broadband connectivity
	Better access to employment, services, social activities	Access to private cars and public transport
	Enablers of walking and cycling	Features of the walking and cycling environment
<i>Impacts of infrastructure on physical and mental health</i>	Access to National Parks	Access to private cars and public transport
	Increased public transport use: increased walking	Access to private cars and public transport
	Increased car use: reduced physical activity	Access to private cars and public transport
	Increased social capital, cohesion, reduced injuries	Features of the walking and cycling environment
	Increased walking, cycling, wellbeing, reduced loneliness	Features of the walking and cycling environment
	Reduced injuries and fatalities, increased play	Road infrastructure , space reallocation, new transport infrastructure
	Experience of flood events	Flooding and flood risk
	Increased physical activity	Sustainable drainage systems
	Reduced flood risk	Sustainable drainage systems
	Reduced fuel poverty, better thermal comfort	Measures to improve energy efficiency
	Inconclusive evidence related to health outcomes	Proximity to waste infrastructure
<i>Impact of infrastructure on the natural and local environment</i>	Increased air pollution and noise	Proximity to road infrastructure
	Reduced air pollution and road damage	Urban freight vehicles and roadways
	Increased air pollution and odours	Proximity to waste water treatment
	Enhanced local environment, increased biodiversity	Sustainable drainage systems
	Increased air pollution	Coal and biomass power stations
	Perceived impact on landscape	Renewable energy infrastructure
	Positive impact on emissions and local environment	Vacuum waste collection
	Positive impact on environmental outcomes	Kerbside recycling
	Positive impact on environmental outcomes	Waste-to-energy plants
<i>Safety and reliability of infrastructure</i>	Community empowerment, energy security	Community and localised energy generation
	Risk of drought, pollution	Water supply
<i>Affordability of infrastructure</i>	Greater affordability	Community and localised energy generation
	Impact on property prices	Flooding and flood risk

Diagram summarises of quality of life themes and pathways



Chapter 1: Introduction

The review was commissioned by the National Infrastructure Commission (NIC) to better understanding the links between infrastructure and quality of life. It is a review of published academic evidence, which has been screened, reviewed and analysed for relevance and quality. This introduction chapter explains the scope of the report, details the methods, and sets out report's organisation and content.

Background and scope of the report

The purpose of this report is to provide a literature review of academic evidence for links between infrastructure and quality of life. The review provides insights on how infrastructure can affect quality of life and wellbeing, particularly at the local level. It is a guide to existing evidence and identifies research gaps and areas where further evidence can be developed.

Broadly, infrastructure is 'a reflection of our social and historical evolution. It is a symbol of what we are collectively...' (Herman and Ausubel, 1988: 1). Infrastructure enables thriving lives and livelihoods. It determines 'the character of urban wellbeing' (Amin, 2014: 138) and provides the 'undergirding' of society, generating the 'ambient environment of everyday life' (Larkin 2013: 328). As Graham and Marvin (2001: 8) point out, while infrastructure and infrastructure networks are commonly assumed to deliver 'broadly similar, essential, services to (virtually) everyone at similar cost across cities and regions...', the local experience of these technical systems can be extremely varied. Yet, one of the main challenges in studying and understanding infrastructure networks is that they are often taken-for-granted; so much a part of daily life that they can go largely unnoticed. The physical infrastructure objects and things people encounter – such as working taps, toilets, electrical sockets and roads – are so ubiquitous they can seem almost invisible. Indeed, when the networks and technical systems that allow for drinking water or electricity work as expected, we generally do not see them as they become part of the backdrop or backstage of life. Infrastructure, in other words, can be made invisible by its own success.

This report focuses on the infrastructure sectors of transport, energy, waste, water and wastewater, flood risk, and digital. The review does not cover all effects associated with infrastructure but rather, centres on evidence that demonstrates impacts on quality of life. Following the NIC guidance, we refer to quality of life as those 'factors other than income and wealth which affect people's wellbeing' (NIC, attachment 3, p. 4). Examples of these factors include connections (e.g., access to services), health and safety, affordability, local built and natural surroundings, and comfort and convenience..

In some circumstances we have drawn on wider conceptions of quality of life. In particular, we note the WHO's definition as "an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the person's physical health, psychological state, level of independence, social relationships, personal beliefs and their relationship to salient features of their environment."

The WHO definition's positioning of an 'individual's perception' signals some challenges in terms of developing universal standards of quality of life. Nevertheless, we can identify a number of domains through which to study quality of life. Following Lee and Sener (2016), these can include domains such as:

- Physical health and wellbeing: fitness, energy, absence of illness or physical dysfunction;
- Mental health and wellbeing: psychological health, mood and self-perception;
- Social wellbeing: the quality of one's social support network, family or personal relationships, and level of community involvement;
- Economic wellbeing: reflects one's financial resources and access to employment opportunities.

Key to these domains is an understanding of 'wellbeing'. Wellbeing is a multidimensional concept that contributes to quality of life, which can be measured both objectively and subjectively. Subjective wellbeing (SWB) captures wellbeing as perceived by individuals, whilst objective dimensions of wellbeing include income and health. The Organisation for Economic Cooperation and development (OECD) defines SWB as "good mental states, including all of the various evaluations, positive and negative, that people make of their lives, and the affective reactions of people to their experiences" (OECD 2013: 10). Quality of life and SWB can be differentiated between hedonic, eudaimonic and evaluative metrics (Mokhtarian, 2019; Graham et al, 2018). Hedonic SWB is about the presence of pleasure and absence of pain. This can be measured in terms of evaluative wellbeing (how satisfied individuals are with different domains of their life and with life overall) and experiential wellbeing (how often individuals experience positive and negative emotions). Eudaimonic wellbeing relates to the achievement of a higher purpose or meaning in life. Evaluative ways of measuring quality of life assess an 'individual's satisfaction with their lives over their lifetime' (Graham et al, 2018: 287). In this study, we are primarily concerned with hedonic approaches where research involves measurable attributes which can clearly delineate the direct impacts between infrastructure and quality of life. However, it is not always possible to disentangle concepts such as quality of life and wellbeing from their subjective positions. Hence, some research on perception and satisfaction is included where we feel it adds value to the discussions.

The review includes evidence from the UK and international sources from relevant economically developed comparator countries. It is not intended to be a global review of infrastructure challenges. Rather, it centres on providing evidence that is particularly relevant to the NIC and the contemporary infrastructure conditions of the UK. The review does not provide advice or policy recommendations but is intended to support decision-making and guide future research activities.

Organising quality of life impacts in the document

This report is structured around specific infrastructure sectors. Each chapter centres on research which has been reviewed within a specific sector. We have organised chapters in order of where we feel the evidence is most thorough and robust. As such, following this introduction, the order of sectors is as follows: Chapter 2 Transport; Chapter 3 Water and Wastewater; Chapter 4 Flood Risk Management; Chapter 5 Waste; Chapter 6 Digital; and Chapter 7 Energy. Further reflections on the comprehensiveness of research identified and key gaps are discussed in Chapter 8 Conclusion.

Each chapter is then organised via sub-topics and themes that have been identified through the review. For every topic we have identified the key relations between infrastructure and quality of life, as discussed in the evidence. We connect these to the NIC framing of quality of life through a colour-coded system in order to help summarise main contributions. This is also evident in the Executive Summary where we highlight main points and links. As such, readers will be guided through the document through the following 'key themes of quality of life' (see below and NIC attachment '*Initial NIC thinking on Quality of Life*')

Quality of Life Theme: Safety and reliability of infrastructure

Consistency of infrastructure services, perceived protection from hazards, and actual protection from hazards.

Quality of Life Theme: Connectivity and accessibility of infrastructure

Ability to make leisure and work connections, and that infrastructure is designed for and used by everyone.

Quality of Life Theme: Affordability of infrastructure

If the same service is offered for a lower price, users have more disposable income – or can consume more of it.

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Mental health (crowding and floods), thermal comfort, noise, physical health (walking / cycling).

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Amenity value of spaces created / impacted by infrastructure, value of design and change in ecosystem services.

Methods

This is a 'Rapid Evidence Assessment' (REA) review. The REA approach is a structured and rigorous approach to searching and assessing the quality of literature. While it is somewhat less extensive than 'systematic reviews', REAs have the benefit of providing a quick turnaround of evidence and literature summaries. They are intended to provide a balanced assessment of literature, recognising certain constraints. Our REA focused on pre-existing, published systematic reviews (where possible) in several thematic areas of infrastructure and quality of life. The central thematic areas of study reflected NIC areas of interest and included infrastructure associated with: energy, waste, digital, wastewater and water supply, flood risk management, and transport. Reviewers were assigned to these areas to conduct searches and produce project specific outputs (pro-forma, evidence table, narrative). Broadly, the review project was organised around three main stages: Stage 1. Strategy refinements, searches, initial screening; Stage 2. Full review; and Stage 3. Write-up, refinements.

Stage 1 focused on organisational and setup activities including refinement of our search strategies, proforma and evidence table structures, and initial screening. We conducted our search through standard academic databases (e.g. Embase, Medline, Global Health, PsycINFO, Opengrey, Scopus) for the years 2010 to 2020. Search terms were developed for each infrastructural category (see appendix A). These were refined after initial screening in order to limit overall numbers, to identify the extent of evidence and to decide whether existing systematic reviews should be supplemented with more recent empirical papers and research.

A total of 8703 papers were identified in total (see appendix B). From this collection, we conducted title and abstract screening (see appendix B).

Stage 2 comprised the full literature review. The intent of this work was to conduct full paper screening and develop the evidence tables for impacts of infrastructure on quality of life. For each infrastructure area, the lead reviewer read the full paper to decide relevance for inclusion. Studies were judged to be relevant where they reported on the **measured** impact of at least one type of infrastructure, or absence of infrastructure, in relation to the quality of life themes defined above. This included any study design, including systematic reviews, meta-analyses, qualitative, observational, longitudinal and before and after studies. Studies that reported the results of predicted or modelled changes in quality of life (e.g. modelled impact on flood risk, or air quality) were excluded from the review. In total, we include 104 studies (energy = 18, waste = 7, digital = 8, water and flooding = 43, and transport = 29).

Proforma summaries were developed for each paper to be included. These summaries provided detail on type of paper (e.g., review, case study, etc), methods, quality, key findings and relevance to the review for inclusion in the evidence tables. Following this work, we assessed coverage of the evidence and then sought out papers and research to fill gaps. For example, to widen coverage we were less restrictive on the date range, sought advice from topic experts and added discussions of emerging research.

Stage 3 focused on summarising the evidence base and draw out the key findings from the review. This included writing the narrative, organising the evidence tables, filling in gaps identified through team discussions, writing up 'exemplary' case examples, and updating references.

Chapter 2: Transport Infrastructure

This is a summary of the reviews carried out on the impacts of transport infrastructure in the health and wellbeing aspects of quality of life. It does not include evidence on impacts of the planning and construction phases of the infrastructure. Most of the papers identified through the screening process concern health impacts of the road network, its characteristics and the associated modes it supports, and features of the built environment (including the design and quality of transport infrastructure) which can affect how people travel and how much they engage in physical activity and other activities relevant to health, wellbeing and quality of life. A few papers provide evidence of impacts stemming from changes to transport infrastructure and its uses (for example the reallocation of road space to non-motorised modes and other activities).

The impacts of access to private cars and public transport

Quality of Life Theme: Connectivity and accessibility of infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Roads are important infrastructure supporting social and economic activity, however they also impose a number of costs on society, including in terms of morbidity and mortality from road traffic injuries. The Department for Transport (2019) reports an average of 5 fatalities and 68 serious injuries every day on Britain's roads. Since 2010 this has remained relatively constant. In terms of absolute counts, car occupants come out as the road user group with the greatest number of casualties and fatalities each year (44% of total fatalities and 59% of total casualties in 2018), pedestrians 26%, motorcyclists 20% and pedal cyclists 6%. Cars account for around 80% of the traffic on British roads.

Cars are the dominant mode of transport in British society, but there is considerable variation across the population in car access and use. Chatterjee et al (2019; Table 1) report that:

- The majority (69%) of the population have personal access to cars and an even larger proportion of the population (87%) are frequent (weekly) car users.
- Driving is less frequent among under 30-year olds and those aged 70 years or over (in line with driving licence holding). On the other hand, trips as a car passenger are more frequent among 17 to 20-year olds and those aged 60 or over.
- Women are more likely than men to be car passengers and less likely to be car drivers.
- Those in the lowest household income quintile use the car less frequently as driver or passenger.
- Single parents drive less frequently and are car passengers more frequently than other household types.
- Those in managerial and professional occupations drive more frequently than other people.
- Those with mobility impairments drive less than those without mobility impairments.

- Car trips (both as driver and passenger) are more frequently made by those living in less urbanised residential contexts.
- Car driving mileage of those with car access is linearly related to personal income and positively associated with being male, being in paid employment, higher skilled employment and living in a less urbanised area.

In terms of the relationship between car access/use and quality of life domains, Chatterjee et al (2019) found that:

- Having personal car access makes it twice as likely that someone can access services (healthcare, food shops and learning facilities). It has greater importance in relation to accessing services for those with health-related mobility impairments and those living in rural areas. Losing car access makes it three times as likely that someone becomes unable to access services.
- Having personal car access makes it 1.7 times more likely that someone can go out socially. It has greater importance in relation to going out socially, for those with health-related mobility impairments and those living in rural areas. Losing personal car access makes it 2.3 times more likely that someone becomes unable to go out socially.
- Amongst the older population aged 50 and over, having personal car access as a driver makes it less likely (by 0.8 times) that someone reports feeling lonely.
- Having personal car access makes it 3.8 times more likely that someone is employed rather than unemployed (compared to not having car access). Continued car access makes it 2.2 times more likely that someone unemployed moves into employment two years later (compared to not having car access). Gaining car access makes it 1.7 times more likely that someone moves into employment two years later (comparing to not having car access).
- Having personal car access has greater importance in relation to being employed for men than women, and for those living outside London and Metropolitan areas. The role of personal car access in relation to accessing employment is the same for all age groups and is not altered by having health-related mobility impairments.
- Existing evidence indicates that people on higher incomes are more likely to buy cars. New evidence shows that having personal car access boosts the rate at which personal income grows over time. Over a two-year period, compared to not having car access, acquiring personal car access is associated with an 11% larger increase in personal income and having continued car access is associated with a 25% larger increase in personal income.

However, Chatterjee et al (2019) also found that a significant minority – nearly a third of the adult population, do not have personal car access and are reliant on public transport or other modes to support their lives. They also reported that lack of personal car access is more common amongst young adults, those in BME groups, those with mobility impairments,

unemployed people and those with low incomes. Looking at the relationship between quality of life and public transport:

- Those who rate local public transport as good are nearly three times (2.8 times) more likely to be able to access services compared with those who rate it as poor.
- Short journeys by public transport to town centres (10 minutes or less) make it 1.7 times more likely that someone can access services (compared to journeys of over 30 minutes).
- Rating local public transport as good rather than poor makes it 1.4 times more likely that someone can go out socially.
- Rating local public transport as good, rather than poor, makes it slightly less likely that someone feels under strain, has poor mental health or reports being dissatisfied with life.

A recent evidence review for the Department for Transport (Cooper et al, 2019; Table 1) found that:

- Unskilled manual workers are less likely than professionals to own a car but are three times as likely to die in a road crash. In general, healthy and affluent groups are more likely to experience positive impacts whereas those on lower incomes, young, and older people are more likely to experience negative impacts.
- Increased car use can have an adverse effect on children's physical health. This is because a greater reliance on car use has contributed to a reduction in the amount of physical activity children engage in.
- A systematized literature review on whether the reliance on private motor vehicles for transport is a contributor to obesity levels in the adult population found (in 8 studies out of 10) a significant positive association indicating that the more time and distance travelled in private motor vehicles the more an individual is likely to weigh.
- Cars can have a positive impact on physical health when they facilitate access to healthy food suppliers and leisure/recreational activities. However, they are more commonly found to have a negative impact in that they tend to reduce overall levels of physical activity for both adults and children.
- Community severance (i.e. the limited accessibility of a community caused by transport infrastructure, such as motorways without pedestrian crossings or railway tracks that divide a city in half, or a high volume of traffic) can lead to increased distances to workplaces and facilities such as schools, parks, shops, leisure centres, and health services. Community severance can negatively affect quality of life and social cohesion, as well as contributing to social exclusion – from the number of neighbours people know, to the level of outside play by children.
- Concessionary bus passes and policies that prolong driving amongst older people or reduce the need for them to give up driving both improve older people's mobility. As a result, older people experience lower levels of social exclusion and higher levels of psychological wellbeing, because their mobility, and in turn, wellbeing, is not restricted or limited.

Building more roads affects, positively and negatively, health and wellbeing, and also the environment, which indirectly impacts on quality of life. A report by Transport for Quality of Life (Sloman et al, 2017), drawing on official evaluations from over 80 road schemes and four original case studies to provide a 20-year 'long view' of the impacts of road building, found that the benefits of road schemes in terms of congestion relief can be short-lived (e.g., one year), particularly in situations where such schemes are associated with car-dependent development. The report documents how road-dominated approaches can lead to car-dependent sprawl which is environmentally damaging and afflicted by congestion. It recommends much tighter focusing of development at existing larger settlements that offer facilities close to hand and strong public transport hubs.

Concerning transport access to National Parks

Quality of Life Theme: Connectivity and accessibility of infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Quality of Life Theme: Impact of infrastructure on the natural and local environment

A review of the literature carried out by the Campaign for National Parks (Bradshaw, 2018; Table 1) found that National Parks, recognised for their natural beauty, wildlife and cultural heritage, are national assets providing natural resources such as clean water and opportunities for tranquillity and healthy recreational outdoor activities. There is increasing recognition of the physical and mental health benefits that the landscape and outdoor recreation provides, for example to children and young people, but unfortunately not everyone is able to visit and enjoy them. Widening access to National Parks through sustainable transport modes would allow more people to enjoy such benefits.

Residents and visitors to National Parks heavily rely on private vehicles: 88% of households residents living in National Parks owned one or more cars compared with 74% nationally and on average 93% of visitors to UK National Parks travel by car. Non-visitors, especially those from disadvantaged backgrounds, report transport accessibility as a key barrier to visiting National Parks.

Barriers to sustainable transport access include: infrequent and/or unreliable weekend bus and rail services, cost of fares, lack of integration between sustainable transport modes, road safety risks from car traffic for those walking and cycling on rural roads.

Increasing the options available for travelling to and around National Parks sustainably would provide many benefits including:

- For individuals – improved physical and mental health through opportunities for engaging with nature.
- For local economies – there is some evidence that visitors by public transport spend more than those arriving by car.

- For the environment and local communities – by reducing the number of people who travel to National Parks by car and the associated impacts in terms of carbon emissions, noise pollution and road danger.

Despite the significant cuts to rural buses in recent years, there are examples of successful services that continue to operate in National Parks. There are also signs that the bus industry is starting to consider the potential to use new technology to deliver flexible on-demand shared journeys for visitors.

