eftec

The Economic Case for Investment in Natural Capital in England:

AIR AND URBAN APPENDIX

Final Report

For the Natural Capital Committee

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URBAN GREEN SPACE EVIDENCE BASE

SUMMARY

There is strong evidence that the availability of accessible green space is important for mental and physical health. Based on the evidence reviewed, there is a strong case for improving the quality of existing areas, and where this is insufficient, expanding the provision of green spaces. The benefits can be increased through better coordinated management so green spaces function as a network, not only providing health benefits, but also helping regulate the local climate and water runoff and absorb air pollution.

According to CABE (2010) approximately 75% of the population in England does not have access to an area of greenspace of 2ha within 500m of their home. Only 40% of people visit green space at least weekly, but over 95% of people think that it is very or fairly important to have green spaces near to where they live (Defra, 2009). There is also evidence that improving green spaces increase their use. For example, HLF-funded improvements to parks have increased their use by 68% (HLF, 2009). Pilot health schemes that utilize green space (e.g. Walking for Health, Green Gyms) have expanded rapidly, but are still only available to a fraction of the population.

The costs of managing green space are relatively modest. Average spend on managing public green space is approx. £9,000 per ha per yr[1]. However, the costs of increasing the area of green space are very variable, as they depend on the demands for land which are location specific. Benefits from existing green space can be increased by improving its quality without increasing its size. For example, current modelling in a large city in the UK (eftec, pers. comm., December 2014) suggests that without any change in land use, enhancement of existing green spaces and waterways would increase the population of the city with proximity to green space by around 15%. This suggests that increased provision of green space can be achieved without major actual or opportunity costs.

The benefits of providing accessible green space largely arise from improvements to human health. The health costs associated with physical inactivity and mental illness currently total between £80bn-115bn/yr in the UK (Walking for Health (2014) and Mental Health Foundation, 2010), or approximately 5% of GDP. Access to green space creates opportunities for people to undertake physical activity, and is linked to reductions in physical and mental health symptoms. Some of these benefits are the direct result of exposure to green space. Others require active use of green space, which needs the encouragement from the health service (e.g. by GPs prescribing exercising outdoors). These complex impact pathways and a lack of integration between management of green space and public health services mean there is limited evidence on the relationship between changes in green space and health. This issue requires further longitudinal medical (rather than cross-sectional environmental) research.

There is a range of economic information on the costs and benefits of measures to protect and improve urban green space. However, it generally consists of local-scale costs and national-scale estimates of the benefits of addressing health problems across the population. Thus cost and benefit estimates linked to a given set of actions that can used to analyse a specific investment case, are not available. The available evidence can only guide the development of investment options in specific local circumstances.

Multi-disciplinary research and green space management initiatives are required to develop:

[1] Source: confidential local government data.

- Investment options for better quality green space, and more green space where local provision is insufficient, and
- Better coordination between different stakeholders responsible for green space and public health.

Investment in provision of green space has relevance across England. The health benefits are very local, and hence there are low, if any, diminishing returns to actions in different communities. The potential mental and physical inactivity health costs that green space can help address are more prevalent in lower income communities, but are relevant to all sections of society.

Example: Benefits of Moving to a Greener Area

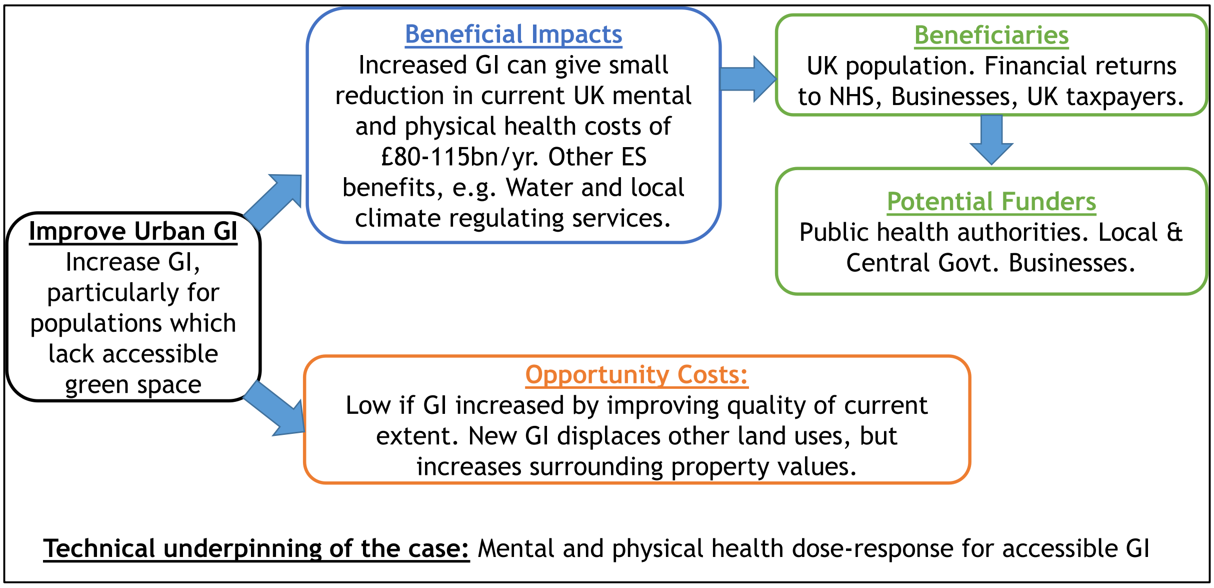
A recent study (White et al, 2013) on the effects of moving house has found that individuals have both lower mental distress and higher well-being when living in urban areas with more green space. While the effect at the level of the individual was relatively small, the cumulative benefit for urban populations is likely to be significant. The study used data over 18 years, took into account prior psychological health, and controlled for other potential explanatory socio-economic variables. In the study sample of over 10,000 individuals, individuals had both lower mental distress and higher well-being when living in urban areas with more green space, reflecting previous findings on better mental health in greener urban areas. Moving to greener urban areas was associated with small but sustained mental health improvements, suggesting that environmental policies to increase urban green space may have sustainable public health benefits.

1. INTRODUCTION

Urban green space is sometimes referred to as part of 'Green Infrastructure'. This is defined as "*a network of green spaces, water and other natural features within urban areas*" (Wentworth, 2013). Connecting green spaces is an integral part of green infrastructure and should seek to achieve "the linking of parks and other green spaces for the benefit of people" and "the linking of natural areas to benefit biodiversity and fragmentation" (Benson & Roe, 2007).