The impacts of features of the built environment

Quality of Life Theme: Connectivity and accessibility of infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Six systematic reviews included here examine the impacts of built environment features on different aspects related to health, wellbeing and quality of life (Table 2):

- A systematic review and meta-analysis of 72 studies looking at the physical activity effects of features of the built environment on older adults (Van Cauwenberg et al, 2018) found that living within walkable, aesthetically pleasing neighbourhoods with good access to public transport and recreational facilities, including parks and open spaces, is associated with more leisure time walking among older adults.
- A systematic review of 28 studies (Smith et al, 2017) found that improving neighbourhood walkability, quality of parks and playgrounds, and providing adequate active transport infrastructure is likely to generate positive impacts on activity in children and adults, particularly among socioeconomically advantaged groups.
- A systematic review of 50 walking studies and 35 pedestrian injury studies (Rothman et al, 2014) found that built environment features that either slow traffic down (traffic calming devices) or separate children in space from traffic (playgrounds and recreation areas) were the only factors consistently associated with more walking and less pedestrian injury.
- A systematic review of ten studies (Barbosa et al, 2019) found that less walkable neighbourhoods are associated with overweight and/or obesity in adult populations.
- A systematic review of 23 studies (Mazumdar et al, 2018) found a significant relationship between social capital and the built environment, specifically between social cohesion and access to destinations/walkability.

There is a lack of longitudinal studies examining the relationship between walking and cycling behaviours and the built environment. One example is the RESIDE study (see case study, below).

Case Study: RESIDential Environments (RESIDE) study

Quality of Life Theme: Connectivity and accessibility of infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

The RESIDential Environments (RESIDE) experiment examined whether the development of 'Liveable Neighbourhoods' in Perth, Australia had an impact on health, wellbeing and quality of life. This is a substantial longitudinal study that included developments constructed following the Liveable Neighbourhoods policy, developed in response to unsustainable development patterns in Perth, as well as conventional developments. This policy focussed on providing neighbourhoods of relatively high density, compact developments with a variety of uses, interconnected street patterns, walking and cycling infrastructure, diverse residential properties, and at least 10% public parkland. Numerous papers have been published from this study covering different outcomes and/or elements of the neighbourhood, including Hooper et al (2020) which brings these findings together.

The RESIDE study included 74 neighbourhoods, of which 19 were liveable neighbourhoods, 44 were conventional developments and the remaining 11 were hybrids that incorporated some elements of the liveable neighbourhoods policy (Hooper et al, 2020). Findings from the RESIDE study include increased transport walking in neighbourhoods with more connected streets, better public transport and pedestrian infrastructure, parkland and street trees, and increased recreational cycling with more street connectivity (Hooper et al, 2020). In addition, more connected streets and pedestrian infrastructure were also associated with an increased sense of community, and perceived safety from crime was associated with better public transport, pedestrian infrastructure and street trees (Hooper et al, 2020).

Overall, the researchers conclude that "the consistency of RESIDE's results suggest that residents living in neighborhoods that incorporate liveable urban design features appear to have better health-supportive behavior and wellbeing outcomes, principally by encouraging more local walking but also by enhancing sense of community, feelings of safety, and mental health" (Hooper et al, 2020).

The impacts of changes in road infrastructure, space re-allocation and new infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Five reviews considered here focussed on the relationship between changes in road infrastructure on health, wellbeing and quality of life (Table 3). A meta-analysis of 44 studies (Elvik, 2017) found that converting junctions to roundabouts is associated with an approximately 65% reduction in fatal accidents and approximately 40% reduction of injury accidents of about 40%. Estimates of effect are stable over time, but larger accident reductions have been found in studies reported in North America and Australia than in other regions of the world.

A systematic review of 46 studies - 33 reviews and 13 evaluation studies (Panter et al, 2019) sought to understand if and how interventions to increase walking and cycling achieve their objectives. The review found that the most effective interventions appeared to target accessibility and safety. This was the case in both 'supportive' (e.g., built environments with a pre-existing high level of conditions for walking and cycling) and 'unsupportive' (e.g., car-dominated) environments. Individual or population levels of walking and cycling and the supportiveness of the physical and wider social environment were important contexts. However, there was little information about potential mechanisms through which interventions achieved their objectives. The most plausible mechanisms concerned (i) improving accessibility and convenience of walking and cycling and (ii) reducing potential conflict between users (Panter et al, 2019).

A systematic review of 6 studies (Umstad Meyer et al, 2019) looking at street closures to allow children play and social activities (Play Streets) found that Play Streets provided safe places for child play, increased sense of community, and when measured, increased physical activity overall and during Play Streets events.

An umbrella review of 5 reviews (Cairns et al, 2015), looking at 10 different studies in total, found convincing evidence that 20 mph zones are effective in reducing collisions and injuries, traffic speed and volume, as well as improving perceptions of safety in a couple of the studies. Such interventions can be cost-effective and supported by local residents. However, effects on physical activity—walking and cycling and children playing outside—were less clear.

Dedicated infrastructure for freight transport is also important. Cities depend upon the efficient and effective transport of goods (Ricci, 2016). However, there are negative social and environmental impacts originating from freight transport in urban environments. These negative externalities include local air pollution, in particular increasing concentrations of NO₂ and particulate matter (PM) that are harmful for public health, traffic congestion, accident-related fatalities and injuries due to freight, noise pollution on road and at delivery locations, and greenhouse gas emissions (in particular CO₂).

Urban Freight vehicles and roadways

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Conventionally-powered freight vehicles, especially Heavy Goods Vehicles (HGVs), disproportionately contribute to urban polluting emissions considering their relatively low modal share. They also disproportionately damage roadway surfaces due to their weight as compared to cars and other light duty vehicles. Moreover, start-stop operation in urban environments can increase freight vehicles' fuel consumption by 140%.

A literature review of urban freight interventions and policies (Ricci, 2016), focusing on 20 studies including reviews, found that Urban Freight Consolidation Centres (UFCCs) can lead to significant reductions in freight transport activity and associated environmental impacts between the UFCC and the final point of delivery for those goods flows that pass through the UFCC. However, given the often limited scale of such schemes and modest goods throughput at UFCCs, any reduction in transport activity and associated environmental impacts due to the UFCC are, unsurprisingly, marginal in terms of total freight traffic and total motorised traffic in the urban area concerned.

Impacts of transport infrastructure use

Quality of Life Theme: Impacts of infrastructure on physical and mental health

In this section we review literature related to the use of transport infrastructure including active commuting (e.g., walking and cycling to work) and public transport. The ways in which people move about their environments is of critical importance to their health. Commuting, in particular, has an impact on people's mental and physical wellbeing.

Active travel and active commuting

Childhood obesity, physical inactivity and sedentary life are increasing dramatically worldwide. Physical inactivity is closely linked to bone health, cardiovascular disease, metabolic disorders, fitness and psychological outcomes. Here we consider five systematic reviews that examine the impacts of walking and cycling on health and wellbeing (Table 4):

- A systematic review (Yazdanpanahi et al, 2012) reports that recent studies have found positive effects of active commuting on physical inactivity, overweight, obesity, survivors of childhood cancer, particularly brain tumours and acute lymphoblastic leukaemia, and links to a reduction of metabolic complications and cardiovascular disease in later life.
- A systematic review and meta-analysis of 23 studies (Dinu et al, 2019) found that people who engage in active commuting have a significantly reduced risk of all-cause

mortality (ACM), cardiovascular disease incidence and diabetes. No association was found between active commuting and cardiovascular disease mortality and cancer.

- A systematic review and meta-analysis of 21 studies (Kelly et al, 2014) found that walking and cycling have population-level health benefits (i.e. reducing risk of ACM) even after adjustment for other physical activity. Public health approaches would have the biggest impact if they are able to increase walking and cycling levels in the groups that have the lowest levels of these activities.
- A systematic review of 7 studies (Marques et al, 2020) looking at the links between active travel travel/commuting and depression reported inconsistent evidence. Switching to more active modes of travel and walking long distances were negatively related to the likelihood of developing new depressive symptoms in two studies. In the other five studies, no significant association between active travel or active commuting and depression was found.
- A systematic review of 17 studies on electrically-assisted cycling and health (Bourne et al, 2018) found that e-cycling leads to reduced activity volume and intensity over the same distance compared to conventional cycling. It requires more frequent and longer rides to accrue comparable health benefits.

Commuting by **public transport**:

A further three reviews consider the relationship between public transport and health and wellbeing (Table 20):

- A systematic review of 27 studies looking at the link between access to public transport and childhood obesity (Xu et al, 2020) reported that evidence is mixed and difficult to compare. The available evidence suggests that an increased level of access to public transport may have a health-promoting effect and hence prevent the development of childhood obesity. However, this conclusion needs to be further corroborated in future research.
- Norgate et al (2020) conducted a systematic review of 47 studies focused on the link between commuting by public transport and health outcomes. The authors found negative impacts on sickness rate, self-rated health complaints and perceived stress, and reduction in sleep, especially for long commutes and involving more than one leg of journey, and for women. Analysis of rail commuters showed increased stress (both objectively measured and subjectively perceived) and affective reactions to crowding.
- A critical review on the links between commuting and wellbeing (Chatterjee et al, 2020) found that mood is lower during the commute than other daily activities. Stress can be induced by congestion, crowding and unpredictability. People who walk or cycle to work are generally more satisfied with their commute than those who travel by car and especially those who use public transport. Satisfaction decreases with duration of commute, regardless of mode used, and increases when travelling with company. The commute experience “spills over” into how people feel and perform at work and home. However, a consistent link between commuting and life satisfaction overall has not been established. The authors suggest that commuters are generally successful in trading off the drawbacks of longer and more arduous commute journeys

against the benefits they bring in relation to overall life satisfaction, but further research is required to understand the decision making involved.

Figure 1 shows the relationship between commuting and subjective wellbeing (SWB), from Chatterjee et al (2020).

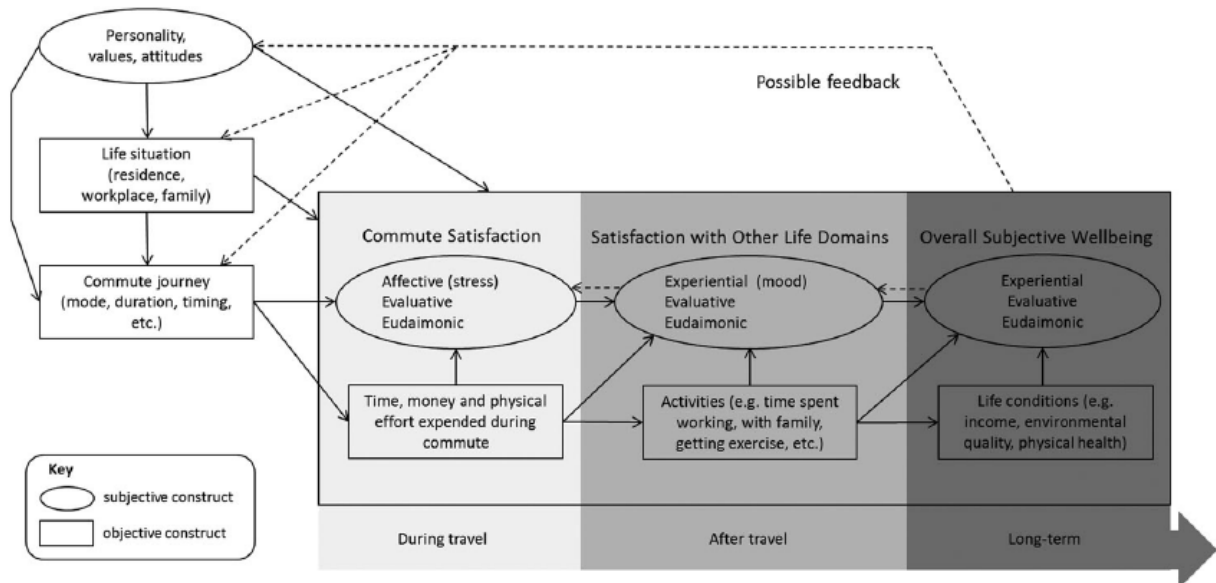


Figure 1 Conceptual model for the relationship between commuting and SWB (from Chatterjee et al, 2020).

Effects of proximity to transport infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

In this section we discuss nine reviews that consider the impact of traffic on health and wellbeing (Table 5). Central here is the role and impact of traffic noise and air pollution on health and wellbeing. In addition, we highlight the efficacy of interventions to reduce transport related air pollution.

Traffic noise is an established risk factor for some cardiovascular diseases such as hypertension and ischaemic heart disease. A systematic review with meta-analysis of 11 studies (Dzhambov and Dimitrova 2016) has established a small but elevated risk of stroke to be associated with both road and air traffic noise exposure, but the association was only statistically significant in the latter.

Sources of transportation noise lead to serious annoyance, sleep disturbance, and cardio-metabolic disorders. A systematic review and meta-analysis of 10 studies (Dzhambov and Lercher 2019) found that increasing exposure to road traffic noise may also be associated with depression and anxiety. In another systematic review and meta-analysis of 9 studies, Dzhambov and Dimitrova (2018) found that residential road traffic noise is associated with higher risk of hypertension in adults, and that risk is lower than previously reported in the

systematic review literature. The risk of hypertension was higher when adjusting for air pollution, and for men compared to women.

Ambient **air pollution** is a complex mixture of particles and gases (Burns et al, 2020). Their concentrations and composition vary from place to place, depending on what sources are present, weather conditions, and how they mix in the atmosphere. Ambient air pollution represents a complex mix of pollutants, originating from a range of sources, with approximately 15% of urban ambient pollution stemming from industrial sources, 20% from residential sources and 25% from vehicular sources.

Over the past several decades, numerous studies have documented associations between ambient air pollution and mortality and morbidity. The Global Burden of Disease project has identified outdoor air pollution as one of the top five risk factors worldwide.

A systematic review and meta-analysis of 26 studies on birth outcomes Wang et al (2020) found that prenatal exposure to traffic pollution is detrimental to the foetus. 'Small for gestational age' was significantly associated with a per 500 m decrease in the distance to roads. Studies with higher Newcastle-Ottawa Score¹ (NOS), cohort studies, and studies in North America revealed a positive and significant association between traffic density and term low birth weight. Traffic density seems to be a better indicator of traffic exposure than the distance to the road.

There is a strengthening evidence base that long term exposure to air pollution, particularly related to traffic, is associated with deficiencies in lung function across all age groups. A systematic review of 33 studies (Tham et al, 2019) looking at air quality (some of which focused on traffic related air pollution) found that long term exposure to higher levels of nitrogen dioxide, particulate matter and ozone was associated with lower lung function parameters in young children, children and adolescents; and declines in some adults' and older adults' lung function parameters. Levels of associations varied depending on the levels of exposures of different pollutants in different areas.

In terms of impacts on health through the air pollution generated by different modes of transport, a systematic review of 39 studies (Cepeda et al, 2017) found that proximity to traffic and high air interchange increased the exposure to air pollution of commuters using motorised transport, mostly cars and buses. Larger inhalation rates² and commuting time increased inhaled dose among active commuters (cyclists followed by pedestrians). However, benefits of active commuting from physical activity are larger than the risk from an increased inhaled dose of fine particles.

¹ The Newcastle-Ottawa Score (NOS) was developed by researchers in Newcastle (Australia) and Ottawa (Canada) to assess the quality of nonrandomized studies.

² Inhalation rate is the volume of air inhaled over a specified period of time.

Effects of interventions to reduce traffic-related air pollution

A systematic review of 42 studies (Burns et al, 2020) assessing 38 interventions to reduce air pollution, including traffic-related air pollution, reported mixed associations between interventions and both health and air quality outcomes. Most reviewed studies found either no clear association in either direction or a significant association in favour of the intervention. A small number of studies observed a significant association favouring the control. There was little evidence that the assessed interventions might be harmful.

For the evidence synthesis of interventions to reduce ambient air pollution from vehicular sources, five studies contributed evidence on health outcomes and nineteen studies contributed evidence on air quality outcomes (Burns et al, 2020). Given the heterogeneity across interventions, outcomes, and methods, it was difficult to derive overall conclusions regarding the effectiveness of interventions in terms of improved air quality or health. In terms of health outcomes, many studies showed mixed, inconclusive impacts. For example, one study showed no clear change in asthma symptoms associated with the opening of a bypass to reduce traffic congestion in North Wales, while another found a significant decrease in all-cause mortality, cardiovascular mortality and respiratory mortality associated with mandatory standards for diesel vehicles entering the Tokyo metropolitan area. In terms of the evidence on air quality outcomes, again, the evidence is somewhat mixed. For example, a London study showed no clear change in PM₁₀, NO_x, NO₂ or NO concentrations at streetside sites associated with the London congestion charging scheme while a study in Beijing found a significant decrease in PM₁₀ concentrations associated with an even-odd driving restriction policy, which was then relaxed to a one-day per vehicle driving ban in Beijing.

Impacts of future technologies

Quality of Life Theme: Safety and reliability of infrastructure

Quality of Life Theme: Connectivity and accessibility of infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Quality of Life Theme: Impact of infrastructure on the natural and local environment

A literature review on the health and wellbeing impacts of autonomous vehicles (AVs) (Singleton et al, 2020) found that AVs are likely to have overall positive impacts on some health and wellbeing aspects (safety, travel satisfaction, access to activities) and overall negative impacts on others (physical activity), while effects are more uncertain for other topics such as urban built environments, air and noise pollution. (see Table 5).

Chapter 3: Water and Wastewater Infrastructure

This chapter looks at wastewater and water supply infrastructure and relationships with quality of life. The discussion is organised into topics associated with key areas of research identified through the search process including water supply; drought; and wastewater. Very few systematic studies were identified that directly addressed the topic of quality of life and infrastructure. Nevertheless, it is clear that water and wastewater infrastructure directly supports the health and wellbeing of people. Globally, clean water for all remains an unrealised goal and the inadequacies of water infrastructures and water supply systems has been well documented. As expected, much of the research on water infrastructure centres on addressing water inequalities, particularly on topics such as pollution (e.g., fluoride, nitrates, etc), the impacts of lead on human health, and the challenges of water security. Much of this research does not fit the profile of the UK where drinking water quality is considered to be of the highest quality in the world. Yet, challenges in the water industry remain. Of particular relevance for this report is the potential for drought, water supply and impacts of sewage overflows.

Drought and quality of life

Quality of Life Theme: Impacts of infrastructure on physical and mental health

All of the five empirical papers identified through the search and reviewed focused on Australian cases of drought and the impacts these experiences had on human health (Table 6). The literature is uniform in identifying the negative health effects associated with drought. For example, Carnie et al (2011) found that prolonged exposure to drought led to an experience in hopelessness, distress and behaviour problems among school-aged children (see also Dean and Stain 2010 for a study of adolescents). Hart et al (2011) described a 'Rural Adversity Mental Health Program' (introduced in 2007) focused on raising awareness of drought-related mental health issues and needs. Their work suggests that the experience of prolonged drought will likely lead to significant mental health challenges that should be addressed through long-term interventions that coincide with a drought period as well as in the time after it has broken. Polain et al (2011) point to the specific pressures facing farmers which can be compounded by industry characteristics (e.g. ageing farmers, climate change, etc) as well as difficulties accessing support services.

Quality of Life Theme: Safety and reliability of infrastructure

Within the UK, Bryan et al (2019) studied the perceptions towards drought management at the household level in England. The researchers conducted a cross-sectional survey of two communities in Exeter. The survey asked residents about their perceptions on the threat of drought and the coping measures they could put in place if a drought were to occur. The research suggests that even though there is low likelihood of drought in Exeter, participating

households would be willing to implement coping measures (e.g., water conservation, grey water use), in the situation of a drought. The willingness to implement coping measures tended to be highest in those who had experienced or were aware of previous droughts³.