This analysis reviews the extent to which the available evidence supports increased investment in greenspaces. It focuses on health and wellbeing benefits that can be generated by investments in accessible semi-natural urban green space, as shown in Figure 1.1. However, it is recognised that urban green space can provide a wide range of ecosystem services (carbon sequestration, air and noise pollution control, local climate regulation (reducing urban heat island effect and wind speeds) and water quality and quantity regulation) and other values (such as social cohesion and property values). For example, a recent study in Birmingham (Holzinger et al, 2012) estimated the value of the ecosystem services provided by Birmingham's green infrastructure at £11.7m annually. This figure corresponds to the benefits of wild species diversity, recreation, aesthetic values and sense of place, cultural heritage and spiritual values, flood regulation, storm buffering and water quality regulation. The study highlighted the uncertain and partial evidence base for this valuation, and regarded the value obtained as an underestimate.

Figure 1.1: Urban Green Infrastructure (GI) investment value chain.



Following this introduction, Section 2 provides information on the quantity and quality of, access to, uses of, and spending on, urban green space in England. Section 3 illustrates some of the investments that can improve urban green space, while Section 4 provides evidence on the benefits of such improvements.

2. URBAN GREEN SPACE IN ENGLAND

Quantity, quality, location and access are key determinants of the value urban green space generates. All these aspects are reviewed here at the scale of England. Also reviewed is evidence on the uses of and spending on urban green space.

2.1 Quantity of urban green space

In 2006, over 80% of England's population lived in an urban environment (NAO, 2006); defined as towns and cities of over 10,000 people. The 'green space' in the urban areas includes parks and public gardens, playgrounds, some outdoor sports facilities, and allotments, corridors along rivers, urban forests and green wasteland. These account for 14% of urban space (NAO, 2006). These areas require ongoing maintenance and repair. In 2006 it was estimated that £693 million was spent each on urban green spaces in England. CABE (2010) state that the historic decline in the quality of urban green space has been reversed, and this is encouraging greater use of them. However, local availability and quality of green space is still variable across the country.

The Public Parks Assessment (PPA) carried out a survey of urban green spaces in England in 2001 and estimated that there were 14,600 urban parks, covering a total of 69,500 hectares (CABE, 2010). Table 2.1 gives us an indication of the types of green space in urban authorities in England. It is currently not known how much of this urban green space in England is publically accessible. HLF research reports that there are 1.8 billion visits to parks in England every year (CABE, 2010).

Table 2.1: Inventory of Green Space in Urban Authorities in England

Green space type	Count	Area (ha)
Allotments	997	1,357
Cemeteries	1,643	3,679
Community Farms	197	473
Country Parks	72	5,757
Doorstep Greens	82	140
Golf Courses	361	5,721
Grass pitches	10,243	8,170
Millennium Greens	91	165
Nature Reserves	663	14,308
Parks	1,770	52,243
National Trust	128	14,573
Total	**16,247**	**106,550**

Source: CABE (2010)

As Table 2.2 illustrates, the average amount of green space for urban areas in England is 1.79 or 1.98 hectares per thousand people depending on which data source is used. The table also shows that the distribution of this average varies across the different regions of England: the South East, South West, and East Midlands have relatively high areas of green space per thousand population compared to areas such as London and the West Midlands that have less green space.

Table 2.2: Green space per thousand population

Region	Green space (ha) per thousand population	
	CABE inventory data	CIPFA and MYB data
North East	1.77	1.55
Yorkshire and Humber	1.82	1.83
North West	1.61	1.86
East Midlands	1.92	3.25
West Midlands	1.36	1.67
South West	2.45	2.70
East of England	1.49	2.37
South East	2.86	3.25
London	1.24	1.24
Average (mean)	**1.79**	**1.98**

Source: CABE, 2010
(CIPFA=Chartered Institute of Public Finance and Accountancy Leisure, culture and recreation statistics (2007/08) and MYB= Municipal year book

2.2 Quality of urban green space

The quality of green space is important as it determines the access to and hence benefits of the area. Green spaces that are in a state of disrepair (broken infrastructure, dead plants, graffiti, litter and so on) are less likely to be visited as they are perceived to be less safe (NAO, 2006). Despite being theoretically accessible, they are less likely to be used. While not all benefits of green spaces are dependent on access and use, links to human health largely are, making quality of green space a crucial determinant of benefits.

There are currently no national standards or criteria for measuring the quality of open spaces. However, measures such as user perceptions and rating (subjective), and expert created measures like Green Flag[2], which reflects biodiversity in green spaces, can be used.

In terms of user ratings, CABE (2010) found that nationally, one in ten urban local authorities has satisfaction levels for green and open space of less than 60% (nearly half of these are London boroughs). One in ten urban local authorities has satisfaction scores of above 85%. Deprived communities have seen less improvement (and have lower satisfaction scores) of their green and open spaces. Over 80% of respondents in affluent areas were satisfied with their urban green spaces, compared with around 50% in the most deprived areas. In addition, young people between 16 and 24, report lower satisfaction with the quality of green space. 15% think that parks and open spaces are the aspect of their areas that need improving, compared with 8% of 55-74 year olds.

CABE (2010) also found that:

- The provision of parks in deprived areas is worse than in affluent areas;
- People from minority ethnic groups tend to live in areas with less local green space of poorer quality;
- The quality of green space is worse in areas with high levels of social renting and those that are long term sick, disabled people and unemployed people all report worse quality;
- The most affluent 20% of wards have five times the amount of parks or general green space (excluding gardens) per person than the most deprived 10% of wards, and

[2] The Green Flag Award® Scheme recognises and rewards the best green spaces in the country. The Scheme is licensed to Keep Britain Tidy by The Department for Communities and Local Government (DCLG) who own the Green Flag Award Scheme. http://www.greenflagaward.org.uk

- People who are not working because of unemployment or sickness (markers of deprivation) tend to live in areas with a lower quantity of green space.

It is recognised that the correlations in this data are not necessarily indicative of causality between the factors involved. Nevertheless, the outcomes in terms of use of green space do have significant implications for public health.

Research from the Heritage Lottery Fund (HLF) shows that parks that have been restored with money from the fund have increased their visitor numbers, on average by 68% (HLF, 2009), suggesting that links between quality of the space and its use are strong. In 2009/10 there were 594 urban parks which received a Green Flag awards award. 81% of urban authorities had one or more green flags, but this covers less than 5% of the estimated 14,600 in England.

2.3 Access to urban green space

The ANGSt standards[3] developed by Natural England are most commonly used to measure proximity to urban green space. ANGSt is a tool to assess the current levels of accessible natural green space[4] and plan for better provision. It identifies those sites that might be considered natural sites, and areas within other green spaces that have a value for nature. More importantly it identifies areas where the standard is not met and where actions may be put in place to address this. Figure 2.1 shows the percentage of households that meet the most local measure in the ANGSt standard, i.e. live within 300 metres to a natural green space of at least 2 hectares.