Water Supply and quality of life

We identified two review papers and an additional three empirical papers which met our search criteria (Table 7). While none of these addressed quality of life directly, they provide insights to some of the general issues facing water supply and water supply infrastructure in the UK. The research highlights a few future challenges to water supply including the negative impacts of nitrates in the UK water supply, the health implications associated with water conservation and how disruptions to water supply can adversely impact communities, resulting in unforeseen costs, particularly in rural areas.

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Stelmach and Clasen (2015) conducted a review of the health effects of household water quantity. As might be expected, they found a positive association between water quantity and health outcomes (i.e., more water consumption equals improved health). Specific benefits varied across areas of hygiene as well as disease. Interestingly, for high-income countries specifically (Australia, USA and Canada), there is evidence to suggest that increased water consumption might lead to an increased risk for some non-communicable diseases (e.g., bladder cancer).

Quality of Life Theme: Safety and reliability of infrastructure

Quality of Life Theme: Affordability of infrastructure

Mankad and Tapsuwan (2011) conducted an international review of literature on decentralised water systems. Their review sought to identify and better understand the drivers that support the acceptance of on-site water systems. These decentralised supplies generally involve the use of greywater or rainwater that is collected and stored on premises or at the point of use. The authors found that these alternative forms of household water supply can provide economic, environmental and social benefits such as savings on water use and costs, delaying the need for new supply sources, mitigating imposed water restrictions, and increasing the sense of environmental responsibility. They suggest that community acceptance of on-site systems is often improved or highest in situations where human contact

³ We highlight the NERC funded 'Drought Risk and You' (<http://dryproject.co.uk/>) research project which is studying seven catchment areas in England, Wales and Scotland. While published research papers from this work are forthcoming, the project is exploring the ways in which stories and memories about drought can help build knowledge and support adaptation and resilience.

with the water is minimised (e.g., it is not wastewater) or if the water is not from a shared source (i.e., it is their own recycled water).

Quality of Life Theme: Impacts of infrastructure on physical and mental health

We included two empirical papers (both specific to the UK) in our review. Stuart et al (2011) reviewed the impacts of climate change on nitrate concentrations in UK groundwater. High levels of nitrates can negatively impact water quality. Their research suggests that climate change will likely to lead to increased nitrate leaching from the soil. According to the authors, nitrate is the most significant groundwater challenge facing the water industry in the UK. Levels of nitrate are expected to rise in the future. Speight (2018) discusses the need for collaboration between water industry and the public sector (e.g., health professionals) in order to raise awareness of the UK's water quality issues and challenges. Critically for health, Speight highlights how lower water consumption could lead to degradation of drinking water quality, particularly in households with lead within their plumbing. In other words, efforts to conserve water at the household level might negatively impact household health.

Water supply and economic outcomes

Quality of Life Theme: Safety and reliability of infrastructure

Our third empirical paper in this category of water supply examined the economic impact of disruption to the water supply on residents (Heflin et al, 2014). This study (Table 7) included focus groups in two locations (Ithaca, New York; Somerset, Massachusetts) and 162 face-to-face surveys in four areas that had been impacted by contamination or outage of water supply lasting more than one day, and within 12 months of the interview (Somerset, Massachusetts; San Luis, Colorado; Questa, New Mexico; East Chicago, Illinois). According to the authors, the mean total cost for disruptions was \$93.96 per event (\$92.68 for water outages and \$96.03 for contamination events), with those in rural areas incurring greater costs than urban residents (\$137.26 versus \$61.84; $p < 0.05$) (Heflin et al, 2014). Some adaptation practices that incurred costs included purchasing bottled water, boiling or bleaching water, replacing water filters, using disposable dishware, eating out and eating less and staying in hotels and other forms of lodging.

Wastewater and quality of life

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Three papers were identified which met our search criteria (Table 8). These papers are recent empirical studies of the quality of life impacts associated with living near wastewater treatment plants. The first, from Fujiwara et al (2020), analyses the association between subjective wellbeing (SWB) and proximity to Sewage Treatment Works (STWs). The research

combines two national (UK) data sets with location and operations data of STWs from UK water companies and government sources. In the paper, the Annual Population Survey (APS), a household survey covering the UK is combined with the Understanding Society (USoc) longitudinal study of households. The findings suggest a negative correlation between proximity to STWs and SWB, which increases in magnitude for STWs with severe odour problems. In other words, living farther away from the nearest STW is associated with higher levels of life satisfaction.

The second paper investigates the impact on the quality of life of people living close to a municipal wastewater treatment plant in the city of Patras, Greece (Vantarakis et al, 2016). The research found that the quality of life was lower for the population living in close proximity to the wastewater treatment plant. For example, there was significant risk for symptoms such as headache, unusual tiredness, and concentration difficulties, an increased possibility for respiratory and skin diseases and a high rate of the cases being irritable and moody. Significantly higher gastrointestinal symptoms were also reported. The air sampling showed the prevalence of pathogenic airborne microorganisms originating from the wastewater treatment plant was reported in high numbers in sampling points close to the wastewater treatment plant.

The third paper reports findings from a bioaerosol investigation in the area of and surrounding a sewage treatment plant in Poland (Pasmionka, 2020). The research shows diverse bacteria and fungal microflora in the area of the plant and suggests that the plant may contribute to poor air quality and adversely affect human health (see case study, below).

Case Study: Air quality impacts of wastewater treatment

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Pasmionka (2020) details the findings of a study into the air quality within and surrounding a wastewater treatment plant. The focus of this research is on the microbiological contaminants found in the air which can be generated from sewage treatment plants, landfills and other forms of waste management infrastructure. The biological aerosols that are produced from these facilities can pose threat to health and wellbeing in people. For example, exposure to these aerosols can lead to a number of serious diseases including alveolitis, conjunctivitis and gastrointestinal infections.

In 2018, Pasmionka investigated the microbiological air quality in a large municipal sewage treatment plant (Oswiecim, Poland). Samples were collected at four points: point 1: raw sewage inlet; point 2: aeration chamber; point 3: purified sewage outlet; and point 4: 150 m from treatment plant (the control site), at multiple times during the year (e.g., to account for seasonal temperature and humidity variations).

The study's main findings were that the largest amount of bacteria were identified in August near the aeration chambers. Overall, the higher levels of microorganism pollution were observed at the inlet of the raw sewage (point 1) while season and temperature impact the quantity of microorganisms that can be found in the air. The air at the sewage plant has a higher content of microorganisms than at point 4 (the control). The results show that air pollution occurs with pathogenic microorganisms in the area of the treatment plant.

This research shows that wastewater treatment plants clearly play a critical role in protecting people and the environment. However, they also pose a threat to the health and wellbeing of people working and living in the vicinity.

Chapter 4: Flood Risk Management Infrastructure

This chapter sets out the evidence on the connection between flood risk management infrastructure and quality of life. Few articles were identified which made a direct connection between flood infrastructure and quality of life. Rather, much of the literature discussed in this chapter focuses on the experience of flooding. It also focuses mostly on 'wellbeing' and health aspects rather than quality of life more generally. Within these areas, we have organised the literature into three general topics: Flooding and quality of life; Flooding and potential impact on house prices; and Sustainable drainage systems (SuDS) and quality of life.

Flooding and quality of life

Quality of Life Theme: Impacts of infrastructure on physical and mental health

There is a substantial literature that examines the impacts of flooding on individual health and wellbeing (Table 9). The majority of research we surveyed focuses on the mental health impacts. We identified seven review papers which bring together evidence on the relations between flooding and health (Lane et al, 2013; Fernandez et al, 2015; Saulnier et al, 2017; Chen and Lie 2015; Alderman et al, 2012; Benevolenza and DeRigne 2019; Stanke et al, 2012). Overall, the evidence is uniform in recognition of the adverse health impacts associated with flooding.

Lane et al (2013) conducted a review of 70 papers to detail the wide range of health outcomes which may occur from storm and flood hazards. Adverse outcomes are associated with exposure to the storm, evacuation processes, inadequate shelter, exposure to secondary hazards (e.g. contaminated drinking water, mould, etc), displacement, trauma and mental health effects, and risks associated with clean-up and recovery. While their review focuses on New York City and the impacts of Hurricane Sandy, the experiences of exposure, displacement, clean-up and trauma have wider relevance. Their review demonstrates the magnitude of impacts and pathways through which health can be adversely impacted during storm and flooding events. Saulnier et al (2017) reviewed 113 studies on the health problems following flood and storm disasters. Their review details many of the physical health problems evidenced including poisoning, wounds, infections and other complications that often occur within four weeks of floods or storms. In another review, Alderman et al (2012) examined 35 studies which detail the health outcomes associated with flooding events and found that these depend largely on the specific characteristics of the flood and an individual's level of vulnerability. This international review highlights that women and children, the elderly, those with pre-existing health conditions, as well those living in poverty are particularly susceptible to negative health outcomes. While this review details a range of global health challenges, recognition that flood experiences will impact people differently, often reflecting levels of vulnerability or fragility, is a key insight from this evidence. For example, in another review Benevolenza and DeRigne (2019) found that the mental and

physical health of vulnerable populations was worsened during and after flood events associated with storms such as hurricanes.

Several reviews centre exclusively on the mental health of those who have experienced flooding. For example, Fernandez et al (2015) performed a systematic review of 83 papers with evidence on mental health impacts. They report that floods have a ‘potentially negative impact on mental health, with increasing levels of PTSD, anxiety, depression...’ (Fernandez et al, 2015: 11) and found that this was applicable to both developing and developed countries. Chen and Liu (2015) conducted a review of 14 articles, analysing mental health of flood victims and again, found that ‘research has shown that natural disasters such as floods leave victims with a wide range of psychosocial and mental health issues’ (Chen and Liu, 2015: 329). Finally, Stanke et al (2012) reviewed 48 papers focusing on the United Kingdom. Their research details that flooding can bring on or worsen mental health problems irrespective of age.

Sixteen empirical papers were included in our search that corroborate these findings (Table 10). Indeed, there is a great deal of evidence that narrate the adverse health impacts associated with the experience of flooding (Bei et al, 2013; Moss et al, 2017; Hilmert et al, 2016; Sihawong et al, 2012; Fontalba-Navas et al, 2017; Bell and Glashki 2014; Brock et al, 2014; Sciulli et al, 2015; Walker-Springett et al, 2017; Felton et al, 2013; Martin et al, 2016; Gibson et al, 2018; Quat et al, 2020; Matsubayashi et al, 2013; Aldrich and Kyota 2017; Depledge et al, 2017). While these articles do not narrate specific infrastructure failures, it is clear from the research that infrastructure plays a critical role in flood management and the quality of life of people living in flood-prone areas. Most notably in this research are the lasting adverse mental health impacts associated with the experience of flooding.

We also highlight Bei et al (2013) as a well-designed approach to future research within infrastructure studies. This research examines the direct impact of floods on the mental and physical health of older adults. The longitudinal design allows for the analysis of before and after flood event indicators of wellbeing. The results, based on the responses of 274 participants, indicate higher levels of PTSD in those affected by floods. Future research could apply a similar methodology to better-understand the impacts of new or updated flood infrastructures.

Flooding and potential impacts on house prices

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Quality of Life Theme: Affordability of infrastructure

Our searches identified two studies that examined the impacts of flooding on house prices (Table 11). One study examined the effect of flood risk on house prices in England (Belanger and Bourdeau-Brien, 2018). Using transaction data for residential properties sold between 1995 and 2016, the study examines the impact of a water front location, proximity to water bodies, and flood risk on property price, controlling for property-level (e.g. building type and

age), and neighbourhood-level (e.g. percentage of home ownership, density, health deprivation) variables (Belanger and Bourdeau-Brien, 2018). In the preliminary analysis the study finds that properties that have experienced flooding in three years prior to sale have an average 2.5% decrease in value ($p < 0.01$) (Belanger and Bourdeau-Brien, 2018). They find that there is a reduction in value associated with introduction of detailed flood map in 2004 and changes to insurance pricing in 2005 ($p < 0.01$) and designation of the area as a high-risk flood plain ($p < 0.10$). However, they find no significant effect of property sale within 12 months of large flood event.

In another study, Lamond et al (2010) examined 13 locations in England that were flooded in 2000 and note that the 'fear that experiencing a flood will devastate the value of a residential home is not supported by the evidence' (Lamond et al, 2010: 351). Their work found that the impact to value was highly variable and not related to flood designation.

Sustainable drainage systems and quality of life

There is an extensive literature that reviews the efficacy of SuDS that mimic nature to manage water (Table 12). These are a type of green infrastructure, which is defined as 'a network of multi-functional green space, urban and rural, which is capable of delivering a wide range of environmental and quality of life benefits for local communities' (MHCLG, 2019). The evidence suggests that green infrastructure makes good social, economic, and environmental sense as it can support health and wellbeing, enhance biodiversity, improve local environments and aesthetics, and facilitate adaptation to climate change, as such SuDS can also provide wider benefits to quality of life in addition to flood risk management (Jerome et al, 2019: 174).

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Yet, there is limited systematic evidence that connects SuDS to specific improvements in quality of life. For example, Venkataramanan et al (2019) found 18 papers that reported on the relationship between health or social wellbeing and SuDS. Moreover, of these papers, they found that none had connected SuDS to mental or physical health outcomes (although there is evidence of a positive association between SuDS and property value). They identify this as a critical research gap in understanding the potential impacts of green infrastructure. Hunter et al (2020) attempt to address this gap in their study of the Connswater Community Greenway in Northern Ireland. The greenway involves £35 million investment in watercourse improvements (bridges, paths, flood alleviation, gardens, parks, etc) with an objective to positively improve several quality of life indicators (e.g., property value, flood alleviation, health, tourism, etc). The greenway project is expected to increase property value, lead to economic growth (e.g., labour productivity, new jobs), contribute to flood alleviation that will help avoid over £50 million in damages, and lead to healthier citizens and savings to the NHS (see case study). Other benefits of the greenway are expected to include an increase in

tourism and reductions in crime. A recent evaluation report (Simpson, 2017) suggests that these benefits have not yet been realised and that significant impact may take many years to emerge. Nevertheless, the Connswater project and associated research sets out a framework understanding how an infrastructure project can positively contribute to many characteristics and indicators that make up quality of life (see case study, below).

Naylor et al (2017: 3) focus on integrated green-grey infrastructure which they define as ‘the greening of hard infrastructure that cannot be replaced with softer green (or blue-green) solutions’. Their research suggests that this form of green infrastructure is usually the same or less expensive than traditional grey infrastructure and have a range of added benefits including the potential to improve local ecologies, support biodiversity, reduce air pollution, and to educate. Yet, specific social benefits are not fully explored and direct relations to ‘quality of life’ are only indirectly considered. This is a characteristic of much of the literature which demonstrates how the application of SuDS, green infrastructure and nature-based solutions can contribute to a range of improvements – often focusing on reduced flood risk, clean air and clean water, and supporting ecosystem diversity.

Case Study: Connswater Greenway

Quality of Life Theme: Connectivity and accessibility of infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Quality of Life Theme: Impact of infrastructure on the natural and local environment

The Connswater Community Greenway (CCG) is a 9-km linear urban park in East Belfast, Northern Ireland. The greenway is intended to provide a range of benefits associated with improved transportation connections (e.g. foot and cycle paths and bridges), flood alleviation, new parks and heritage facilities, and other civic features. Completed in 2016, the CCG connects over 110,000 people who live in some of the most deprived areas of Northern Ireland (Hunter et al, 2020).



Knock River Diversion (source: communitygreenway.co.uk/)

The CCG project seeks to use green infrastructure investment and improvements to impact and benefit several key areas including property value, employment, flood management, climate change, health, tourism and quality of place. Researchers estimate that the greenway could result in significant quality of life improvements in all of these areas over the next 40 years. For example, property value is expected to increase in value up to 10% directly due to the greenway. In addition, improved health of residents could result in upwards of £50 million in savings to healthcare and avoidable deaths while £40 million in savings is expected from flood alleviation elements.

The Connswater's PARC study. The Physical Activity and the Regeneration of Connswater (PARC) study is a before (prior to construction) and after (6 months after completion) investigation and assessment of the greenway's impact (Simpson 2017). It involved surveys of health and wellbeing, assessments of the built environment, interviews with residents and stakeholders and an evaluation of the social return on investment. The PARC study showed quality of life improvements in some areas (e.g., perception of vandalism, littering), while other areas had not yet achieved targets. For example, physical activity, health and wellbeing elements were generally below expectation or were unchanged. It is suggested that the current lack of evidenced improvement could reflect the study's short time period (6 months). Further longitudinal studies would help better understand these impacts as the project matures.

Chapter 5: Waste Infrastructure

This chapter examines evidence on the relations between waste infrastructure and quality of life. The review includes a discussion of landfill and incineration infrastructure, e-waste, Kerbside recycling, and other waste collection systems.

Waste infrastructure and quality of life

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Literature on the relationship between waste infrastructure and quality of life mainly focused on the potential health implications of landfill and incineration infrastructure.

Two systematic reviews on the relationship between incineration infrastructure and health were selected (Negri et al, 2020; Tait et al, 2020; Table 13). Both were up-to date international reviews which covered a broad range of studies.

The two reviews highlighted distinctions in existing evidence on the potential health implications of newer and older incinerators. Negri et al (2020) included a range of outcome measures including (but not limited to) respiratory and cardiovascular diseases, pregnancy outcomes, genetic or congenital malformations, and immunological diseases. They reported little conclusive evidence on health implications associated with new incinerators, although acknowledged some scattered evidence that suggests a potential link between proximity to incinerators and lymphohematopoietic and soft-tissue sarcoma (STS) cancers. Negri et al (2020) concluded that whilst there is no consistently reported excess risk associated with living near or working at an incineration plant, the available evidence does not enable them to conclude an absence of health risk associated with new incinerators. Tait et al (2020) examined both internal and external measures in people living near or working in an incinerator plant. They found some significant evidence of risks associated with older incineration plants, whilst other studies reported no excess risk. Whilst acknowledging that some studies suggest newer incinerators are safer, Tait et al (2020) emphasise that exposure diseases tend to manifest after a number of years and that it may be too soon to draw firm conclusions on the safety of newer technology.

Lack of consideration of the potential latency of some diseases was raised in both reviews of available studies. Additionally, Tait et al (2020) highlighted how many of the studies they reviewed did not account for other contributing factors, for example occupation, lifestyle, smoking, diet, and alcohol consumption.

Reviews on the relationship between landfill infrastructure and health came out of our searches. Martuzzi et al (2010) reviewed 47 studies on the health implications of living near a landfill site in Europe and the USA. Their review identified that people who were most likely to face health impacts associated with living near a landfill site were also likely to be experiencing multiple disadvantage. Their review included a national study of environmental

inequalities in France which reported that marginalised communities were more likely to be exposed to environmental hazards. Spatial regression analysis of 36,600 French towns highlighted a correlation between higher rates of hazardous sites and higher numbers of local residents from immigrant communities. Broadly, the literature identifies limited conclusive evidence documenting a correlation between living near or working in incineration and landfill sites and health. However, there is also insufficient evidence to conclude that even newer versions of these waste infrastructures are safe for human health.