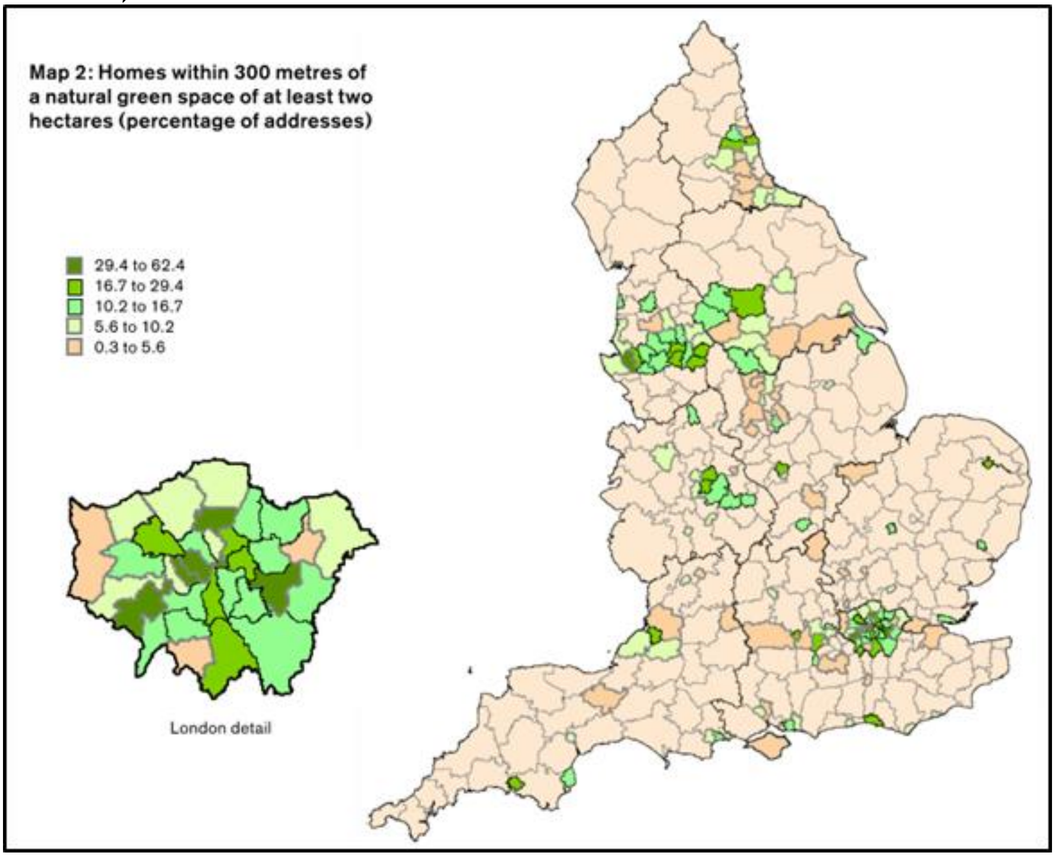
[3] Access to the natural environment varies considerably throughout England. ANGSt has set a range of standards to address this. It recommends that everyone, regardless of where they live, should have an accessible natural green space:

- Of at least 2 hectares in size, no more than 300 metres (5 minute walk) from home;
- At least one accessible 20 hectare site within 2km of home;
- One accessible 100 hectare site within 5km of home; and
- One accessible 500 hectare site within 10km of home; plus
- A minimum of one hectare of statutory Local Nature Reserves per thousand population.

http://publications.naturalengland.org.uk/publication/40004?category=47004

[4] 'Natural' is defined as places where human control and activities are not intensive so that a feeling of naturalness is allowed to predominate. There are typologies of natural and semi-natural greenspace (Natural England, 2010), but it usually exists within larger areas of green space.

Figure 2.1: Households within 300 metres of a natural green space of at least 2 hectares (% of addresses)



Source: CABE (2010)

The highest proportion of households that meets this standard is in the West Midlands (17%) and North West (17%), followed by London (16%). The areas with the lowest proportions meeting the ANGSt standard are in the South East (8%), and Yorkshire and the Humber (7%). Table 2.3 shows the percentage of households that live within 300 and 500 metres of a natural green space.

Table 2.2: Percentage of homes within 300 and 500 metres of a natural green space

Region	% of homes within 300m of a natural green space of at least 2ha	% of homes within 500m of a natural green space of at least 2ha
North East	8.4	17.5
Yorkshire and the Humber	7.4	15.9
North West	16.7	32.9
East Midlands	9.6	20.5
West Midlands	18.0	35.0
South West	13.6	24.9
East of England	11.8	23.6
South East	7.9	15.0
London	15.9	30.4
England	**12.9**	**25.4**

Source: CABE (2010)

2.4 Use of urban green space

The mental and physical human health benefits of using green spaces are determined by how frequently individuals visit such spaces, the activities they undertake during these visits as well as the quantity and quality of green space.

Historically lack of user and use data for open-access green spaces has hindered investment cases for such spaces against other local facilities for which user data exist (e.g. swimming pools, libraries). To address this gap, there have been attempts to create/define indicators to represent use and condition of urban environments. The MENE survey (Natural England, 2012) collects data, on a monthly basis, of people's use of the outdoors to contribute towards the indicator 'Percentage of people using outdoor places for exercise/health reasons'. This data showed that, during 2011/12, an average of 42% of the adult population in England visited the natural environment at least once over the previous seven days. This is a similar level to that identified in CABE (2010), as shown in Table 2.4, which shows 40.7% of people using parks and green space at least once a week. Table 2.4 shows that people in London and the south of England use (urban and rural) green space more often than people in the north of the country, which is similar to the pattern found by the quality indicators. Quality and frequency of use are generally higher in the south, and poorer in the north — and the two are likely to be related (CABE, 2010).

Table 2.4: Percentage of people using parks and green space by frequency of use

Region	Daily	Weekly	Monthly	Twice yearly	Yearly	Less than yearly	Never
North East	12.0	24.1	20.7	17.8	9.7	7.3	8.4
Yorkshire and the Humber	10.5	23.0	21.4	18.6	10.1	8.2	8.3
North West	12.0	26.5	20.6	17.0	8.7	7.1	8.1
East Midlands	13.3	25.6	20.7	16.3	9.3	6.9	7.9
West Midlands	11.5	24.7	20.9	16.9	9.3	8.2	8.5
South West	16.2	30.3	20.9	14.7	7.4	5.2	5.3
East of England	14.7	26.7	21.2	16.5	8.5	6.5	5.8
South East	16.2	30.0	20.9	15.2	7.1	5.0	5.6
London	16.7	31.9	21.4	13.5	6.3	4.6	5.6
Average	**13.7**	**27.0**	**21.0**	**16.3**	**8.5**	**6.6**	**7.1**

Source: CABE (2010) Best Value Performance Indicator (BVPI) data

Levels of physical activity are positively correlated with affluence. The most deprived wards have only 40% of adults doing moderate physical activity regularly, while this rises steadily across affluence bands to almost 60% in the most affluent. As a result, there are opportunities to improve public health through greater physical activity in all income groups.

Given the strong correlations between the quality and quantity of spaces and the levels of physical activity of residents, investments should be designed to both improve the condition of greenspaces, and take additional steps to encourage increased physical activity. Recent initiatives such as Green Gyms[5] and Walking for Health, which have expanded rapidly, but still cover only a small proportion of the population. There is a now Green Gym in every London Borough, but some counties have only a few. Walking for Health now offers over 3,000 free, short walks every week[6].

2.5 Spending on urban green space

CABE (2010) used data from CIPFA's leisure, culture and recreation statistics for 2008/09 to calculate spending on green space per head of population. This data suggests spending appears to be relatively high in the North East and to a lesser extent the East Midlands and relatively low in

[5] Green Gyms are practical projects to manage local green spaces which are specifically designed to benefit participants health. http://www.tcv.org.uk/greengym/what-green-gym

[6] http://www.walkingforhealth.org.uk/

the South West and London. This pattern of spend does not correlate with the levels meeting the ANGSt standard show in Table 2.3. However, there may be other factors, such as economies of scale with population density, influencing this pattern.

The data from CIPFA suggests that the average spend per person is approximately £17 a year. Data on spending is also available from CABE's Local authority green space skills survey (2008) which provides figures across 23 urban authorities. This reveals per head spending of between almost nothing (less than £1 per person a year) and £30 per person a year on parks. The average spend across the 23 authorities is approximately £15 per person a year.

3. IMPROVING URBAN GREEN SPACE

Improving urban green space involves increasing its quantity, improving its quality and encouraging better access and use by individuals.

Opportunities for increasing the quantity of urban green space are often connected to a new development or other changes in land use. Increased provision of green infrastructure may not always be feasible, however, particularly in densely developed urban areas. Nevertheless, there are exceptions to this. An example of a large scale project is the Queen Elizabeth Olympic Park, which is one of the largest parks built in the UK this century. Comprised of 45ha of wildlife habitat contained within 102ha of open land, the park further extends out to existing green space creating links with the surrounding area (Neal, 2011).

Increased provision of benefits from natural green space can also be achieved by improving the quality of green space, by addressing the pressures that affect it. These include lack of maintenance, anti-social behaviour, demand for land for development, relaxation of planning controls, impacts of increased air and noise pollution. Quality of green spaces is also reduced when they are inaccessible to the public; lack flora and fauna diversity; and lack management.

The following provides some examples of actions that can address these pressures and hence improve urban green spaces. Overall, these actions (and their costs and benefits) are extremely variable because they are dependent on the current land use and cover.

Urban Trees

Many of the benefits from urban green space result from the presence of a diverse vegetation structure, in particular trees. Forest Research (2010) identifies a range of case studies, all of which demonstrate some actions taken to improve public spaces including by planting of trees and raised beds, drainage works and community engagement. For example, as a result of the Mayor's Street Tree Programme (MSTP), 10,000 street trees were planted throughout London between 2008 and 2012. By March 2015, the MSTP aims to plant an additional 10,000 trees to improve local neighbourhoods (Greater London Authority, undated).

Waterbodies

River restoration can play a positive role in creating green space and in urban regeneration, particularly where it focuses on improving the quality, structure and function of river environments (Environment Agency, 2006). Numerous projects have been undertaken to restore stretches of urban rivers, 64 case studies of which (not all urban) can be found in the "Manual of River Restoration Techniques", as well as numerous case studies from North London (Environment Agency, 2006).

Within urban settings, river channelisation is one of the major problems. A key action for many projects has therefore been to remove the hard banks (usually concrete lined) of straightened channels to be replaced with earth banks. This in turn, allows the re-meandering of rivers along their original or other a more natural route. Re-meandering of rivers re-creates a connection between the rivers and their corridors, as well as their floodplains. As a result, there is an increase in the diversity and abundance of terrestrial and aquatic habitats and fauna. Furthermore riparian vegetation has been recognised to affect the strength of river banks and increase the hydraulic resistance of the floodplain. When floodplains are reinstated; this provides a natural increase in the storage capacity of the entire river, thus reducing risk of flooding. Physical improvements to the river and surrounding area over time also help to improve water quality (Environment Agency, 2006; Teske, 2013). Whilst regulating ecosystem services are improved, cultural services are also re-established. Improvement of the aesthetics, diversity and accessibility to rivers and the surrounding area provides local communities with green space. However, such investments are often capital intensive.

Green Roofs

It is estimated that there is at least 200 million m^2 of roof space in the UK (Green Roof Guidelines, undated) and in most developed cities, roofs account for approximately 40-50% of the impermeable urban surface area which contributes to storm water runoff (Stovin, 2010). Retrofitting green roofs is not always practical, for example being constrained by the strength of the existing roof structure. Yet, it is thought that concrete roofs in the UK could support green roofs without any requirement for structural modification (Stovin, 2010).

Green Roof Case Studies from the City of London Corporation (2011) show that, irrespective of size, green roof installations transform of the use and/or functionality of the roof area. Oberndorfer et al. (2007) identified three main functions which are provided as a result of green roofs:

- Storm Water Management: A simulation study by Buccola & Spolek (2011) found that an increase in green roof soil depth improved water retention, delayed storm water runoff and normalised pH of rainwater independent of plant type (the latter also independent of soil depth).
- Energy Conservation: A review by Saadatian et al. (2013) found energy saving capabilities of green roofs is dependent on type of green roofs, depth and composition of the growing mediums, type of climates, plant selections, type of irrigations and insulation specifications.
- Urban Habitat Provision: In London green roofs have been shown to attract invertebrates, including rare species (Kadas, 2006). Another study found bat activity to be significantly higher over biodiverse, green roofs in comparison to conventional roofs (Pearce & Walters, 2012).