E-waste and quality of life

Quality of Life Theme: Impacts of infrastructure on physical and mental health

The literature screening process produced one review paper on the relationship between e-waste and quality of life (Grant et al, 2013; Table 13). The review included 23 papers and focused on China. Whilst falling outside of the geographical parameters for inclusion this paper speaks to an international audience and is therefore included here. The review searched for papers that included reference to e-waste and physical or mental health impacts. Existing literature demonstrates a plausible relationship between e-waste and changes in 'thyroid function, changes in cellular expression and function, adverse neonatal outcomes, changes in temperament and behaviour, and decreased lung function' (Grant et al, 2013: 350).

The review reported that people were most likely to inhale, ingest or come into dermal exposure with hazardous e-waste, commonly through 'contaminated soil, dust, air, water, and through food sources, including meat' (Grant et al, 2013: 351).

Grant et al (2013) conclude that whilst there is evidence to suggest health impacts of e-waste exposure, a lack of epidemiological data and longitudinal studies precludes a definitive causal relation.

Kerbside recycling and quality of life

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Our review found limited literature on kerbside recycling and quality of life. Rather we inferred that increased kerbside recycling could reduce waste to landfill and incinerators which has some causal links to health issues. Larsen et al (2010) conducted a quantitative environmental and economic assessment of increased kerbside recycling in Denmark (Table 14). Their study concluded that increased kerbside recycling led to positive environmental impacts in several categories although the economic assessment was less conclusive. This study was limited to the life cycle of the waste product but did not account for other

associated impacts such as the impact on air quality associated with changes in recycling truck collection patterns. The quality of life impacts associated with kerbside recycling presents a potential area for further study. According to this review, it is possible that this infrastructure could support physical health (e.g., through less waste in landfills) as well as improvements to natural and local environments.

The potential benefits of vacuum waste collection systems

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Our searches highlighted a small body of evidence on vacuum waste collection systems (Table 14). Both Hidalgo et al (2018) and Nakou et al (2014) compare vacuum waste collection to general refuse collection. Nakou et al (2014) point out that when compared with conventional systems, automated vacuum collection (AVAC) improves the aesthetics and quality of urban environments, reduces noise and traffic congestion, and provides benefits in air quality (for example, fewer trucks are used; see case study, below). Hidalgo et al (2018) assess the CO₂ emissions savings for vacuum compared to conventional truck waste collection methods reporting an average reduction in emissions of 90% from vacuum systems. Additionally, this study concludes that vacuum waste systems can provide good alternatives to truck waste collection in harder to reach areas.

Case study: Automated vacuum waste collection systems

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Nakou et al (2014) conducted a detailed analysis of the environmental and economic assessment of a proposed automated vacuum waste collection system (AVAC) compared with the existing vehicle operated waste collection system in Athens. This study uses an equivalent annual cost methodology (EAC) to calculate both capital expenditure and operational and maintenance costs for the existing vehicle operated system and a proposed AVAC system.

An environmental analysis examines the total annual emissions of eight pollutant types for both the vehicle operated and AVAC system. The economic assessment calculates that the AVAC system has a significantly higher initial set-up cost of €3,095,000 compared to the conventional vehicle-based system which costs €418,600 including the cost of trucks and bins. However, annual operation and maintenance costs for an AVAC system total €254,500 compared to the conventional system that costs €439,150. Additionally, the AVAC system has an expected life expectancy of 30 years compared to the conventional trucks and bins of 10 and 5 years respectively. The environmental assessment estimates that the AVAC system could result in a 90% reduction in emissions. Specifically, the study estimates that the AVAC system would produce 5476.1 kg of CO₂ per year compared to 59062.6 kg produced through a conventional system. This suggests the potential CO₂ saving of almost 53 tons per year. The authors emphasize that this number is even more significant when considered over the lifespan of the system.

The study concluded that despite significantly higher initial investment costs, the AVAC system has lower annual operation and maintenance costs, which minimises this over the lifespan of the infrastructure. Additionally, this study highlights the wider potential benefits of using an AVAC system including, reduced traffic congestion, potential space saving, reduced risk of containers overloading which leads to odour, hygiene issues, and littering. Finally, the authors concluded that AVAC systems are more resilient to external factors such as storms and public events such as strikes and protests.

Chapter 6: Digital Infrastructure

This chapter focusses on research related to digital infrastructure. This includes levels of connectivity, digital exclusion, and smart city connectivity.

Broadband connectivity and quality of life

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Quality of Life Theme: Connectivity and accessibility of infrastructure

There were few studies identified on the relationship between broadband connectivity and quality of life (Table 15). Our search found one relevant paper that examined how the implementation of superfast broadband in Cornwall (UK) impacted on resident's engagement with e-health services (Abbott-Garner et al, 2019). Whilst this study only looks at e-health we can make some assumptions that individuals reporting increased engagement with e-health are likely to be experiencing better connectivity more generally. Abbott-Garner et al (2019) conducted before and after surveys with randomly selected postcodes in an area which had seen the implementation of superfast broadband. The study found that respondents reported significant increases in their internet speeds. Whilst there was not firm evidence of increased engagement with e-health services the paper concludes that the resident's broadband connection means they are more prepared to use e-health services in the future.

Digital exclusion and poor-quality connectivity

Quality of Life Theme: Connectivity and accessibility of infrastructure

A small collection of studies examined the impact of digital exclusion and poor-quality connectivity on people quality of life in developed countries (Table 15). These studies focused primarily on the urban / rural divide rather than looking in detail at other potential factors such as economic exclusion.

Salemink et al (2017) conducted a systematic literature review on rural digital exclusion in developed countries. The review identified 157 relevant papers under the categories of digital inclusion and exclusion, and/or rural connectivity. The review highlighted how rapid digitalisation increased the risk of both digital and social exclusion for specific groups, including, older people in rural and urban areas, and women and young people living in rural areas. The review highlights how people who are digitally excluded are also more likely to be excluded off-line in everyday life. In summarising the key recommendations this review emphasises that people living rurally need to, first, have a high level of connectivity and, second, be confident in using digital technology. Without both of these being in place, individuals are at risk of being socially marginalised and suffering adverse economic impacts.

Townsend (2015) conducted a similar qualitative study on the impact of different levels of digital connectivity in rural Scotland, UK. However, this study focused on business owners who had established since the widespread uptake in internet usage and had poor digital

connectivity. Interviewees were asked about the role of the internet in their rural communities and the impact of poor connectivity on their business and wider lives. Whilst this study focused primarily on business, the findings demonstrated that poor connectivity can have a knock-on impact to other people's quality of life. The findings highlighted how business owners commonly felt both professionally and socially isolated due to poor internet connection as well as reporting how it was harder to keep up to date with developments in their field. Townsend (2015) emphasises differences in the experiences of rural businesses based on their sector, with some areas, such as creative industries, becoming generally more reliant on the internet than others.

A further study (Park et al, 2019) examined the factors affecting digital inclusion in rural communities in Australia (see case study, below).

Case Study: Connectivity and digital inclusion in rural communities

Quality of Life Theme: Affordability of infrastructure

Quality of Life Theme: Safety and reliability of infrastructure

Park et al (2019) conducted qualitative research with two rural communities in New South Wales (Australia). This study examined broadband connectivity and accessibility, focusing specifically on the quality of connection, cost of broadband or data packages, and the ability to physically access spaces with connected devices.

The research found that whilst infrastructure is a key component of digital inclusion and exclusion, other factors such as connectivity speed and cost are also significant. As more education, services and businesses have moved online there has been an increase in people who have found themselves newly excluded (e.g., people who used to attend education face-to-face and do not have the ability to access online courses). Additionally, the study found that many enterprises who are used to dealing with customers in person are failing to make the transition to online and are subsequently seeing their business fall behind. This research also highlighted disparities between people who can get broadband connection, and rural areas that are still reliant of mobile data packages. Not only is mobile data more expensive for the consumer, this study found that people often waste their data allowance by having to re-download items due to fluctuations in the quality of the connection.

This study concluded that improvements to rural digital infrastructure need to be part of a broader set of interventions to ensure residents are able to access broadband when it is available. Park et al (2019: 152) claim that: 'A diverse range of quality in user experiences and contexts must be considered when we examine the access dimension of digital inclusion. Modes of access, including devices and methods of connection, are critical in determining the types of online activities with which people engage, which impacts on the resulting outcomes of digital engagement'.

Additionally, this research highlights the importance of understanding how local residents experience barriers to digital connectivity and how they may be overcome. In setting out a future research agenda Park et al (2019) recommend more in-depth research into the nuances of resident experiences

Chapter 7: Energy Infrastructure

This chapter reviews evidence which examines the relationships between energy infrastructure and quality of life. The first set of research highlights the role of place and place-attachment towards levels of acceptance of renewable energy. Further studies indicate the role of local energy systems and their potential acceptance, the health and wellbeing impact of reducing fuel poverty and the economic outcomes associated with energy infrastructure (or its lack).

Renewable, low carbon energy and quality of life

Quality of Life Theme: Impact of infrastructure on the natural and local environment

Our literature search highlighted three key papers on the relationship between renewable energy and quality of life (Table 16) - Bidwell (2016), Devine-Wright and Howes (2010), and Devine-Wright (2011). These studies reflect the critical importance of how a person's feeling about 'place' interacts with how they understand the impact of large energy infrastructure. Clearly, energy infrastructure such as wind farms and tidal plants impact the natural and local environment. The work highlighted in this section, rather than demonstrating a direct connection between infrastructure and quality of life, shows a diversity of interpretations related to amenity values and aesthetics. In other words, the 'impact' of infrastructure on the natural and local environment will have a subjective component that, in part, comes across through place attachment.

Bidwell (2016) examined residents' perceptions of a proposed wind farm, in Michigan USA, before and after receiving information on wind farm technology. The trial group attended information evenings where they heard about the opportunities and benefits of wind farms whilst the control group did not receive any intervention. Bidwell's study concluded that residents who attended information evenings were significantly more enthusiastic about wind energy development and reported higher levels of confidence in the technology and less negative perceptions.

Devine-Wright and Howes (2010) conducted an in-depth study with two coastal communities in North Wales (UK) using a questionnaire, in depth interviews and focus groups to understand how residents responded to proposals for an off-shore wind farm on their coastline. The study found that residents from one town had significantly higher place attachment than residents from the other and that residents with higher place attachment were more likely to oppose the proposed development. Devine-Wright and Howes (2010) concluded that whilst these findings represent the views of residents at one moment in time the fact that this was not a longitudinal study means it is not possible to comment on what happened over time.

In another study, Devine-Wright (2011) reports on research conducted in Northern Ireland to examine the relationship between place attachment and level of acceptance towards a tidal

energy project. The study examined place-related symbolic meanings and strength of place attachment using an eight-point scale of place attachment, and measured emotional response using a list of ten emotional descriptors. The findings demonstrated that greater place attachment positively correlated with project acceptance whilst socio-demographic variables did not predict the level of project acceptance. The study found a lack of local opposition to the project and much public support for tidal technology as a form of renewable energy. The findings present an interesting and less common phenomena of the positive relationships between place-attachment and larger-scale renewable energy development. Devine-Wright (2011, 342) concluded that the results ‘...support McLachlan’s (2009) claim that development companies proposing renewable energy projects should take emotional bonds and place related symbolic meanings into account when planning and implementing land-use changes and engagement with affected communities’.

Overall, the three papers demonstrate somewhat contradictory findings (Table 16). On the one hand, it is understandable that high quality public outreach and consultation could positively influence residents’ opinion and levels of acceptance of nearby energy infrastructure. However, the studies by Devine-Wright (2011) and Devine-Wright and Howes (2010) suggest that the role of ‘place’ and people’s local bonds will play a significant role in how energy developments are perceived.

The potential negative health implications of energy infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Johnston et al (2013) conducted a longitudinal study in two towns in Australia (Table 17). Residents in Launceston received an intervention, including campaigns and education, environmental enforcement regulations and a wood heater replacement programme, whilst residents of Hobart did not receive any intervention (Hobart served as the control). The study documented the effect of reductions in air pollution on daily mortality by measuring changes in mortality during a 6.5-year period before and after the start of the intervention programme. The results show an improvement in air quality (particulate matter fell) and small ‘non-significant’ reductions in annual mortality in Launceston (the intervention town). There was no mortality change in the control city. In conclusion, the research found that by reducing biomass smoke, there was a decrease in measurable air pollution, which was directly associated with reduced annual mortality (primarily in males).

Community and localised energy systems

Quality of Life Theme: Affordability of infrastructure

Quality of Life Theme: Safety and reliability of infrastructure

There were a number of studies documenting the benefits of community and localised energy systems (Table 18). Two studies focused on community energy projects, one in Spain (Cuesta-Fernandez et al, 2020) and the other in Denmark and Germany (Islar and Busch, 2016). Both studies report that the local communities were empowered by having greater control in their energy production. Cuesta-Fernandez et al (2020) argue that larger scale national energy co-operatives are not able to produce the same empowerment benefits to local energy production. Islar and Busch (2016) identified that residents' engagement in local energy production was motivated by economic resilience, including reducing energy costs and increasing local jobs.

Another study examined how different approaches to relaying the benefits of localised energy schemes to residents could impact the level of acceptance (Walker et al, 2017). This research relates to a proposed (hypothetical) off-shore wind farm off the coastline in Devon (UK) where one group of residents were informed that the community benefits were written into policy and the second group were advised that the developer would be responsible for negotiating with the community. Walker et al (2017: 78) concluded that 'if communities are to believe that they are getting a "good deal" through the siting of wind farms, then this needs to come through government legislation and not discretionary acts by developers'.

Whilst this study drew clear conclusions, it is important to note that this was based on a hypothetical off-shore wind farm development and required residents to envisage how they might respond. Broadly, this research shows there is a value in connecting people to their energy systems and ensuring they feel empowered as active agents in how local systems are developed and deployed.

Energy infrastructure and fuel poverty

Affordability of infrastructure

Quality of Life Theme: Impacts of infrastructure on physical and mental health

Fuel poverty is a way of understanding the costs of household energy spending and the extent to which this takes up a significant proportion of household spending. These costs are generally focused on keeping homes warm in winter and cool in summer. Five studies are included in the review that consider fuel poverty (Table 19).

Cotter et al (2012) discuss the impact of fuel poverty on health and wellbeing, reporting on a qualitative study of older people's experiences in Ireland. The study highlights how 62% of

respondents were concerned about the cost of heating their homes, whilst 50% of the sample reported that they had to forego other household necessities to be able to heat their homes. The research identified that homes without central heating were more likely to be experienced as too cold. The reported health implications of living in a cold home included higher levels of chronic illness and falls, as well as increased loneliness and lower levels of participation in social activities.

Liddell and Morris (2010) conducted a review of studies exploring the relationships between fuel poverty and health. Their review focused on five large-scale studies, between 1400-6400 households, in three developed countries (UK, New Zealand and USA). The review reported the impact of fuel poverty on both physical and mental health. The review concluded that there was little evidence of improvements to respiratory health when fuel poverty was reduced, including in children with respiratory conditions such as asthma. However, the study did document improvements in the severity of symptoms reported in participant diaries. Other benefits associated with reduced fuel poverty in children was increased attendance at school. The review concluded that the majority of physical health improvements were self-reported and if there is clinical evidence, it may take longer to be seen. Liddell and Morris (2010) report a more significant relationship between tackling fuel poverty and mental health, in both children and adults. Perceived mental health benefits were particularly clearly evidenced in the New Zealand study, which found improvements in each area of mental health included in the assessment. A study of fuel poverty interventions in England recorded a 40% reduction in the perceived financial strain of households, post-intervention, however, actual consumption measures showed a slight increase in expenditure on heating. The disparity between consumption data and perceptions is associated with people feeling their homes are more energy efficient and having a greater sense of control over their energy consumptions, which in turn makes them less concerned by the cost of heating.

A similar study by Heymen et al (2011) examined the impact of energy and heating interventions on the health and wellbeing of people living in fuel poverty in North East England. The research involved an annual measurement of energy performance, using Standardised Assessment Procedure (SAP), as well as households' room temperature, fuel costs, satisfaction with home warmth and a range of other health indicators over four years. The study found very little evidence of physical health improvements associated with the interventions. However, data suggested that there were notable improvements on the social functioning scale, with warmer rooms leading more people to socialise in their homes. The researchers highlight the need for longer term studies to examine the impact of fuel poverty interventions on physical health, concluding that four years may not have been a long enough time period to see noticeable changes to individual's physical health.

Literature on the relationship between interventions to tackle fuel poverty and health outcomes remains under-developed and existing studies recommend greater attention to the demographics of people experiencing reductions in fuel poverty and whether the benefits associated with reduced fuel poverty are statistically measurable or based on self-reporting and individual perception. One exception, is a study in Northern Ireland that examined the impact of the Neighbourhood Renewal Programme on fuel poverty (see case study, below).

Case study: Area based urban regeneration policies and fuel poverty

Quality of Life Theme: Affordability of infrastructure

Mohan et al (2018) conducted a study measuring levels of fuel poverty in Northern Ireland before and after the introduction of the Neighbourhood Renewal programme (NR). The study used a difference-in-difference regression model to examine the impact of NR policy on fuel poverty. The study included one treatment group from an area included in the NR and two control groups in areas not included. The mean annual household income and mean annual household fuel spend was recorded before and after the NR intervention, whilst the presence or absence of the NR intervention was the parallel trends assumption for comparison.

Generally, there was a greater overall reduction (4.7%) in fuel poverty in areas of NR compared to the control groups. This was particularly prevalent in males - who experienced a 7.5% decline, and owner occupiers - who saw a 7.3% decline. There was no statistically significant difference in fuel poverty for women in the NR area and control groups.

This study concludes that NR policy may contribute, albeit modestly, to overcoming fuel poverty. Economic improvements in communities experiencing high levels of fuel poverty, as well as local championing of resources, is suggested to contribute towards reducing fuel poverty inequalities.

In setting out its recommendation, Mohan et al (2018: 616) state that 'multifaceted urban regeneration policy may be an effective vehicle in tackling fuel poverty in areas earmarked for support. Improving the economic prosperity of residents in communities which have higher concentrations of fuel poor households and local championing of resources may combine to remedy inequalities in fuel poverty between disparate groups'.

Chapter 8: Conclusion

The purpose of this report was to provide a literature review of academic evidence for links between infrastructure and quality of life with a geographic focus on the UK and comparable countries and contexts. The document identifies a range of literature and research which shows the critical importance of infrastructure to human health and wellbeing. The evidence documented in the reviews and empirical studies we have collected demonstrates the myriad ways infrastructure influences quality of life. However, in much of the research reviewed, it was the absence of infrastructure that produced adverse health impacts. For example, literature is uniform in detailing the mental, physical and social impacts of flooding. This, of course, is unsurprising. However, the research also identifies how flooding and similar events can differently impact people and communities. This divergence is associated with levels of vulnerability (e.g., part of the infrastructural condition), fragility (e.g., a household's economic status, or an individual's mental health), and social capital (e.g., community bonds) which may be called on in moments of need. Similarly, evidence on waste, incinerators and landfills suggests that those who live near these facilities are likely to be experiencing multiple forms of disadvantage. These examples point to the way that infrastructure is not experienced uniformly across an entire population.