In relation to urban heat intensity, a study by Smith et al (2011) showed that green roofs can reduce temperatures in urban environments as much as 3ºC due to the ability of vegetation to increase albedo and evapo-transpiration. Finally, The City of London Corporation (2011) also demonstrates that some green roof installations can provide new amenity spaces for public or private use, as well as providing aesthetic value to the building.

4. BENEFITS OF IMPROVED URBAN GREEN SPACE

This section examines the evidence on the impacts of urban green space on mental and physical health.

4.1 Mental Health

In the UK, it is estimated that 16.7 million people, or around 26% of the population, suffer from mental health problems, the most common of which being depression experienced by 8% – 12% of the adult population. It is also estimated that approximately 10% (~850,000) of children and young people aged between 5 and 16 have mental health problems. More conservative estimates put the number experiencing mental illness near one in six people or over 16% (mentalhealth.org.uk).

The positive impacts on wellbeing resulting from the exposure to green space have the potential to alleviate some of these associated large medical and social costs. There is strong evidence from a large number of high-quality studies spanning several years that green space alleviates stress, fatigue and other mental health issues, with positive effects on mood, concentration, selfdiscipline, and physiological stress (see, for example, Health Council of the Netherlands, 2004; Kaplan and Kaplan, 1989; Halpern, 1995; Berman et al., 2008; Ulrich, 1984; Ulrich et al., 1991; Grahn and Stigsdottir, 2003). This effect was found to be especially marked for residents in large urban areas, and in particular for children and young people (Kaplan, 1995; Taylor et al., 2001). Similar effects can be found when people have contact with nature in work, as revealed by a study by Largo-Wright et al. (2011) of university staff in the south-eastern US (eftec and CRESR, 2013).

4.2 Physical Health

The links between green space and physical health improvement are dependent on the amount and frequency of visits that people make to green spaces. Green space may act as a catalyst for physical activity, as a number of studies have noted that people living in areas close to accessible green space have a higher propensity to take moderate exercise that leads to enhanced physical health (see for example Jones et al., 2009; Mitchell and Popham, 2008; Kuo and Sullivan, 2001a; Nielsen and Hansen, 2007; Takano et al., 2002; Pretty et al., 2003). Access to local, safe and natural green space can help individuals sustain higher levels of physical activity, as the motivation to continue physical activity schemes is more likely to be sustained through the natural environment. Activities in which exercise becomes secondary to environmental or social benefits (e.g. Gardening, Green Gym or walking in green space) appear to be more sustainable than activities in which exercise remains the primary driver (Bird, 2004).

In the US the various studies by the Trust for Public Land (Table ***4***.4.1) have produced estimates for cost savings with respect to medical care and public health from green spaces. These were derived by applying a set of annual figures for over and under 65s to survey findings in terms of residents' use of local green space, with the results representing the difference in health care costs between active and inactive people.

Table 4.1: Estimated monetary value of benefits of US city parks

City/Area	Pop'n (m)	Park area (acres)	Prop'rty tax ($m)	Sales tax ($m)	Net income ($m)	Health benefits ($m)	Water/ drainage ($m)	Air quality ($m)
Wilmington, DE	0.07	444	1.08	0.13	0.72	4.32	0.41	0.04
Seattle, WA	0.61	5,400	14.77	4.39	30.03	64.09	2.31	0.53
Philadelphia, PA	1.53	10,334	18.13	5.18	40.26	69.42	5.95	1.53
Mecklenburg Co., NC	0.92	17,600	3.91	4.37	18.77	81.49	18.89	3.89

Sources: Trust for Public Land (2008; 2009; 2010; 2011).

However, other research that has examined the relationship between exercise levels, health improvement and physical distance to green spaces has produced mixed results. Coombes et al. (2009; 2010) found a positive relationship between levels of activity and proximity to a formal park, even when controlling for respondent and area characteristics. Those living further from green spaces were less likely to meet guidelines on physical activity levels and were more likely to be overweight or obese. Conversely, in an earlier study Hillsdon et al. (2006) found no significant relationship between distance to and quality of parks on the one hand, and activity levels on the other. Maas et al. (2008) could find no consistent relationship between the amount of urban green space and whether or not people living in the area met the Dutch public health recommendations for physical activity.

4.3 Economic Implications of Health Improvements

There is also an emerging body of evidence linking improved mental and physical health to economic impacts. Literature, including Mourato et al. (2010), identifies four main types of economic benefits arising from improved health:

- Cost savings to the National Health Service (NHS);
- Increased economic output due to a reduction in ill health (morbidity), stress and absence from work;
- Increased economic output due to a reduction in the incidence of premature death (mortality); and
- Avoided cost of pain and suffering associated with ill health.

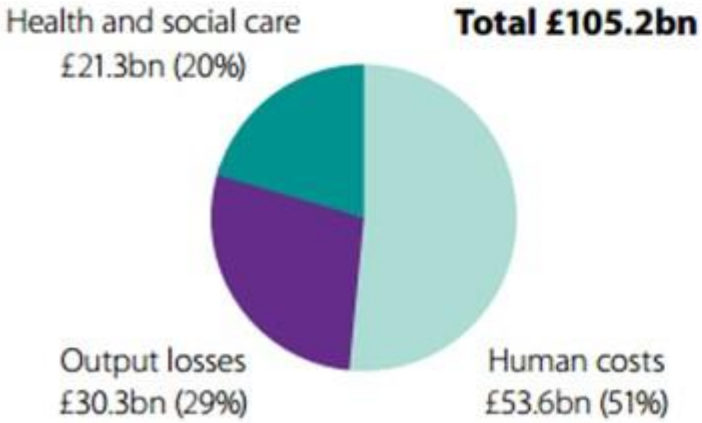
The potential national economic benefits of improved public health as a result of improving the availability of accessible urban green space are not known. However, the improvements in health described in Sections 4.1 and 4.2 can result in savings by reducing the total costs of physical and mental ill-health. Notably, relatively small improvements in health can potentially result in significant savings, as the costs of ill-health to society and the economy are substantial.

Walking for Health (2014) estimates that physical inactivity could be costing England's economy up to £10 billion a year in healthcare costs, premature deaths and sickness absence from work. These estimates include direct costs to the NHS of between £1 billion and £1.8 billion (in 2007), implying an average of £6.2 million a year spent by each Primary Care Trust (PCT).

In 2010, the total economic and social cost of mental health in England was estimated by the Mental Foundation (2010) to be between £70 - £105 billion (which is, assuming 16.67% of population with mental illness, between £7,923 - £11,884 per afflicted person). Sickness absence from work as a result of poor mental health accounted for around £8 billion of this total, or around £905 per person with mental illness based on 70 - 113 million working days missed (equivalent to 2.8 days per UK employee) (The King's Fund, 2012; Mental Health Foundation, 2010). Estimates from Walking for Health (2014) and Mental Foundation (2010) therefore suggest an overall cost of physical inactivity and mental health in England of between £80-115 billion per year.