In terms of our evaluation of the evidence, we have found a robust and comprehensive set of research that details the critical importance of infrastructure on quality of life. However, there are a number of research gaps and opportunities worth identifying (much of which has been highlighted in the literature). First, in our estimation, many of the studies detailing the positive impacts of infrastructure tend to be completed as part of approval processes and are conducted through scenario-building and modelling. Long-term assessments of impact are less common. Second, and relatedly, much of the literature examining the impacts of infrastructure tend to focus on its lack or failure. This is particularly relevant for water supply, flooding, and waste components of our review. We identify a need for further academic study of the benefits of specific infrastructural investments and assets. Research gaps are evident across all sectors. However, it is perhaps those sectors which have become most successful (and thereby invisible) which are under-examined. Third, there are numerous methodological approaches available and these decisions reflect disciplinary and scientific norms. However, we note a strong need, identified within many of the review authors, for both before/after, longitudinal studies as well as studies which employ control cases. Fourth, we note some challenges encountered in drawing out the evidence in this review. Due to the nature of the endeavour and the use of health-related search terms, a great deal of evidence emerged in early searches that was not related to infrastructure. Further, after initial searches, gaps remained in some infrastructure areas (e.g., wastewater). These were addressed through targeted scanning and discussions with expert colleagues. A critical point here is to note both the benefits and limitations of the systematic approach to our rapid assessment. We have made a significant effort to strengthen the search process through dialogue and engagement with stakeholders, including NIC partners.

Appendix A: Search Strategy

Search carried out in Ovid (Embase, Medline, Global Health, PsycINFO), ProQuest (theses database), Scopus and Open Grey.

Energy

#	Searches
1	energy OR power OR electric* OR gas* OR frack* OR oil OR "power plant*" OR nuclear OR "generation plant*" OR "transmission network*" OR "distribution network*" OR "interconnector*" OR coal OR petrol OR diesel OR solar OR photovoltaic OR wind OR tidal OR microgeneration OR "community heat" OR "heat network*" OR biomass OR "wood fuel" OR fuel OR substation** OR "wind farm*" OR "solar farm*" OR voltage OR "charging point*" OR "ground source" OR "heat pump*" OR "smart meter" OR "energy efficien*" OR neighbourhood OR tariff* OR "energy from waste" OR microgrid* OR "energy management system*" OR "energy recovery facility*" OR "renewable resources" OR "renewable energy" OR "green energy" OR "security of supply" OR "local energy planning" OR "local energy production" OR "localised production" OR "system flexibility" OR "community energy"
2	"energy drink*" OR chemotherapy OR gastro* OR gastric* OR "irritable bowel syndrome" OR cancer OR storm OR appliance OR diet* OR "coconut oil" OR "palm oil" OR "massage oil" OR gastric OR gastro OR "energy drink*" OR "electrical stimulation" OR alcohol OR "physical activity" OR diet OR "essential oils"
3	1 NOT 2
4	health* OR mortality OR morbidit* OR disease OR chronic OR "quality of life" OR "quality-of-life" OR QoL OR "life satisfaction" OR "neighbourhood satisfaction" OR depression OR anxi* OR nervous OR stress OR sleep OR insomnia OR concentrat* OR cognitive OR poverty OR "mental health" OR "thermal comfort" OR noise OR "work life balance" OR work-life-balance OR "social connection*" OR "environmental quality" OR "personal security" OR security OR wellbeing OR "wellbeing" OR safety OR reliabl* OR affordab* OR pric* OR depriv* OR natu* OR biodiverse* OR econom* OR "return on investment" OR inequalit* OR "local econom*" OR "local labour market*" OR "place-based economy" OR "local job*" OR "local employment" OR "local multiplier*" OR "local investment*" OR "buying local*" OR flourish* OR sautogen* OR resilien* OR empower* OR wellness OR happiness OR self-esteem OR social capital OR empower* OR cohesion OR integrat* OR loneliness OR connectedness OR psychological OR "life quality"
5	3 AND 4
6	review OR narrative OR meta-analysis OR "meta analysis" OR evaluate OR evaluation OR "impact assessment" OR impact OR efficacy OR benefits OR beneficial
7	5 AND 6
8	remove duplicates from 7

Transport

#	Searches
1	commut* OR train* OR rail* OR "public transport" OR bus* OR tram* OR "community transport" OR airport* OR seaport* OR port* OR boat* OR canal* OR embankment*
2	care OR caregiver OR caregivers OR caring OR training OR trainer OR trainers OR trainee OR trainees OR cyclic OR cyclosporin OR cyclosporine OR cycloserine OR cyclophosphamide OR single-port OR portal OR portugal OR portuguese OR roadmap
3	1 NOT 2
4	health* OR mortality OR morbidit* OR disease OR chronic OR quality of life OR QoL OR "life satisfaction" OR "neighbourhood satisfaction" OR depression OR anxi* OR nervous OR stress OR sleep OR insomnia OR concentrat* OR cognitive OR poverty OR "mental health" OR "thermal comfort" OR noise OR "work life balance" OR work-life-balance OR "social connection*" OR "environmental quality" OR "personal security" OR security OR wellbeing OR "wellbeing" OR safety OR reliabl* OR affordab* OR pric* OR "physical activity" OR "social interaction" OR obesity OR BMI OR "body mass index" OR depriv* OR employ* OR "air pollution" OR "air quality" OR inequality* OR flourish* OR sautogen* OR resilien* OR empower* OR wellness OR happiness OR self-esteem OR social capital OR empower* OR cohesion OR integrat* OR loneliness OR connectedness OR psychological
5	3 AND 4
6	review OR narrative OR meta-analysis OR "meta analysis"
7	5 AND 6
8	remove duplicates from 7

Digital

#	Searches
1	digital OR "digital communication" OR "information system" OR "fibre optic" OR broadband OR satellite OR wireless OR WiFi OR "data storage" OR "data warehouse" OR "data processing centre" OR "smart cit*" OR connectivity OR "digital wellbeing" OR "digital wellbeing" OR "digital divide" OR "digital exclusion"
2	health* OR mortality OR morbidit* OR disease OR chronic OR quality of life OR QoL OR "life satisfaction" OR "neighbourhood satisfaction" OR depression OR anxi* OR nervous OR stress OR sleep OR insomnia OR concentrat* OR cognitive OR "mental health" OR "thermal comfort" OR noise OR "work life balance" OR work-life-balance OR "social connection*" OR "environmental quality" OR "personal security" OR security OR wellbeing OR "wellbeing" OR safety OR reliabl* OR affordab* OR pric* OR education OR skill OR employ* OR worklessness OR poverty OR depriv* OR inequality* OR flourish* OR sautogen* OR resilien* OR empower* OR wellness OR happiness OR self-esteem OR social capital OR empower*OR cohesion OR integrat* OR loneliness OR connectedness OR psychological OR isolation
3	1 AND 2
4	"transport connectivity" OR "sickle cell" OR diabetes OR stroke OR "digital learning" OR healthcare
5	3 NOT 4
6	review OR narrative OR meta-analysis OR "meta analysis" OR evaluate OR evaluation OR "impact assessment" OR impact OR efficacy OR benefits OR beneficial
6	5 AND 6
7	remove duplicates from 5

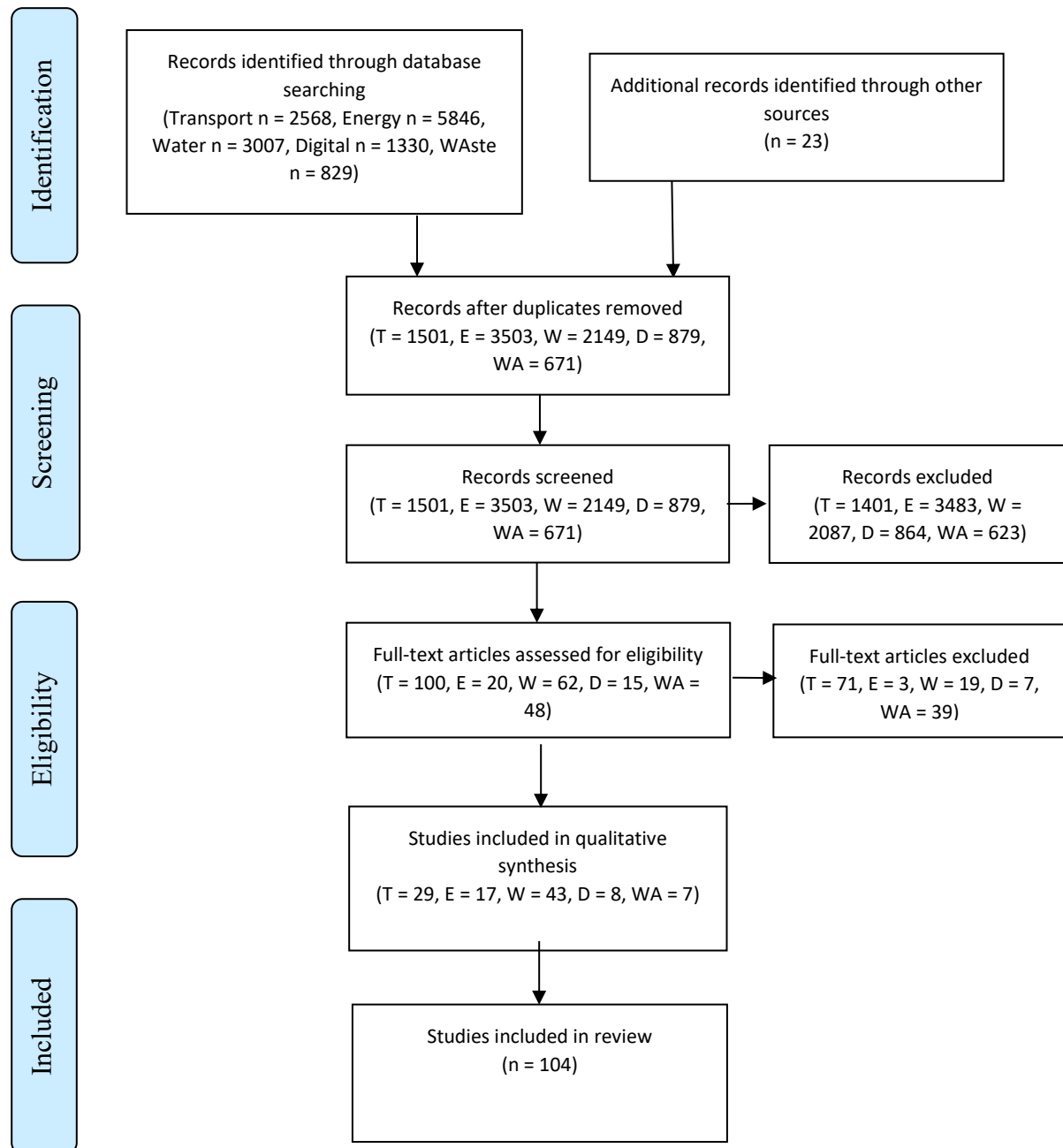
Water and flooding

#	Searches
1	infrastructure OR "temporary flood barrier*" OR "flood warden*" OR "flood defence*" OR "sustainable urban drainage system*" OR SUDS OR "Shoreline Management Plan*" OR "catchment flood management plan*" OR floodplain* OR "flood zone*" OR "flood risk management" OR "integrated coastal zone management" OR "coastal erosion" OR "surface water flood*" OR "coastal flood*" OR "inland flood*" OR "hard flood defence*" OR "natural flood management" OR "managed realignment" OR "managed retreat" OR levee* OR breakwater* OR seawall* OR groyne* OR floodwall* OR "tide gate*" OR "storm surge barrier*" OR barrage* OR dyke* OR revetment* OR well OR wells OR "water filtration plant*" OR "pump station*" OR "water meter*" OR aqueduct* OR drought* OR desalination OR "water reuse" OR "demand management" OR dam OR dams OR reservoir* OR "water security" OR sewer* OR sewage OR "wastewater overflow*" OR fatberg* OR stormwater OR "wastewater management" OR "sludge treatment" OR "Thames Tideway Tunnel" OR "water abstraction"
2	lung* OR cardiac OR cardiovascular OR agriculture OR exercise OR "physical activity" OR "tidal volume" OR Pakistan OR "South Africa" OR Bangladesh OR fluoride OR nitrate* OR arsenic OR chlorine
3	1 NOT 2
4	health* OR mortality OR morbidit* OR disease OR chronic OR quality of life OR QoL OR "life satisfaction" OR "neighbourhood satisfaction" OR depression OR anxi* OR nervous OR stress OR sleep OR insomnia OR concentrat* OR cognitive OR poverty OR "mental health" OR noise OR "work life balance" OR work-life-balance OR "social connection*" OR "environmental quality" OR "personal security" OR security OR wellbeing OR "wellbeing" OR safety OR reliabl* OR affordab* OR pric* OR depriv* OR econom* OR "return on investment" OR insurance OR inequalit* OR "local econom*" OR "local labour market*" OR "place-based economy" OR "local job*" OR "local employment" OR "local multiplier*" OR "local investment*" OR "buying local*" OR flourish* OR sautogen* OR resilien* OR empower* OR wellness OR happiness OR self-esteem OR social capital OR empower* OR cohesion OR integrat* OR loneliness OR connectedness OR psychological
5	3 AND 4
6	review OR narrative OR meta-analysis OR "meta analysis" OR evaluate OR evaluation OR "impact assessment" OR impact OR efficacy OR benefits OR beneficial
7	5 AND 6
8	remove duplicates from 7

Waste

#	Searches
1	waste OR "waste treatment" OR "waste management" OR recycl* OR landfill OR "kerbside collection" OR incinerat* OR disposal OR "uncontrolled waste disposal" OR "waste crime" OR reuse OR waste OR pyrolysis OR gasification
2	"global south"
3	1 NOT 2
4	health* OR mortality OR morbidit* OR disease OR chronic OR quality of life OR QoL OR "life satisfaction" OR "neighbourhood satisfaction" OR depression OR anxi* OR nervous OR stress OR sleep OR insomnia OR concentrat* OR cognitive OR poverty OR "mental health" OR noise OR "work life balance" OR work-life-balance OR "social connection*" OR "environmental quality" OR "personal security" OR security OR wellbeing OR "wellbeing" OR safety OR reliabl* OR affordab* OR pric* OR depriv* OR econom* OR "return on investment" OR "circular economy" OR inequalit* OR "local econom*" OR "local labour market*" OR "place-based economy" OR "local job*" OR "local employment" OR "local multiplier*" OR "local investment*" OR "buying local*" OR "circular economy" OR flourish* OR sautogen* OR resilien* OR empower* OR wellness OR happiness OR self-esteem OR social capital OR empower* OR cohesion OR integrat* OR loneliness OR connectedness OR psychological
5	3 AND 4
6	review OR narrative OR meta-analysis OR "meta analysis" OR evaluate OR evaluation OR "impact assessment" OR impact OR efficacy OR benefits OR beneficial
7	5 AND 6
8	remove duplicates from 7

Appendix B: Modified PRISMA 2009 Flow Diagram



Based on: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

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Appendix D: Evidence Tables

Chapter 2 evidence table: Transport

Table 1 Evidence table for reviews examining impacts of access to transport.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Chatterjee et al, 2019	Analysis of longitudinal datasets	England	Access to transport	People living in England	Wellbeing: (i) Feeling under strain; (ii) Poor mental health; (iii) Dissatisfaction with life overall; and (iv) Loneliness, specifically amongst the population aged 50+.	Personal car access plays an important role in accessing employment. Both personal car access and public transport access are important for being able to access services (healthcare, food shops and learning facilities) when needed, and to go out socially. Transport access plays a minor role for the measures of personal wellbeing examined in the study.
Bradshaw, 2018	Literature review and key informant interviews	National Parks in England and Wales	Transport access to National Parks	Residents, visitors and non-visitors	N/A	Increasing the options available for travelling to and around National Parks sustainably would provide the following benefits: For individuals – improved physical and mental health through opportunities for engaging with nature. For local economies – there is evidence that visitors by public transport spend more than those arriving by car. For the environment and local communities – by reducing the number of people who travel to National Parks by car and the associated impacts in terms of carbon emissions, noise pollution and road danger.
Cooper et al, 2019	Rapid Evidence Assessment of published and unpublished (grey) literature	Western Europe, North America and Australasia	Links between transport and health and wellbeing	Systematic search followed by abstract/title and text screening. Total number of studies included was 30.	Transport and health and wellbeing. Reviews in the following areas: Transport use and physical health; mental health;	Transport is both positive and negative for health (e.g., access and opportunities as well as pollution, accidents). Transport provides access to health services. Overall, older people, younger people and disadvantaged groups will see more negative impacts of transport on physical health and wellbeing. Transport is critical to enable social interaction and prevent isolation; Traffic noise can cause both physical and mental health problems.

Table 2 Evidence table for systematic reviews examining impacts of the built environment on transport behaviours.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Smith et al, 2017	Systematic review of 28 studies	Mainly USA then Australia, Belgium, England, Scotland, and New Zealand.	Infrastructural interventions for facilitating walking and cycling. Park and playground improvements.	Children and adults of all ages	Physical activity (self-reported, observed, or objectively assessed), active transport (self-reported or observed), and visitation to or use of a setting (e.g. counts of riders on new cycleways; counts of playground users).	Improving neighbourhood walkability, quality of parks and playgrounds, and providing adequate active transport infrastructure is likely to generate positive impacts on activity in children and adults. Some indication that infrastructure improvements may predominantly benefit socioeconomically advantaged groups.
Rothman et al, 2014	Systematic review of 50 walking studies and 35 pedestrian injury studies	Mainly USA, Australia, New Zealand, followed by Canada, UK and other European countries.	Built environment features, e.g. density, land use diversity and roadway design.	Children aged 0-12	Levels of walking, injuries, fatalities and severity of injuries.	Built environment features that either slow traffic down (traffic calming devices) or separate children in space from traffic (playgrounds and recreation areas) were the only factors consistently associated with more walking and less pedestrian injury. Many built environment factors associated with more walking (higher pedestrian volume, population and road density, schools, urban location, land use mix, proximity to services/facilities and crosswalks) were also associated with a greater risk of injury.
Mazumdar et al, 2018	Systematic review of 23 studies	USA (n=13), Australia (n=5), one each from Norway, Ireland, the Netherlands, Japan, UK.	Built environment, including walkability (Density, Diversity, Design and Destination).	Neighbourhood residents	Four social capital metrics (social capital, social cohesion, neighbourhood attachment and collective efficacy).	There is a significant relationship between social capital and the built environment, specifically between social cohesion and access to destinations/walkability. Positive relationships exist between social capital, design, and diversity, whereas the effect of population density on social capital is negative and unclear.
Barbosa et al, 2019	Systematic review of 10 studies	USA, Canada, Australia.	Neighbourhood walkability	Adults aged 18 years and over.	Weight and height as measures for determining BMI (mostly self-reported).	Less walkable neighbourhoods are associated with overweight and/or obesity in adult populations.
Van Cauwenberg et al, 2018	Systematic Review and Meta-Analysis of 72 studies.	North America, East Asia and Pacific region, one from Sub-Saharan Africa.	Attributes of the neighbourhood physical environment.	Older adults aged 65 years and above,	Leisure-Time Physical Activity (LTPA) metrics: engagement in, frequency and/or amount of leisure-time walking, cycling and/or PA.	Living within walkable, aesthetically pleasing neighbourhoods with good access to public transport and fewer barriers is associated with more leisure time walking among older adults. Having access to recreational facilities and parks/open spaces is associated with more leisure-time physical activity among older adults.