The breakdown of costs as a result of mental illness are show in Figure 4.1 (OECD, 2014; Davies, 2014; The King's Fund, 2012; Mental Health Foundation, 2010; and Faculty of Public Health, 2010), or 4.5% of the UK's GDP.

Figure 4.1: Total cost of mental illness in England in 2009/2010



Source: Mental Health Foundation, 2010

Definitions of the categories shown in Figure 4.1 are:

- HEALTH AND SOCIAL CARE: NHS services, informal care, local authority social services, private expenditure on services, private expenditure on services, other public sector costs;
- HUMAN COST: the total QALYs lost each year (at £30,000 per QALY), including children, institutional populations, and premature mortality; and
- LOSS OF OUTPUT: sickness absence, non-employment, premature mortality, unpaid work) (Mental Health Foundation, 2010).

Poor mental and physical health has significant impacts on the UK's economic performance. Lost productivity, including amongst those present at work, costs £15billion per year, while replacing staff who leave as a result of mental health problems is estimated to cost £2billion (OECD, 2014; Davies, 2014; Faculty of Public Health, 2010). In addition, it is estimated that physically inactive people spend 37% more days in hospital and visit the doctor 5.5% more often.

It should be noted that there are complex interactions between physical and mental health issues, and therefore their costs to society and the economy. For example, depression has been linked to a number of chronic diseases such as coronary heart disease and cancer, and has more damaging long-term effects on health and wellbeing than angina, arthritis, or diabetes. Other physical diseases that have been associated with depression include osteoporosis, multiple sclerosis, immunological problems and arthritis (The King's Fund, 2012; and Mental Health Foundation, 2010). As discussed in Sections 4.1 and 4.2, it is widely reported that physical activity can increase mental wellbeing by improving self-perception and self-esteem, reducing stress and improving mood and sleep quality. These complex relationships can make distinguishing between changes in physical and/or mental health and their individual impacts difficult. However, the literature suggests that, in general, an improvement in either physical or mental health is likely to lead to some form of improvement in the other. Therefore, any policy or investment aimed at improving either of these aspects is likely to impact both. Likewise, a lack of investment which consequently leads to deterioration in either physical or mental health is likely to impact both.

5. CASE STUDY: LONGITUDINAL EFFECTS ON MENTAL HEALTH OF MOVING TO GREENER AND LESS GREEN URBAN AREAS

This study used British Household Panel Survey (BHPS) data from over 10,000 individuals living in urban areas in England to explore the relationship between green space and well-being (indexed by ratings of life satisfaction) and between green space and mental distress (indexed by General Health Questionnaire scores) for the same people over an 18 year period. The amount of green space available to each person was assessed at the Lower Super Output Area (or neighbourhood) level, using data from the Generalised Land Use Database (GLUD). The study found that individuals had both lower mental distress and higher well-being when living in urban areas with more green space.

This relationship is important to understand, because while benefits to an individual may be small, the cumulative benefit for urban populations is likely to be significant. The authors estimate that 77.7% of people in the 'more developed' regions reside in urban areas with reduced access to 'natural spaces', whilst in England, this figure is 80%.

If someone moved from an urban area with little green space to one with a lot of green space, it would be expected that, although their mental health may be better, on average, across the years following the move, this average improvement may reflect a number of possible temporal processes. In order to address these, Alcock et al. (2013) developed three scenarios about how moving to greener or less green areas may affect mental health over time:

- *Adaption hypothesis*: At first, an initial improvement in mental health may be observed, followed by a decrease in benefits as individuals adapt to their new greener surroundings and the novelty wears off.
- *Sensitisation hypothesis:* There may be little initial benefit from moving because, for example, it takes time to get to know where local parks are and to begin to use them. Only as these new opportunities are taken up does mental health improve gradually.
- *Shifting baseline hypothesis:* Mental health may improve directly following a move to a greener area and remain at a similar heightened level thereafter.

Knowing which of these is at work is important for two reasons. First, around 10% of households in most OECD countries, and 20% in the US and Nordic countries have relocated within the last two years, and thus issues of home relocation are important to millions of people annually. Second, patterns of how mental health may be affected by moves to greener/less green urban areas have different implications for planning policies through environmental interventions.

5.1 Method

Adult samples were drawn from the BHPS, a nationally representative longitudinal survey of over 5,000 UK households that ran annually from 1991 to 2008. The analyses investigated GHQ scores of two subsets of respondents: those who moved to greener urban areas, and those who moved to less green urban areas. Estimation samples were limited to residents in England. Relocations were restricted to those within urban areas to avoid confounding green space with urbanity.
The results were controlled for independent variables drawn from four LSOA socio-economic deprivation statistics derived from the English Indices of Deprivation:

- Income: based on social benefit data (higher scores indicate less deprivation);
- Employment: based on unemployment data (higher scores indicate less deprivation);
- Education: based on school performance, participation in higher education and working age adult qualifications (higher scores indicate less deprivation), and
- Crime rate index, based on the number of reported crimes (higher scores indicate more deprivation).

"Mental Health" was measured with the short-form twelve item GHQ, a self-report instrument used to aid diagnosis of disorders such as anxiety and depression. Scale scores were reverse coded in the analysis (i.e., Inverse GHQ) so that higher scores represented better mental health.

The level of greenness around pre- and post-move homes was derived from the Generalised Land Use Database (GLUD). The GLUD classification of high resolution land parcels was distributed to 32,482 lower-layer super output areas (LSOAs) across England, each encompassing approximately 1,500 residents (mean area c.4 km^2). Land use is divided into nine categories: green space; domestic gardens; water; domestic buildings; nondomestic buildings; roads; paths; railways; and other (largely hard standing) and area cover was accurate to approximately 10 m^2 at the time the data were collected (2005). Green space was defined as the 'percentage of land cover accounted for by "green space" and "gardens" combined'. On average, LSOA green space rose from 58% to 74% for individuals moving to greener areas, and fell from 74% to 59% for those moving to less green areas.

5.2 Results

On average, movers to greener areas were slightly older at the reference year (i.e. specified time before the move) (39) than movers to less green areas (37), more likely to be married (74% vs 63%), more likely to be retired (11% vs 8.5%), less likely to live in a detached house (11% vs 23%), and more likely to be non-commuters (30% vs 26%).