Table 3 Evidence table for reviews examining impacts from changes in road infrastructure.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Elvik, 2017	Meta-analysis of 44 studies	UK, US, Australia and European countries.	Converting junctions into roundabouts	Road collisions (involving people and property)	Accident severity (fatal, serious injury, slight injury, injury, property-damage-only)	1. Converting junctions to roundabouts is associated with a large reduction in fatal accidents of about 65% and a reduction of injury accidents of about 40%. 2. Estimates of effect are stable over time, but larger accident reductions have been found in studies reported in North America and Australia than in other regions of the world.
Panter et al, 2019	Systematic review of 46 studies (33 reviews and 13 evaluation studies)	Unspecified (international studies)	Interventions promoting walking and cycling (e.g. improving safety, accessibility, connectivity and user experience)	Unspecified	Walking or cycling in the intervention area; changes in weekly levels of active travel.	Individual or population levels of walking and cycling and the supportiveness of the physical and wider social environment were important contexts. However, there was little information about potential mechanisms. The most plausible mechanisms concerned (i) improving accessibility and convenience of walking and cycling and (ii) reducing potential conflict between users. The most effective interventions appeared to target accessibility and safety in supportive and unsupportive individual and physical contexts.
Cairns et al, 2015	Umbrella review of 5 reviews (looking at 10 different studies in total)	High-income European countries, e.g. UK, The Netherlands and Germany.	20 mph zones and limits.	Children and adults of all ages	Health and Socio-Economic Status inequality outcomes	Convincing evidence that 20 mph zones are effective in reducing collisions, injuries, traffic speed and volume, as well as improving perceptions of safety in a couple of the studies. Such interventions can be cost-effective and supported by local residents. However, effects on physical activity, walking, cycling and children playing outside, were less clear. Including local stakeholders in the planning process can help with public perceptions and approval of such schemes.
Ricci, 2016	Literature Review of 20 studies, including reviews.	Europe (Germany, UK, Netherlands, Italy and France), US, Canada and Japan.	Urban freight interventions, mostly Urban Freight Consolidation Centres (UFCCs).	The resident and working population in urban areas where freight measures were implemented.	Cost savings, environmental impacts (reduction in emissions, miles travelled...), NPV	UFCCs can lead to significant reductions in freight transport activity and associated environmental impacts between the UFCC and the final point of delivery for those goods flows that pass through the UFCC. However, given the limited scale of such schemes and modest goods throughput at UFCCs, any reduction in transport activity and associated environmental impacts due to the UFCC are, unsurprisingly, marginal in terms of total freight traffic and total motorised traffic in the area.
Umstattd Meyer et al, 2019	Systematic review of 6 studies	USA (n=2), UK, Belgium, Chile and Australia.	Play Streets	Residents (adults and children) and users of Play Streets	Active play, physical activity, and neighbourhood and community impacts.	In general, Play Streets provided safe places for child play, increased sense of community, and when measured, data suggest increased physical activity overall and during Play Streets.

Table 4 Evidence table for reviews examining impacts from uses of transport infrastructure.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Norgate et al, 2020	Systematic review of 47 studies	Europe and North America.	Commuting by public transport	Commuters by public transport	Absenteeism, mental health, motivation, sleep quality, commuting stress, mood, and musculoskeletal and gastrointestinal complaints.	Multimodal comparisons showed negative impact on sickness rate, self-rated health complaints, perceived stress level and reduction in sleep, especially for long commutes and involving more than one leg of journey, and for women. Analysis of rail commuters showed increased stress (both objectively measured and perceived) and affective reactions to crowding.
Kelly et al, 2014	Systematic Review and Meta-Analysis of 21 studies	Majority from Western Europe followed by the US, China and Japan.	Walking and cycling	Adults engaging in walking and cycling	Risk of All-Cause Mortality (ACM)	Walking and cycling have population-level health benefits (i.e. reducing risk of ACM) even after adjustment for other physical activity. Public health approaches would have the biggest impact if they are able to increase walking and cycling levels in the groups that have the lowest levels of these activities.
Bourne et al, 2018	Systematic review of 17 studies	Mainly high-income European countries, including UK, followed by the USA.	Riding electric bicycles	Adult populations aged 18+	Objective measure of physical activity intensity whilst e-cycling, cardiorespiratory, metabolic or quality of life.	E-cycling leads to reduced activity volume and intensity over the same distance compared to conventional cycling; requiring more frequent and longer rides to accrue comparable health benefits. Moderate evidence that e-cycling provided physical activity of at least moderate intensity; lower than that of conventional cycling, but higher than walking. Moderate evidence that e-cycling can improve cardiorespiratory fitness in physically inactive individuals, but impact of e-cycling on metabolic and psychological health outcomes is inconclusive.
Chatterjee et al, 2020	Critical review	International scope	Commuting	Adult commuters	Subjective Wellbeing	Mood is lower during the commute than other daily activities. Stress can be induced by congestion, crowding and unpredictability. People who walk or cycle to work are generally more satisfied with their commute than those who travel by car and especially those who use public transport. Satisfaction decreases with duration of commute, regardless of mode used, and increases when travelling with company.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
						The commute experience “spills over” into how people feel and perform at work and home. However, a consistent link between commuting and life satisfaction overall has not been established. The evidence suggests that commuters are generally successful in trading off the drawbacks of longer and more arduous commute journeys against the benefits they bring in relation to overall life satisfaction.
Xu et al, 2020	Systematic Review of 27 studies	USA, Australia, Portugal, China, Germany, Cyprus, Iran, Ireland, New Zealand, Norway, and South Korea	Access to public transport	Children and adolescents aged less than 18 years	Weight-related behaviours (e.g. PA, sedentary behaviour, and diet) and/or weight outcomes (e.g. BMI, overweight/obesity, waist circumference, waist-to-hip ratio, and body fat);	Evidence is mixed and difficult to compare. An increased level of access to public transport may have a health-promoting effect and hence prevent the development of childhood obesity. However, this conclusion needs to be further corroborated in future research.
Marques et al, 2020	Systematic Review of 7 studies	USA, Japan, Canada, UK and one in Latin America	Active commuting	Adults aged 18+	Depression or depressive symptoms	Evidence is inconsistent. Switching to more active modes of travel and walking long distances were negatively related to the likelihood of developing new depressive symptoms in 2 studies. In the other five studies, no significant association between active travel or active commuting and depression was found.
Yazdanpanahi et al, 2012	Systematic Review	Not specified	Active travel to school	Not specified	Not specified	Childhood obesity, physical inactivity and sedentary life are increasing dramatically worldwide. Physical inactivity is closely linked to bone health, cardiovascular disease, metabolic disorders, fitness and psychological outcomes. Recent studies have found positive effects of active commuting on physical inactivity, overweight, obesity, survivors of childhood cancer, particularly brain tumours and acute lymphoblastic leukaemia, and links to a reduction of metabolic complications and cardiovascular disease in later life.
Dinu et al, 2019	Systematic Review and Meta-Analysis of 23 studies	Northern Europe (including the UK), rest of Europe, Asia and the US.	Active commuting (walking and cycling)	Commuters using active travel.	Risk of all-cause mortality, incidence and mortality from cardiovascular diseases, cancer and diabetes.	People who engaged in active commuting had a significantly reduced risk of all-cause mortality, cardiovascular disease incidence and diabetes. There was no association between active commuting and cardiovascular disease mortality and cancer.

Table 5 Evidence table for reviews examining impacts of proximity to transport infrastructure.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcome	Results
Dzhambov and Lercher, 2019	Systematic Review and Meta-Analysis of 10 studies	All except one were from Europe (mainly The Netherlands).	Road traffic noise	Adult populations aged 18+ exposed to road traffic noise	Anxiety and depression	Sources of transportation noise lead to serious annoyance, sleep disturbance, and cardio-metabolic disorders. This review found that increasing exposure to road traffic noise may also be associated with depression and anxiety.
Dzhambov and Dimitrova, 2018	Systematic review and meta-analysis of 9 studies	8 in Europe, one in Canada	Road traffic noise	People exposed to road traffic noise	Arterial hypertension (Hypertensive diseases) morbidity or mortality	Residential road traffic noise is associated with higher risk of hypertension in adults, and that risk is lower than previously reported in the systematic review literature. The risk of hypertension was higher when adjusting for air pollution, and for men compared to women.
Burns et al, 2020	Systematic Review of 42 studies assessing 38 interventions	Studies from 19 countries. Mostly high income, urban.	Vehicular interventions e.g. low emission zones (LEZ), vehicle charging schemes, public transportation expansion, permanent infrastructure change; fuel and technology changes.	All relevant populations exposed to interventions	Mortality from the following causes: all-cause, cardiovascular, respiratory. Concentrations of particulate matter and related measures. Respiratory and cardiovascular effects. Concentrations of: CO, SO ₂ , NO _x , O ₃ , Ultrafine particles (UFP), Personal PM exposure.	Observed associations between interventions and both health and air quality outcomes were mixed, with most studies observing either no clear association in either direction or a significant association in favour of the intervention. A small number of studies observed a significant association favouring the control. Little evidence that the assessed interventions might be harmful.
Wang, et al, 2020	Systematic Review and meta-analysis of 26 studies	Unspecified (studies in English and Chinese were searched)	Traffic-related air pollution	Infants	Preterm birth (PTB), term low birth weight (LBW), small for gestational age (SGA), and birth defects (BDs)	SGA was significantly associated with a per 500m decrease in the distance to roads. Studies with higher NOS, cohort studies, and studies in North America revealed a positive and significant association between traffic density and term LBW. Traffic density seems to be a better indicator of traffic exposure than the distance to the road. Prenatal exposure to traffic pollution is detrimental to the foetus.
Singleton et al, 2020	Literature review	Unspecified (international studies)	Autonomous Vehicles (AVs)	General population	Health (both physical and mental health) and wellbeing (happiness, satisfaction and fulfilment)	AVs are likely to have overall positive impacts on some health and wellbeing aspects (safety, travel satisfaction, access to activities) and overall negative impacts on others (physical activity), while effects are more uncertain for other topics (urban built environments, air and noise pollution).

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcome	Results
Marques et al, 2020	Systematic Review of 7 studies	USA (n=2), Japan (n=2) one each in Canada and several Latin American countries.	Active commuting	Adults aged 18+	Depression or depressive symptoms	Evidence is inconsistent. Switching to more active modes of travel and walking long distances were negatively related to the likelihood of developing new depressive symptoms in 2 studies. In the other five studies, no significant association between active travel or active commuting and depression was found.
Dzhambov and Dimitrova, 2016	Systematic review with meta-analysis of 11 studies	Most in high income European countries, one in the US and one in Canada.	Traffic noise	People exposed to road and air traffic noise	Risk of stroke morbidity	Traffic noise is an established risk factor for some cardiovascular diseases such as hypertension and ischaemic heart disease. This study has established a small but elevated risk of stroke to be associated with both road and air traffic noise exposure, but the association was statistically significant only with the latter.
Cepeda et al, 2017	Systematic review of 39 studies	European (n=24), west Pacific (n=11), American (n=3), and southeast Asian (n=1) countries.	Modes of transport	Users of different modes of transport	Years of life expectancy (YLE).	Proximity to traffic and high air interchange increased the exposure to air pollution of commuters using motorised transport, mostly cars and buses. Larger inhalation rates and commuting time increased inhaled dose among active commuters (cyclists followed by pedestrians). Benefits of active commuting from physical activity are larger than the risk from an increased inhaled dose of fine particles.
Tham et al, 2019	Systematic review of 33 studies	Unspecified	Air pollutants: particulate matter, PM10, PM2.5, ozone, nitrogen dioxide, sulphur dioxide, carbon monoxide.	Young children, children, adults and older adults, across a range of geographic settings.	Lung function parameters	Overall, long term exposure to higher levels of nitrogen dioxide, particulate matter and ozone was associated with Lower lung function parameters in young children, children and adolescents; and declines in some adults' and older adults' lung function parameters. Levels of associations varied depending on the levels of exposures of different pollutants in different areas. Overall there is strengthening evidence that long term exposure to air pollution, particularly related to traffic, is associated with deficiencies in lung function across all age groups.

Chapter 3 evidence table: Water and Wastewater

Table 6 Evidence table for studies examining impacts from drought.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Polain et al, 2011	Semi-structured workshops at the community scale. The researchers performed a content analysis of issues and priorities raised during the activities.	NSW, Australia	Drought	150 older farmers and their families, support service representatives (e.g. rural financial advisors, mental health services) and government and non-government agencies.	Pressure on farmers	The study demonstrates how extended periods of drought led to increased pressures on farmers. These pressures added to the everyday pressures associated with farming (and older farmers). The research details three key themes and challenge areas: loss, government compliance pressures and difficulties accessing and/or inappropriate services.
Hart et al, 2011	Empirical article that describes how the Rural Adversity Mental Health Program was introduced in 2007 to raise awareness of the mental health issues associated with drought.	NSW, Australia	Drought	In the project, over 3000 people received mental health literacy training (2007 to 2010).	Mental health events, attended by thousands of people (led by collaborating stakeholders); development of a free rural mental health support telephone line to provide help in times of crisis and connect people in need to mental health services.	The paper summarises the work by suggesting that long-term interventions are needed to effectively address mental health challenges associated with long-term drought. It further elaborates that these needs can change over time, and will likely continue even after the drought is broken.
Carnie et al, 2011	Series of semi-structured forums and workshops. Content analysis of issues and priorities was conducted on research data.	NSW, Australia	Drought	Young people, teachers and service providers. It focused on the health impacts associated with drought (amongst young people).	The project included study of six youth and community forums. These were set up under the 'Rural Adversity Mental Health Program'.	The research details that long-term exposure to drought amongst young people can lead to increased hopelessness, distress and behavioural problems. This is despite some evidence of an ability to cope at early stages of a drought.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Dean and Stain, 2010	This research resamples young people from a rural area of NSS, Australia, initially studied in 2004, three years prior. Sought to understand if 'resilience' remained 3 years after the drought.	NSW, Australia	Drought	111 male and female adolescents aged 11–17 years completed questionnaires, 61 of these also participated in focus groups.	Questionnaire and a Drought and Community Survey to detail the experiences of drought amongst young people.	The research demonstrates significantly higher levels of emotional distress in the new cohort than those in the previous study. The first group (2004) did not report levels of emotional distress higher than adolescents of similar age and gender in the Australian community. The second group (3 years later) reported new themes and higher levels of distress. Researchers conducted a thematic analysis which shows new themes of grief, loss and the impacts of global climate change as key areas of concern.
Bryan et al, 2019	Investigates the perceptions and intentions of South West England households towards drought and drought coping.	Exeter, England	Drought	A total of 250 and 97 households took place in each community. Of these, only 91 valid cases for analysis were included.	Questionnaire that was randomly administered in the flood risk areas of two communities.	According to the survey, most participants (76%) believed that a major drought would have a low to very low likelihood of affecting their local area. According to the authors, despite low perceived likelihood and consequences of drought in their local area, participants were willing to implement household drought coping measures.

Table 7 Evidence table for reviews and studies examining impacts from water supply infrastructure.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Mankad and Tapsuwan, 2011	The intent of this review paper is to examine empirical scholarship that centres on the adoption of alternative and decentralised water systems.	International	Water Supply	The review focused on social science literature pertaining to alternative forms of household water, with an emphasis on research examining decentralised water acceptance.	Decentralises and alternative water supplies are defined here at 'the collection, treatment and use of rainwater, stormwater runoff, greywater and blackwater.	The vast majority of internationally published literature in the area of decentralised water systems confirms that there are economic, environmental and social benefits that would stem from using decentralised water systems Some of these benefits include savings on household water usage bills; delaying augmentation of new supply sources; mitigating the effects of imposed water restrictions on lifestyle and property value (i.e., the benefits of being able to maintain green lawns); and increasing the sense of environmental responsibility and community mindedness. Key factors for public acceptance include the level of 'risk perception' and health concerns (a preference for re-used water with limited human contact) where re-used water can be considered 'dirty' when compared to conventional sources.
Stelmach and Clasen, 2015	This review examines the health effects of household water quantity. The authors searched MEDLINE, embase, the Cochrane Library, Web of Science, and article reference lists.	International	Water Supply	Twenty-one studies met the authors' eligibility criteria.	According to the review there is a positive association between water quantity and health outcomes. This depends largely on use and context (e.g., global north / south, etc).	The findings detailed in this review indicate that increased water consumption among residents of high-income countries might be associated with increased risk of a few specific NCDs, but these increased risks are not enough to significantly affect all-cause mortality rates.
Stuart et al, 2011	Using a source-pathway-receptor framework, reviews the potential impacts of climate change on nitrate concentrations in groundwater of the UK.	United Kingdom	Water Supply		Nitrates are present in much of the UK groundwater. These can exceed drinking water standards. Nitrates is a significant problem facing the water industry in the UK. Nitrate concentrations are predicted to rise in over the next decade.	Climate change will impact soil processes and agricultural productivity. Climate change is likely to lead to increased nitrate leaching from the soil.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Speight, 2018	Concept paper	UK / USA	Water supply		The authors point out how increases in population can stress ageing infrastructure and presents challenges for water industry and utilities to meet public demand.	Interestingly, the paper highlights a dilemma posed by transitioning to sustainable water systems (e.g., lower water consumption, improved water efficiency) which at could lead to degradation of drinking water quality. This was particularly relevant for consumers with lead within their plumbing who may increase exposure to lead through conservation measures.
Heflin et al, 2014	Two focus groups and 162 face-to-face interviews examining the adaptations residents adopt using water contamination or outage events and their associated costs. Qualitative description of the types of behaviours that are adopted and descriptive statistics of the economic impact.	US Focus groups: Ithaca, New York; Somerset, Massachusetts Interviews: Somerset, Massachusetts; San Luis, Colorado; Questa, New Mexico; East Chicago, Illinois	Disruption to water supply through either contamination or water outage for more than one day.	162 residents across four locations, based on a convenience sample. Analyse of average costs comparing between urban and rural locations and contamination and outage events.	Costs associated with adapting to the disruption.	Mean total cost for disruptions was \$93.96 per event; \$92.68 for water outages and \$96.03 for contamination events, rural areas incurred greater costs than the urban residents (\$137.26 versus \$61.84; $p<0.05$). Four adaptations: 1. direct water consumption: extra bottled water (mean=\$19.50 per event), boiling or bleaching water (\$5.83) or replacing water filters (\$7.75); 2. cooking and eating: using disposable dishware (\$6.06), eating out more (\$49.14) or less (\$5.72 saving); 3. work/school schedules: additional child care (\$2.06), working more (\$14.90) or less (\$10.94) than usual; 4. travelling for supplies (\$6.71) and having to pay for lodgings (\$35.19). Rural versus urban: boiling or bleaching water (\$9.39 versus \$3.19; $p<0.05$); disposable dishware (\$8.26 versus \$4.43; $p<0.01$); travelling for supplies (\$10.58 versus \$3.95; $p<0.01$) and having to pay for lodgings (\$85.00 versus \$5.88; $p<0.01$). Water outage versus contamination: extra bottled water (\$14.63 versus \$22.52; $p<0.05$); eating out less (\$2.58 versus \$10.82; $p<0.05$); . Those experiencing contamination incurred greater costs for lodgings than those affected by water outages (\$8.33 versus \$88.89; $p<0.001$).