Movers to greener areas, who were currently living in less green areas, also had lower mean (inverse) GHQ scores at the reference year (9.78) than movers to less green areas, who were currently living in more green areas, (10.15). This baseline difference reflects previous findings related to better mental health in greener urban areas.

There was little change in the means and proportions of some of the control variables over time for both groups. Income, labour market status, household space and commuting time are relatively stable. Both groups show increases in the proportions married, highly qualified, living with children and in older age categories, and, among movers to greener areas only, with work-limiting health. House type also shows change over time in both samples.

Importantly, move motives were highly similar across the two samples. The most frequent motive was "larger accommodation" (n = 254), stated by 26% of those who moved to a greener area and 22% of those who moved to a less green area. Among movers to greener areas, only four respondents indicated that area greenness was a reason for the relocation though a few did include factors such as noise (n = 11) and traffic (n = 4), both of which may be related to local area green space.

For both samples mental health was lower when individuals had work limiting health problems and were unemployed. For movers to more green space, mental health was also lower when they lived in areas where the mean level of education was higher. Movers to greener areas showed no difference in GHQ in both time intervals leading up to the move, but a significant improvement in mental health for each of the three years post-move was experienced.

Movers to less green areas showed a significant decrease in mental health one year before the move compared to 2 years before the move, ($b = -0.34$, $P = 0.031$), but no significant difference for the three years post-move. This suggests that people appear to have adapted fairly rapidly to living in a less green area.

5.3 Discussion

These tests and controls suggested that for movers to greener areas, the shifting baseline hypothesis best fit the data: Mental health improved within a year and stayed approximately the same for the following two years. Results for movers to less green areas were less straightforward. The predicted decline in mental health for this group occurred before the move and was followed by rapid adaptation to the new circumstances. Move motivations were broadly similar across the two samples and employment related reasons, for instance, were rare among movers to less green space. Thus, at least with the current data, it is difficult to offer move motivation as an explanation for the findings.

5.4 Summary

Compared to pre-move mental health scores, individuals who moved to greener areas ($n = 594$) had significantly better mental health in all three post-move years ($P = 0.015$; $P = 0.016$; $P = 0.008$), supporting a “shifting baseline” hypothesis. Individuals who moved to less green areas ($n = 470$) showed significantly worse mental health in the year preceding the move ($P = 0.031$) but returned to baseline in the post-move years. Moving to greener urban areas was associated with sustained mental health improvements, suggesting that environmental policies to increase urban green space may have sustainable public health benefit.

6. CONCLUSION

There is evidence of correlation between greater provision of greenspace and its use, including for physical activity. These uses of green space are correlated with better physical and mental health of the population – a daily walk was recently described as a ‘magic health pill’[7]. As with any health intervention, a reduction in mortality or morbidity within the economically active population will increase their ability to participate in the workforce and contribute to a productive economy. Improved health and improved attendance at the workplace lead to enhanced productivity and subsequent increases in economic output and performance.

There is a range of economic information on the costs and benefits of measures to protect and improve urban green space. However, as the evidence generally consists of local-scale costs and national-scale estimates of the benefits of addressing health problems across the population. The current evidence base does not include studies that directly quantify increases in economic output resulting from physical and mental health benefits of green space. This area clearly requires further research, particularly in relation to the scale of labour productivity gains associated with reduced mental ill-health (at a variety of levels, from stress that may reduce productivity, through to conditions such as depression that result in absence from work).

[7] Dr James Brown. Lecturer in Ageing Metabolism. Aston University. pers. com. Oct, 2014.

Thus cost and benefit estimates linked to a given set of actions that can be used to analyse a specific investment case, are not available. The available evidence can only guide the development of investment options in specific local circumstances. This is partly due to the partial information available on the provision of urban green space, which both reflects and perpetuates under-investment in it.

Investment in provision of green space has relevance across England. The health benefits are potentially very large, and therefore a priority for further, multi-disciplinary, analysis. Key questions include developing the health impacts summarised in this evidence base, better measurement of availability, and the consequences of changing patterns of use of urban green space (e.g. over-crowding). The benefits are also very local, and therefore there are low, if any, diminishing returns to actions in different communities.

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AIR EVIDENCE BASE

SUMMARY

Air quality in England has steadily improved over recent decades and this is predicted to continue. However, significant impacts of continued pollution on human health and the environment will continue unless emissions are reduced further. Therefore there will be costs in future, due to the measures necessary to reduce emissions, and/or the impacts of remaining emissions (including costs of health treatment, reduced quality of life and premature deaths, and lower workforce productivity) , and impacts on the environment and the ecosystem services it provides.

For example, the effect of the smallest particulates (PM2.5) on mortality in the UK in 2008 was estimated to be equivalent to 29,000 premature deaths, valued at around £16 billion. In 2011, that was estimated to have risen to approximately 40,000[8] premature deaths. Emissions of ammonia, primarily from agriculture, are also high and cause significant damage to ecosystems and wildlife, with an estimated value of £630m per year in England[9]. There are further impacts from other air pollutants on ecosystems services with both market (e.g. agriculture - crop growth, animal health) and non-market (e.g. biodiversity) values which are not estimated.

Air borne emissions come from a mix of short range (local) and longer-range (regional) sources. This note reviews the evidence base on air quality improvements in the context of identifying potential investments in natural capital. The scope of the evidence mainly focuses on urban air pollution abatement (primarily from transport) and abatement of ammonia released through agricultural activities. Therefore, the pollutants of primary interest include: nitrogen oxides (including nitrogen dioxide), particulate matter, and ammonia. Sulphur dioxide, formation of ozone, and metals (such as lead, arsenic and cadmium) are not considered in detail, due to the complexity of the evidence base and/or being a lower priority for action.

The costs and benefits of tackling urban air pollution are significant but mostly poorly defined; the evidence available allows the case for reducing of ammonia emissions from agriculture to be examined in more detail.

Urban Air Quality

Further actions are needed to achieve air quality targets for some pollutants particularly in urban areas (e.g. for NOx and for particulate emissions in London by 2020). Reductions in air pollution beyond current targets will have significant health benefits - lower levels of air pollution improve the cardiovascular and respiratory health of the population, in both the long- and short-term[10]. The value of these benefits will be a reduction in the substantial current health and socio-economic (e.g. workforce productivity) costs of mortality and morbidity. Health benefits are higher for the elderly and the young, and in lower income groups where exposure is often higher. Exact health benefits depend on other health factors in the population.