Table 8 Evidence table for studies examining impacts from wastewater infrastructure.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Fujiwara et al, 2020	Combines the Annual Population Survey (APS) and the Understanding Society (USoc) survey with proximity to Sewage Treatment Works (STW) data (water companies and other data).	United Kingdom	Wastewater Treatment Plant	APS covers the UK at the household level. USoc is large longitudinal study of UK households.	Life satisfaction from APS (four waves from April 2011 to March 2015) and USoc (six waves, 2009–15).	The study shows that living farther away from the nearest STW is associated with higher levels of life satisfaction. The findings suggest a negative correlation between proximity to STWs and 'subjective wellbeing'. The negative correlation increases in situations with severe odour problems. The research also notes that people living close to an STW would pay for reductions in odour levels. The research suggests that living farther away from the nearest STW is associated with higher levels of life satisfaction.
Pasmionka, 2020	Bioaerosol assessment (air samples) at four points in vicinity of the treatment plant	Poland	Wastewater Treatment Plant	Researchers examined the raw sewage inlet; aeration chamber; purified sewage outlet; and 150 m from treatment plant	Air quality analysis tested for microorganisms.	Highest air pollution with microorganisms located at the inlet of raw sewage and the biological reactor. Season and temperature impact the air quality. The bioaerosol generated at the treatment plant may contribute to poor air quality in the environment
Vantarakis et al, 2016	Case study of people who live within 500m of a wastewater treatment plant. A questionnaire was self-completed by the participants. Airborne pathogenic microorganisms were collected around the wastewater treatment plant.	City of Patras, south western Greece	Wastewater Treatment Plant	The population was comprised of inhabitants living up to 500m of the Wastewater Treatment Plant. A control group included residents living >5 km from the WTP.	The questionnaire included: Baseline characteristics (demographics); Health status; Medical history; Health related quality of life and overall life satisfaction. The air sampling was performed once a week for four consecutive weeks in an area of 500 m radius around of the Patras' WTP.	The research found that there is significant risk for symptoms such as headache, unusual tiredness, concentration difficulties, and an increased possibility for respiratory and skin diseases. The researchers also found evidence of a high rate of irritability and moodiness. In comparison to the control groups, those close to the WTP presented significantly higher gastrointestinal symptoms. In sampling points close to the wastewater treatment plant, there were high numbers of pathogenic airborne microorganisms connected to the WTP.

Chapter 4 evidence table: Flood Risk Management

Table 9 Evidence table for systematic reviews examining impacts from flooding

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Benevolenza and DeRigne 2019	Systematic literature review that investigates the psychological and physiological outcomes on vulnerable people who have experienced adverse weather and natural disasters.	United States	Flooding and Natural Disasters (vulnerable)	The research is focused on three major USA hurricanes and 12 years of research. The search identified 42 articles of which 13 met the final study criteria.	Psychological and physiological outcomes.	Role of social capital in supporting mental health and wellbeing is critical to support vulnerable populations. The review summarises the research as such: the mental and physical health of marginalized populations during and after a natural disaster were elevated and/or exacerbated by circumstances pertaining to the weather event and the lack of disaster-response actions. Across this work, the review identified that 'social capital' can be fostered as a means to minimise stress and challenges amongst vulnerable populations.
Stanke et al, 2012	Systematic review of literature (2004 – 2010) on the health impacts of flooding.	International	Flooding	The search identified 48 papers. However, additional grey literature was added (e.g., government and NGO guidance and studies).	Mental health	According to the review, flooding affects people of all ages and can exacerbate or provoke mental health problems. The review specifically highlights the role of 'secondary stressors' which can worsen and prolong mental health problems. Moreover, as time passes, it can be difficult to distinguish between disaster-related and no-disaster related mental disorders. This signals a need to address and reduce 'primary and secondary stressors' (e.g., economic stress, recovery challenges) on people living in vulnerable circumstances.
Lane, et al, 2013	Review paper that examines the health impacts of US coastal storms, relevant to New York City, to contribute to adaptation efforts. It incorporates experiences associated with Hurricane Sandy.	USA	Flooding	Following abstract screening, 70 studies were reviewed in detail. These papers addressed a range of exposures and adverse health outcomes.	Health outcomes including injury and death directly from flooding and storms, physical and mental health problems, and injury and illness related to repair and recovery, those related to exposure to damaged housing (e.g., moisture)	Adverse health outcomes can occur through multiple pathways: (1) exposure to storm impact; (2) evacuation; (3) post-storm hazards from utility outages and sheltering in place in inadequate housing; (4) exposure to secondary hazards (e.g. contaminated drinking water) (5) population displacement and disruption of services; (6) mental health effects from traumatic or stressful experiences; (7) clean-up and recovery activities. Finally, the research indicates that areas with high levels of deprivation are likely to be at an increased risk of prolonged adverse health impacts.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Fernandez et al, 2015	Systematic mapping review of studies on floods and mental health (dates 1994 to 2014).	International	Flooding	The authors' search strategy identified 1331 potentially relevant papers. Of these 83 papers were included in the review.	Measures of study included PTSD, Anxiety, Depression, Suicide, Psychological Wellbeing, increase in tobacco, alcohol and other substance use, increase in medication usage.	The review found that higher levels of mental health problems were reported along with higher levels of exposure to flooding. This review suggests that floods have a potentially negative impact on mental health (increasing levels of PTSD, anxiety, depression and use of psychotropic medication). As an international review, the authors note that the impact of flooding on mental health is similar in both developed and developing countries.
Saulnier et al, 2017	Details the health problems associated with flood and storm disasters.	International	Flooding	The review included 113 studies.	Health impacts	The review identified a range of health problems, detailed in the literature. These include poisonings, wounds, and infections. The majority of these occurred within four weeks of the storm event.
Alderman et al, 2012	Systematic Review	International	Flooding	The review brought together 35 key studies looking at health and flood relationships.	Health outcomes	According to this review paper, health outcomes depend on both the characteristics of the flooding event and people's vulnerability. A central focus here is on 'vulnerability'. The authors detail how the urban poor, elderly, women and children and those with chronic conditions will require significant attention including efforts to address flood preparedness and mitigation. Many adverse health impacts associated with flooding are worsened in populations with poor hygiene, limited resources.
Chen and Liu, 2015	This review brings together evidence on posttraumatic stress disorder (PTSD) among flood victims.	International Review paper	Flooding	Fourteen articles were included in this review.	Relations between disasters, flooding and mental health.	According to the review, it is clear that natural disasters (e.g., floods) can lead to a wide range of mental health issues. These can include psychological distress, anxiety, depression, and posttraumatic stress disorder (PTSD), among other issues.

Table 10 Evidence table for studies examining impacts from flooding.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Bei et al, 2013	Before and after surveys measuring mental health including PTSD.	Victoria and New South Wales, Australia	Flooding	274 participants (older adults over 60) who completed both pre- and post-flood surveys	Post-traumatic Stress Disorder (PTSD)	Individuals affected by flooding (21.2%) reported significantly higher PTSD symptoms compared to those in the control group. The authors show how flood experience and the social support deficiencies contributed to mental and physical health problems. The research shows that flood experience has negative impacts on personally affected older adults.
Moss et al, 2017	Queensland flood study (2011) – survey of pregnant mothers.	Queensland, Australia	Flooding	145 participants (mother–infant) at least 36 weeks into pregnancy who were exposed to a flood.	Maternal PTSD, cognitive development in infants.	Flood exposure predicted child cognitive development and maternal PTSD symptoms and negative cognitive appraisal were significantly negatively related to child motor development, with all relationships moderated by timing of exposure. The research shows that timing of flood exposure is critical to adverse health impacts. For example, with children’s cognitive scores suggest that cognitive development worsened when flood exposure occurred closer to birth.
Hilmert et al, 2016	Participants in this research filled in questionnaires after the 2009 Red River flood. The research also gathered medical data, including birth weight and gestational age.	North Dakota, USA	Flooding	Pregnant residents who were at least 18 years old (N 169).	Health impacts of flood exposure and pregnancy.	For pregnancies earlier in gestation during the crest, birth weight decreased as distance from flooding decreased. For pregnancies later in gestation at crest (1 SD 26 weeks), distance was not associated with birth weight. The research demonstrated a reduction in foetal growth amongst pregnant women who experience a major flood during the first trimester. These findings suggest that experiences of a catastrophe earlier in pregnancy have significant pregnancy outcome impacts.
Sihawong et al, 2011	Data gathered from participants through a self-reported survey.	Bangkok, Thailand	Flooding (physical impacts to health)	377 healthy office workers, who had reported no neck and low-back symptoms at the end of September 2011 and who were affected by a flood in October 2011	Musculoskeletal symptoms in the neck and low back.	Eighty-two percent were affected by the flood. The research found an increased rate of musculoskeletal symptoms in the neck and low back during flood events in Bangkok (2011).

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Fontalba-Navas, et al, 2017	A case-control study was developed to study the relationship between PTSD and socio-demographic risk factors. Participants completed a sociodemographic questionnaire and the trauma questionnaire in order to examine PTSD symptoms.	Almeria, Spain	Flooding	The population included a sample of people directly (and severely) affected population (n=70). A second population sample was included of people who at the time, lived in adjacent areas (less than 30 kms from the affected areas) (n=91).	PTSD	Individuals who resided in the affected areas at the time of the flood were at much higher risk of developing PTSD symptoms when compared to people in non-affected sites.
Bell et al, 2014	A two-stage 'critical computational linguistics' analysis was conducted of 753 community submissions to the Queensland Floods Commission of Inquiry.	Queensland, Australia	Flooding (vulnerable)	Population of the study included vulnerable groups. These included people experiencing poverty, women and children, CALD communities, Aboriginal people, people with disabilities, elderly, people with mental health conditions.	The researchers conducted (i) content scoping and quantification using linguistics software and (ii) traditional critical discourse analysis.	The analysis shows that discourses of risk, warning, evacuation and recovery are prevalent in language referring to vulnerable people. Meanwhile, discourses related to preventative needs assessment and impact assessment were generally absent.
McCabe et al, 2014	Systematic investigation of the role of prenatal partner support in perinatal maternal depression.	Iowa, USA	Flooding	145 females who experienced a flood during pregnancy; were provided prenatal measures of support; were in relationships and cohabiting.	Maternal depression	The research contributed to understanding women's level of hardship resulting from exposure to floods (2008). Results of the research suggest highlights the importance of partner support during pregnancy which can contribute to managing hardship during flood events.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Sciulli et al, 2015	Semi-structured interviews to investigate seven Italian LCs that were severely impacted by the flood event.	Italy	Flooding (management)	7 Italian local councils / 15 council managers were interviewed		The findings suggest that the adoption of the concept of resilience is at an early stage in the Italian LCs decision and policy making. The term resilience is not mentioned frequently in the LC policy documents.
Walker-Springett et al, 2017	Mixed-method approach drawing on data from repeated qualitative semi-structured interviews (n=60) and a structured survey (n=1000) with individuals that experienced flooding directly during winter 2013/14 in two UK regions.	United Kingdom	Flooding	The population for the survey (n=1000) was split between Boston (n=500) and Somerset (n=500). The survey focused on two areas that had been flooded during 2013-2014.	in-depth analysis of four key social dimensions that explain, contribute to, and affect wellbeing following a major flood event. These concern temporal dynamics and the passage of time; social capital and the relevance of relational networks; perceptions of agency and self-efficacy; and capacities for sense-making and coping with changed futures	The data offers evidence of a strong impact on wellbeing as a result of the 2013/14 flood events. The research findings suggest that wellbeing follows a non-linear trajectory through the recovery process after an initial negative peak. Social capital is critical to managing these events. The data also indicates that flood events can support the formation of new social networks. Overall, the analysis indicates that the impacts on wellbeing from a major flood event will be exhibited over long time periods. This could be years in developing.
Felton et al, 2013	Questionnaire designed to ask participants to state whether 19 different flood-related experiences had occurred in their experience with a flood. There were two waves of participants involved in the study.	Nashville, USA	Flooding	The first wave of participants (wave 1) included 239 students (133 girls, 56%) in grades 5–8 (Tennessee, USA). The second group (wave 2) was made up of a subset of the wave 1 participants (n=227). Participants ranged in age from 10–15 years.	Measures of rumination, depressive symptoms and flood-related experiences.	Symptoms of depression after a flood correlated with preflood depression, and rumination. The severity of participant's flood-related experience correlated negatively with preflood distraction

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Martin et al, 2016	Longitudinal study to measure PTS symptoms and mental health.	Nashville, Tennessee, USA	Flooding	Prior to a flood event (Nashville, Tennessee, USA), 239 youth participants. After the flood, 125 participants.	Pre-flood: depressive symptoms, rumination, negative life events, and social support measures Post-flood: PTS symptoms and mental health.	The research indicated that participants' report of severity of flood experience was a strong predictor of post-flood trauma symptoms. The research shows that the reported experience of disaster is a critical variable in the prediction of post-disaster trauma.
Gibson et al, 2018	Qualitative study of family caregivers interviewed flood experience to better understand experiences and perceptions during and after the flood.	South Carolina, USA	Flooding (vulnerable people)	Family caregivers (n=27) in South Carolina (2015)	Role of caregiver before and after flood events.	The research showed that the caregiving role affected caregivers' ability to prepare for the storm. It also influenced their decision-making regarding evacuation and utilization of recovery resources. The caregivers identified a disconnection between expectations as citizens versus caregivers. They highlighted a conflict between their own safety and the care for the individual they were caring for.
Quan et al, 2020	The research design included questionnaire to assess the traumatic exposure of flood victims. It also included interviews with 15 flood victims.	Wuhu, China	Flooding	A total of 187 flood victims from Wuhu, China. The city was severely impacted by a flood (July 2016). Flood victims completed a survey measuring traumatic exposure, feelings of safety, fear, posttraumatic negative cognition, and posttraumatic stress disorder.	The study showed prevalence of Feeling of lack of safety fear, and PTSD.	The results demonstrate that exposure and experience of serious flooding could directly predict PTSD.
Matsubayashi et al, 2013	Examines the relationship between natural disasters and suicide rates. The research looks at 47 prefectures of Japan from 1982 to 2010.	Japan	Natural Disasters	The total number of observations is 1,363 prefecture-years. Population size of prefectures in 2010 ranges from 589,000 (Tottori) to 13,159,000 (Tokyo).	Suicide rates associated with experience of natural disaster.	This study provides evidence on the relationship between natural disasters and suicide rates. The results indicate that some subgroups (working-age males and elderly females, are particularly at risk of suicide following the experience of natural disasters.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Aldrich and Kyota, 2017	Carried out surveys in the city of Ofunato (Tohoku, Japan), 1 year after a support intervention (a programme called Ibasho).	Japan	Natural disaster. Ibasho was an intervention that places elderly residents in vulnerable areas within larger social networks.	Pilot phase included testing and refinement. Second round took place in 2013 (before basho began): 599 participants. Third round took place over a year later (2014): 1142 respondents.	Participation levels in Ibasho, demographic characteristics, efficacy, social networks, and sense of belonging.	The programme encouraged participants to participate in a variety of activities. Ibasho project sought to improve resilience and capacity in the case of future disasters among older people. Participation in the Ibasho project strengthens social capital. According to the study, the Ibasho project led to measurable results in: efficacy, friends, and sense of belonging. The research shows that building social capital among older survivors of disasters can help manage adverse impacts. The project shows that an investment on social infrastructure is an important part of managing disaster risk.
Heflin et al, 2014	Two focus groups and 162 face-to-face interviews examining the adaptations residents adopt using water contamination or outage events and their associated costs. Qualitative description of the types of behaviours that are adopted and descriptive statistics of the economic impact.	US Focus groups: Ithaca, New York; Somerset, Massachusetts Interviews: Somerset, Massachusetts; San Luis, Colorado; Questa, New Mexico; East Chicago, Illinois	Disruption to water supply through either contamination or water outage for more than one day.	162 residents across four locations, based on a convenience sample. Analyse of average costs comparing between urban and rural locations and contamination and outage events.	Costs associated with adapting to the disruption.	Mean total cost for disruptions was \$93.96 per event; \$92.68 for water outages and \$96.03 for contamination events, rural areas incurring greater costs than the urban residents (\$137.26 versus \$61.84; $p < 0.05$). Four adaptations: 1. direct water consumption: extra bottled water (mean=\$19.50 per event), boiling or bleaching water (\$5.83) or replacing water filters (\$7.75); 2. cooking and eating: using disposable dishware (\$6.06) and eating out more (\$49.14) eating out less (\$5.72 saving); 3. work/school schedules: additional child care (\$2.06), working more (\$14.90) or less (\$10.94) than usual; 4. travelling for supplies (\$6.71) and having to pay for lodgings (\$35.19). Rural versus urban: boiling or bleaching water (\$9.39 versus \$3.19; $p < 0.05$); disposable dishware (\$8.26 versus \$4.43; $p < 0.01$); travelling for supplies (\$10.58 versus \$3.95; $p < 0.01$) and having to pay for lodgings (\$85.00 versus \$5.88; $p < 0.01$). Water outage versus contamination: extra bottled water (\$14.63 versus \$22.52; $p < 0.05$); eating out less (\$2.58 versus \$10.82; $p < 0.05$); . Those experiencing contamination incurred greater costs for lodgings than those affected by water outages (\$8.33 versus \$88.89; $p < 0.001$).

Table 11 Evidence table for studies examining impacts of flooding on property value.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Belanger and Bourdeau-Brien, 2018	Price paid data for residential properties between January 1995 and January 2016. Building type, age of property, elevation, proximity to water, flood risk, socioeconomic variables included in a linear mixed-effects model.	England	Flood risk	1,042,244 transactions included in the final dataset; 608,095 properties and 400,948 locations, across 5581 LSOAs.	2015-adjusted trade price of residential property.	Main results: flood risk-related discount increased from 0.5% to 1.3% between 2001-2005 ($p<0.10$) and 2006-2010 ($p<0.01$) and to 2.4% in 2011-2016 ($p<0.01$). Reduction in value associated with introduction of detailed flood map in 2004 and changes to insurance pricing in 2005 ($p<0.01$), designation as a high-risk flood plain ($p<0.10$) but no significant effect of property sale within 12 months of large flood event. Discounts are greater where the local housing market is depressed (<0.01), including where the property is sold within 12 months of a flood event ($p<0.01$).
Lamond et al, 2010	The study used data from locations which had flooded or nearly flooded in autumn 2000 in order to study the impact of flooding on housing value.	United Kingdom	Flooding (housing impact)	This study encompassed 13 locations that were flooded or nearly flooded in a 2000 flood event. They cover a large geographical area of England and South Wales.	Data from these locations were collected for seven years (2000 to 2006). This contained data before and after the 2000 flood event.	The results of this study revealed that the impact of flood events is highly variable and temporary. Further, flood designation does not impact value. This might reflect a lack of awareness of flood risk. According to this research, flood experience does not necessarily devastate residential value.

Table 12 Evidence table for studies examining impacts from sustainable drainage systems.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Naylor et al, 2017	Case study analysis includes a review of social benefits and costs of 'Integrated Green Grey Infrastructure' (IGGI). The report is an effort to evidence the economic justifications for implementing IGGI.	United Kingdom	Green Infrastructure	Analysis of the inclusion and use of IGGI in areas of: historic structures / walls; in urban areas; mowing; and coastal settings. Specific sites were selected through discussion with project stakeholders.	In terms of understanding benefit, the study looked at costs, performance (including maintenance), ecosystem services, and social value.	<u>Historic structures</u> : the study suggests that the use of IGGI in these contexts is often less expensive than traditional methods. <u>Urban</u> : In this context, costs were found to be generally the same or more than as business as usual approaches. The study suggests, however, that there is potential to improve urban ecology; human wellbeing and economic activity through IGGI. For example, 'green' infrastructure can contribute to a reduction of air pollution. <u>Mowing</u> : in this context, costs were reduced where mowing was less frequent. This was also shown to contribute to improved biodiversity, wellbeing and community cohesion. <u>Coastal</u> : the study found that IGGI in the coastal setting could lead to habitat improvements, reduced flooding, and improved access for use and enjoyment.
Venkataraman et al, 2019	Systematic review of academic and grey literature. The review examines the effects of GI for stormwater and flood management.	International	Green Infrastructure	Following screening 20,000 papers, only 18 studies reported health or social wellbeing outcomes, nearly half of which were from Portland, Oregon.	Physical health; mental health; economic wellbeing; and flood resilience and social acceptance of green infrastructure.	None of the reviewed studies make connections between GI and mental or physical health outcomes. Thirteen studies reporting a positive association between GI and property values. According to the authors, evidence on health and social wellbeing outcomes in relation to GI (stormwater and flood management) is needed. The study demonstrates some of the challenges associated with connecting infrastructure directly to social impacts.
Hunter et al, 2020	The report and study examine seven key impacts from the development of the greenway.	Belfast, Northern Ireland	Green Infrastructure	The Connswater Community Greenway was a - £35 million investment in a major urban rejuvenation project.	Land and property values; labour employment and productivity; flood alleviation; climate change; health; tourism; quality of place.	A property adjacent to the greenway could see an increase in value by up to 10%. Estimated benefits in improved labour productivity within east Belfast as well as new employment opportunities. Greenway is expected to prevent 1,741 properties along the greenway route from future flooding, costs avoided valued at £54.7 M. Cost savings and the societal value of improved health and deaths prevented could be as much as £52 million over 40 years.
Simpson, 2017	Evaluation of the Connswater greenway in areas of environmental, social, economic and overall	Belfast, Northern Ireland	Green Infrastructure	The project included the development of key indicators. Baseline information was gathered before	Land and property values; labour employment and productivity; flood alleviation; climate	According to the evaluation, the project has met 11 of the 13 environmental targets; 8 of 14 social targets and 7 of 9 economic targets. In terms of quality of life, the report details achievements related to new accessible green space, improved ecological

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
	quality. Measures the greenway's impact in key areas.			completion of the greenway. This allowed for before/after assessment of impacts. This is set out in the project's 'PARC' study.	change; health; tourism; quality of place.	resources, self-reported health, safety, increased social connectivity and many other areas. However, the PARC study (part of the report) details the health and wellbeing impacts have not yet been realised.

Chapter 5 evidence table: Waste Infrastructure

Table 13 Evidence table for studies examining impacts from waste infrastructure

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Negri et al, 2020	Systematic review of epidemiological studies	International (all developed countries)	Incinerator	Population living near an incinerator or staff working at incinerator sites.	All-cause mortality/hospitalization; cancer incidence/mortality; pregnancy outcomes; respiratory system and cardio- and cerebrovascular diseases; genetic or congenital malformations; other.	Lymphohematopoietic cancers and STSs are linked to incinerator exposure. Some scattered evidence that exposure to incinerators may impact on pregnancy outcomes is evidence in third generation studies on PTB. However, a more recent larger UK study found no correlation. There was no consistent excess risk for people living near incinerators and there was limited data available for workers.
Tait et al, 2020	Systematic review	International (any studies written in English)	Incinerator	Human and non-human impact of incinerators.	External measures: of air, soil, water, food, etc. Internal measures: of serum, urine, breast milk, hair, or direct effects on cells and/or DNA. Health outcomes were further subclassified as neoplasia, reproductive health and other.	There is evidence of significant risk associated with waste incineration. Older incinerators were linked to issues with reproductive health and neoplasia, as well as other diseases. The results were not consistent across all studies, however, there is insufficient evidence to suggest that incineration is a safe form of waste management. The reviewed studies suggest that newer incinerators may be safer, however, exposure diseases commonly take a number of years to come to light due to cumulative exposure. The review concluded that it is too soon to claim that newer incinerator technology is safe.
Martuzzi et al, 2010	Review of grey and peer reviewed literature (n=47)	Europe and USA	Landfill	Population living near a landfill site.	Distance from landfill sites and level of inequality based on multiple disadvantage.	The review showed that people who experience multiple disadvantage are more likely to live near a landfill site and that when health impacts of living near a landfill are detected these are often compounded by the effects of multiple disadvantage.
Grant et al, 2013	Review (23 papers)	China	E-waste	People exposed to e-waste.	Mental health and neurodevelopment, physical health (including mechanistic events such as DNA damage and effects on gene expression), education, violence, and criminal behaviour.	Recorded plausible outcomes associated with exposure to e-waste included change in thyroid function, changes in cellular expression and function, adverse neonatal outcomes, changes in temperament and behaviour, and decreased lung function. Exposure to the hazardous components of e-waste is most likely to arise through inhalation, ingestion, and dermal contact. People can come into contact with e-waste materials, and associated pollutants, through contact with contaminated soil, dust, air, water, and through food sources, including meat.

Table 14 Evidence table for studies examining impacts from alternative waste management technologies

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Larsen et al, 2010	Quantitative case study (economic and environmental assessment).	Denmark	Municipal waste management schemes	Recyclable waste.	Life cycle and economic cost assessment of five different alternative recycling collection system. Resource consumption, emissions and economic costs (of all parts of the collection system) were used.	In general, the results showed that enhancing recycling and avoiding incineration was recommendable because the environmental performance was improved in several impact categories.
Hidalgo et al, 2018	Quantitative study of CO ₂ savings.	Spain and Greece	Underground automated vacuum waste collection system	Vacuum waste compared to general garbage collection.	CO ₂ savings	The study identified a 90% reduction in CO ₂ emissions compared with traditional models of collection involving trucks.
Nakou et al, 2014	Quantitative study of CO ₂ savings and costings.	Greece	Underground automated vacuum waste collection system	Vacuum waste compared to general garbage collection.	CO ₂ savings and exhaust emissions. Total cost of AVAC (vacuum waste) system v's total cost of conventional garbage collection.	AVAC and conventional garbage collection have roughly the same cost performance using the equivalent annual cost analysis. However, operational and capital costs are almost 40% lower in the AVAC system. The AVAC system is also attributed with better air quality. Underground infrastructure offers equivalent financial performance as well as superior operational and environmental characteristics.

Chapter 6 evidence table: Digital Infrastructure

Table 15 Evidence table for studies examining impacts from digital infrastructure

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Abbott-Garner et al, 2019	Quantitative before and after study.	Cornwall, UK	Superfast broadband	Residents; before and 18 months after.	Reported internet speeds.	The implementation of superfast broadband may have contributed to people being readier to use e-health services. People reported faster broadband speeds.
Park et al, 2019	Qualitative case study in two communities	Australia, New South Wales	Broadband connectivity and accessibility.	Residents of two rural communities.	Access, cost, quality of connection.	Infrastructure is a key component to digital inclusion and exclusion, but factors such as connectivity speed and cost are also significant. As more services/education/business have moved online those people with either no or poor connectivity are excluded (e.g. where face to face education has moved online some people are now excluded). People who ran their businesses in person are falling behind because they cannot switch to online. Constrained use of internet (for people who were reliant on mobile data packages) were also impacted because they were either unable to get the data they required/were paying more for their household data/ were wasting their data by having to re-download because connection was less reliable.
Salemink et al, 2017	Systematic literature review	Developed countries	Rural digital connectivity and access	Adults living in rural locations.	Connectivity (including related subthemes). Inclusion (including related subthemes).	Rapid digitalisation makes certain groups e.g. older people in rural and urban contexts/ children, young people and women living in rural areas- more at risk of digital and social exclusion. People who are not ICT literate and also more likely to be excluded and marginalised in off-line life. The following key points come through: that people living rurally must have the same level of connectivity, and that people need to be confident in using the internet. Without these- people are at risk of exclusion or economic decline.
Townsend, 2015	Qualitative interviews	Scotland	Digital connectivity for rural business owners	Business owners living in rural Scotland with poor connectivity and a business founded since internet became	Interviewees were asked about the role of the internet in their rural communities in Scotland and the impact that their level of connectivity had on their lives.	Whilst the study focuses on businesses there is evidence of a knock-on effect for the rest of the community. Concludes that 'Better connectivity in rural areas is essential if such areas are to remain economically and socially sustainable'. Some business sectors are becoming more reliant on connectivity than others e.g. creative. Reduced opportunities to socially network was a problem for people living in rural communities and running business- not

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
				central to everyday life.		only for keeping up to date with developments in their field of business but also for addressing feelings of professional and social isolation.
Townsend et al, 2013	Discussion piece	UK	The availability and quality of broadband	People living in rural areas.	N/A	The paper argues that broadband plays an important role in addressing social and physical isolation in rural areas. They also suggest that broadband is particularly vital in rural areas which already suffer from being further from services and other people. The paper claims that the differences between the quality of connection in rural areas can influence where people live, which in turn causes rural areas with poor connectivity to be less socially and economically sustainable.
de Wijs et al, 2016	Qualitative interviews	Netherlands	Smart technology in railway stations	Stakeholders from each and smart city consultants.	4 levels of smart tech infrastructure (customer facing through to management of services).	Smart tech in railways is often reported to get stuck before the application stage. This is attributed to a lack of financial investing in the network infrastructure eg: the wifi connection. Digital infrastructure is enabling the railway stations to adapt to accommodate more people (reducing the dependence on the car) despite a lack of space to expand (the railway stations were old buildings in city centres). Technology such as digital infrastructure to support bike parking or to keep people up to date with travel schedules.
Simkó and Mattsson, 2019	Review of empirical papers written in English up to the end of 2018 (n=94)	International	Exposure to higher frequency 5G	Adults	Exposure conditions, frequency ranges, dose levels.	The majority of studies (70%) show biological responses. The reactions occur both in vivo and in vitro and affect all biological endpoints studied. No firm conclusions drawn on the effects (health and biological) of MMW exposure in the higher frequency range and there are few studies on exposures between 6-100 GHz. No consistent relationships between the density of power, length or frequency of exposure and the effects.
Bailey et al, 2020	Single experiment on one 5G transmitter	USA	5G small cell transmitter mounted on a telephone pole, transmitting at 39 GHz	Radio frequency	Measured radio frequency exposure from 5G small cell transmitter.	The radio frequency is low and diminishes quickly over distance 'the RF signal at a middle distance from a 5G small cell antenna is roughly 5 times lower than a cordless phone and 20 times lower than a cell phone, both of which are typically used close to the body, but is higher than some other common sources of RF.'

Chapter 7 evidence table: Energy Infrastructure

Table 16 Evidence table for studies examining impacts from renewable and green energy technology.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Bidwell, 2016	Before and after study and quantitative survey	Michigan, USA	Potential wind farm development. Information of wind farm technology	Residents of coastal communities	Whether residents who had/had not received information were in support or opposition of wind farm development	People who attended the information events were significantly more enthusiastic about wind energy development than the control group who did not attend events.
Devine-Wright and Howes, 2010	Two case studies involving questionnaires (457), in-depth interviews and focus groups (33)	North Wales, UK	Proposed large scale offshore wind farm	Residents of two coastal towns who would be affected by the proposed development.	Thematic analysis with a particular focus on place attachment and symbolic meanings, as well as interpretive, evaluative and behavioural responses towards the proposed project.	The town with greater place attachment believed the industrial scale offshore wind farm would be more of a threat than the second town which had lower place attachment.
Devine-Wright, 2011	Case study – mixed methods	Northern Ireland, UK	Tidal energy project	Residents from the area local to the tidal energy project.	The study examined place related symbolic meanings and strength of place attachment, as well as emotional responses. Measures: Place attachment measured on- 8 point scale of place-attachment. Emotional response measured by asking residents to select how they felt about the project from 10 emotional descriptors.	Greater place attachment positively correlated with project acceptance whilst social-demographic variables did not predict the level of project acceptance. There was a lack of local opposition to the project and much public support for tidal energy. This study makes a unique contribution in examining positive relationships between place-attachment and large-scale renewable energy development. The results support McLachlan's (2009) claim that development companies proposing renewable energy projects should take emotional bonds and place related symbolic meanings into account when planning and implementing land-use changes and engagement with affected communities. P.342.

Table 17 Evidence table for studies examining impacts from air pollution related to energy generation.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Johnston et al, 2013	Before and after, Longitudinal comparison-Two cases (one with intervention, one without) Time series analysis of daily mortality rates.	Australia	Biomass Interventions in Town one: educational campaigns, enforcement of environmental regs, and a wood heater replacement programme. Town two had no intervention.	Health information of residents from the two case study towns.	Changes in daily mortality rates in Town one and two over the 6.5 year period before and after Town 1's interventions in 2001.	Periods of improved air quality were associated with small reductions in annual mortality. The results were more significant for males. There were no changes in mortality in the control city with no interventions. Decreased air pollution from biomass smoke was linked to reduced mortality in males (specifically reduced mortality from cardiovascular and respiratory causes during winter months).

Table 18 Evidence table for studies examining impacts from community and localised energy generation.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Cuesta-Fernandez et al, 2020	Case study Interviews (18)	Spain	Renewable energy co-operative.	Members of an energy co-operative.	Reported benefits and challenges of the case study energy co-operative. Wider commentary on the size, focus and values of energy co-operatives and the role in energy transitions.	Scale is identified as an important consideration in energy transition. Physically proximity to co-op participants is believed to be important, whilst capacity is also seen as a key factor. The case study participants identify that larger national co-operatives are less able to engage members and act democratically, whilst localised co-ops can support member participation. The study also concludes that local energy co-operative are more likely to engage a broader demographic, compared to national co-ops that tend to attract middle class members and focus primarily on ecological impact rather but less on other factors such as fuel poverty.
Walker et al, 2017	Cross-sectional, quantitative. Survey of 229 households.	Torbay, UK	Information regarding a hypothetical off-shore wind farm.	Residents	Perceptions of residents based on two ways of framing community benefits from off-shore wind farm: 1: written in policy 2: as negotiation with developers.	Community benefits should be institutionalised when developers want to carry out unpopular energy projects. If communities are to believe that they are getting a “good deal” through the siting of wind farms, then this needs to come through government legislation and not discretionary acts by developers.
Islar and Busch, 2016	Comparative case studies.	Samsø, Denmark) and Feldheim, Germany	Community energy project	People involved in local energy transition.	Residents motivations.	Economic resilience was a motivation in both cases. Creating local jobs and reducing energy costs were important to participants. Feldheim (Germany) Still has some issues to resolve around grid management, distribution of costs and peak load management. The transition success is largely attributed to the feed in tariff which enabled decentralisation of energy to municipalities. Samsø (Denmark)- has transitioned to fully renewable energy supply- primarily through wind power (and to a lesser extent solar and agricultural waste). The main motivation at the beginning was economic development through job creation and boosting local economy. Farmers, the Municipality, co-operatives were able to invest in wind turbines. The transitions began with domestic energy projects then expanded to heat-plants and networks.

Table 19 Evidence table for studies examining impacts from fuel poverty.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Lorenc et al, 2013	Before and after study. Interviews	West London, UK	Providing information and advice on energy tariff switching to research participants.	150 participants- the majority were financially disadvantage (income below UK average).	Decision to switch or not switch energy tariff.	The study found high levels of apathy towards tariff switching despite the financial and health implications. Individually tailored advice improved uptake of switching. The finding identify the need for public health and local government to be involved in supporting people to make energy switch.
Mohan et al, 2018	Difference-in-difference regression modelling. Pre and post Neighbourhood Renewal (NR) policy in one NR area and two non- NR control groups.	Northern Ireland, UK	NR policy (which included energy saving measures such as increased insulation, double glazing, heating conversions.	3458 residents 775 (22.4%) living in NR areas.	Fuel poverty of people living in both areas was measured pre of post NR policy (mean annual household income and mean annual household fuel spend). The presence or absence of the intervention (NR policy) was the 'parallel trends' assumption (for comparison).	Generally, there was a greater overall reduction in fuel poverty in areas of NR compared to the control groups. This was particularly prevalent in males (7.5% decline), and owner occupiers (7.3% decline). There was no statistically significant difference in fuel poverty for women in the NR area and control groups.
Liddell and Morris, 2010	Review of literature (5 large scale studies)	Developed countries (UK and New Zealand)	Studies looking at the impact of tackling fuel poverty on health.	5 x case studies (criteria for inclusions- over 2000 participants, between 2000-2009).	Physical health outcomes. Mental health outcomes. Participant demographics.	Minimal evidence that reducing fuel poverty leads to improvements in respiratory health (even in children who had a diagnosis of asthma). However, studies did document reduction in the severity of symptoms reported in patient/parent diaries. Additionally, children living in fuel poverty had increased school attendance after heating interventions. After 3 years the majority of evidence of change is self-reported. Clinical evidence may take longer to be seen (if at all). There was more evidence of positive impacts on children's (non respiratory) physical health from tackling fuel poverty- including weight gain, hospital admissions. Improvements to mental health were recorded for both children and adults. There were more significant than physical health improvements. Study highlights the importance of differentiating between perceived improvements and demonstratable ones.

Reference	Study design and follow-up	Location	Intervention or type of infrastructure	Population and comparator	Outcomes	Results
Heymen et al, 2011	Longitudinal (4 year) quantitative study	North East England, UK	Energy and heating interventions	People living in fuel poverty (and one control group of people not living in fuel poverty).	Energy efficiency in homes was measured through Standardised Assessment Procedure (SAP) annually. Measures included room temperature, fuel costs, satisfaction with home warmth and a range of other health indicators.	Very little evidence of physical health improvements associated with interventions. The timeframe for improvements was small but some change was expected). The notable improvements related to increased scores on the social functioning scale. Warmer rooms led to more people socialising in their homes- which facilitated social relations. Study concluded that there is yet to be any clear relationship drawn between fuel poverty interventions and physical health improvements from the UK and other countries with comparable housing stock.
Cotter et al, 2012	Qualitative case study Postal and online survey (722)	Ireland	Being asked about their experiences	Older people	Physical and mental health experiences of people in periods of cold weather.	Half of the people in the project sample reported that they had to forego other household necessities to be able to heat their homes. A total of 62% of participants reported being concerned about the costs of heating their homes. Homes that did not have central heating and had damp and draughts were not commonly associated with those that were experiences as 'too cold'. The study identified that common responses to cold housing included staying indoors, keeping the heating on, eating hot food and drinks. The study found links between living in a cold home and physical health, including higher levels of chronic illness and falls, as well as mental health implications including higher levels of loneliness and lower levels of participation in social activities.