The costs of reducing air pollution depend on the level of improvements and the type of measures taken. Potential measures to tackle air pollution include changes in transport technologies (e.g. cleaner buses), shifts in transport modes, and reduction of demand for transport. Further work is

[8] Simon Birket (founder and director of Clean Air London) stated in an interview that “30,000-50,000 people are dying early due to poor air quality” (EurActiv, 2011).
[9] See example on next page for computation.
[10] WHO Fact sheet 313 See: http://www.who.int/mediacentre/factsheets/fs313/en/

needed to understand the costs of potential measures – such as the proposed London ultra-low emissions zone (ULEZ). The existing trend for air quality improvement has been induced by ongoing policy actions, but this will not eradicate human health impacts, so there are additional benefits of further policy action beyond this baseline.

The marginal value of benefits of tackling air pollution does not diminish across time or space. There are health benefits in the short term for those who are directly affected by air pollution, but in the long term, there are likely to be greater changes in health and ecosystems that begin to be restored. In terms of spatial scale: the marginal value of health benefits in one urban area is not dependent on impacts in other locations. The marginal value of reducing air pollution are likely to diminish as pollution levels are reduced, but the rate at which this value will diminish is not well understood, and marginal benefits of reducing current levels of pollution remain significant.

There is a range of economic information on the costs and benefits of measures to protect and improve urban air quality. However, this information typically relates to the impacts of general exposure of the population and the costs of actions to tackle emissions. The link between these is not straightforward and hence the specific benefits associated with the emission reduction due to a particular set of actions are not known.

Example of Air Pollution Impacts: Health Costs in Bristol[11]

The cost of the health effects attributable to air pollution in Bristol is estimated to be £12-84 million per year (at 2013 prices). This reflects the following annual impacts attributed to air pollution: 188 premature deaths of Bristol residents (over the age of 30, in 2010, range 65-328 premature deaths), with 24 of these attributable to local road traffic emissions; also 52 respiratory hospital admissions and 42 cardiovascular hospital admissions.

Agricultural Ammonia

Emissions of Ammonia, primarily from livestock, contribute to formation of airborne particulates which cause nitrogen deposition on habitats and human health effects. Only a proportion of particulate matter (e.g. PM2.5) in urban areas is from local sources. Therefore there is also a need to consider control strategies for the regional background concentration levels, of which secondary inorganic aerosol (ammonia, NOx and SO_2) is by far the largest component according to models[12].

The cost of ammonia emissions to human health and climate regulation is estimated at £2,300 per tonne[13], giving a total cost of approx. £630m for the 274,000t of emissions annually in the UK in 2012 (NAEI). While on a downward trend, predicted future ammonia emissions levels will result in ongoing significant impacts on habitats, climate and human health. Measures to tackle ammonia emissions are therefore of widespread relevance to livestock farming in England.

Agroforestry measures creating shelter belts to absorb ammonia from livestock can mitigate approximately 20% of emissions, but have net costs to farmers (costs to establish and manage the forest and opportunity costs of using productive land). Implementing this shelter-belt measure involves a trade-off between the short term costs to livestock farming, and the longer term benefits to the wider population and the environment. These costs depend on the proximity of the planting to the emissions source and the size of shelterbelt required. For a typical slurry lagoon the

[11] Based on Air Quality Consultants (2014). Health Impacts of Air Pollution in Bristol. April 2014.

[12] AQEG's Fine Particulate Matter (PM2.5) in the United Kingdom, 2012.

[13] Following the Inter-Departmental Group on the Costs and Benefits of Air Quality (IGCB) guidance and DECC (2009). For IGCB guidance, see: https://www.gov.uk/air-quality-economic-analysis.

private costs to the farm are estimated to have a present value (over 25 years) of £26,000-£142,000. The balance of costs and benefits on individual farms will vary, being less favourable where there is a higher opportunity cost of land, but more favourable where economies of scale can be achieved from shelterbelts tackling multiple sources of ammonia. There is also a lag between planting a shelterbelt, and it maturing to provide emissions reductions benefits, which takes approximately 10 years.

The benefits of reducing ammonia emissions and depositions depend on the proximity of the measures to the habitats affected. Human health benefits also depend on proximity of emissions to population centres, and on other health factors in that population. The environmental benefits of reducing emissions, (and to a lesser extent the health benefits) are also conditional on local features and meteorological conditions.

The marginal value of reducing air pollution impacts on the environment is likely to diminish if pollution levels are substantially reduced, for example as nitrogen deposition falls below the critical load thresholds. However, the UK is some way from this threshold for ammonia and the marginal benefits of reducing current levels of pollution remain significant. There may be a case for spatial targeting of ammonia abatement measures and the spatial calculation of the effects of air pollution on the environment is necessary to best estimate economic impact.

Using shelter-belt to tackle ammonia emissions has a clear synergy with other potential investments in natural capital. It complements the proposed investments in lowland woodland, and in catchment management. Impacts from ammonia can extend to potential improvements in ecosystem services like water purification and atmospheric carbon regulation.

Example: dairy farm shelter-belts

An illustrative example of a dairy farm suggests there is a potential economic case for shelter-belt measures to mitigate ammonia emissions from agriculture. Private net benefits have been under-estimated as revenue from periodic tree felling is omitted, but overall shelter-belt measures appear to represent an opportunity cost for farmers. Therefore, the feasibility of this measure is likely to be dependent on public subsidy to incentivise farmers to take on such action through grant schemes. A similar methodology can be applied for pig and poultry farming. However, it requires further research into understanding how farm specific conditions impact costs and benefits for various forms of livestock.

1. INTRODUCTION

This evidence base considers air, which is one of the natural capital assets defined in previous Natural Capital Committee work. The benefits it provides are: an adequate level of air quality to humans, and a supporting ecosystem service of adequate air quality for the existence of species and habitats. Pressures on the natural capital asset (e.g. emissions of pollutants to air) reduce the level of these benefits.

Improvement in air quality is a key policy objective in the UK. Negative health impacts related to poor urban air quality have been estimated to be £9-20 billion per annum (Defra, 2010). This is based on the effect of the smallest particulates ($PM_{2.5}$) on mortality in the UK in 2008, which is estimated to be equivalent to 29,000 deaths (COMEAP, 2010).

This note reviews the evidence base on air quality improvements in the context of identifying potential investments in natural capital. Based on the Review of Transboundary Air Pollution (RoTAP, 2012), recent Defra work on air pollution (Defra, 2014a), and expert input from within the study team, the scope of the evidence focuses on urban air pollution abatement (primarily from transport) and abatement of ammonia released through agricultural activities. Therefore, the pollutants of primary interest include: nitrogen oxides (including nitrogen dioxide), particulate matter, and ammonia.

The evidence is summarised in Figures 1.1 and 1.2.

Figure 1.1: Air Evidence Value Chain - Urban Air Quality

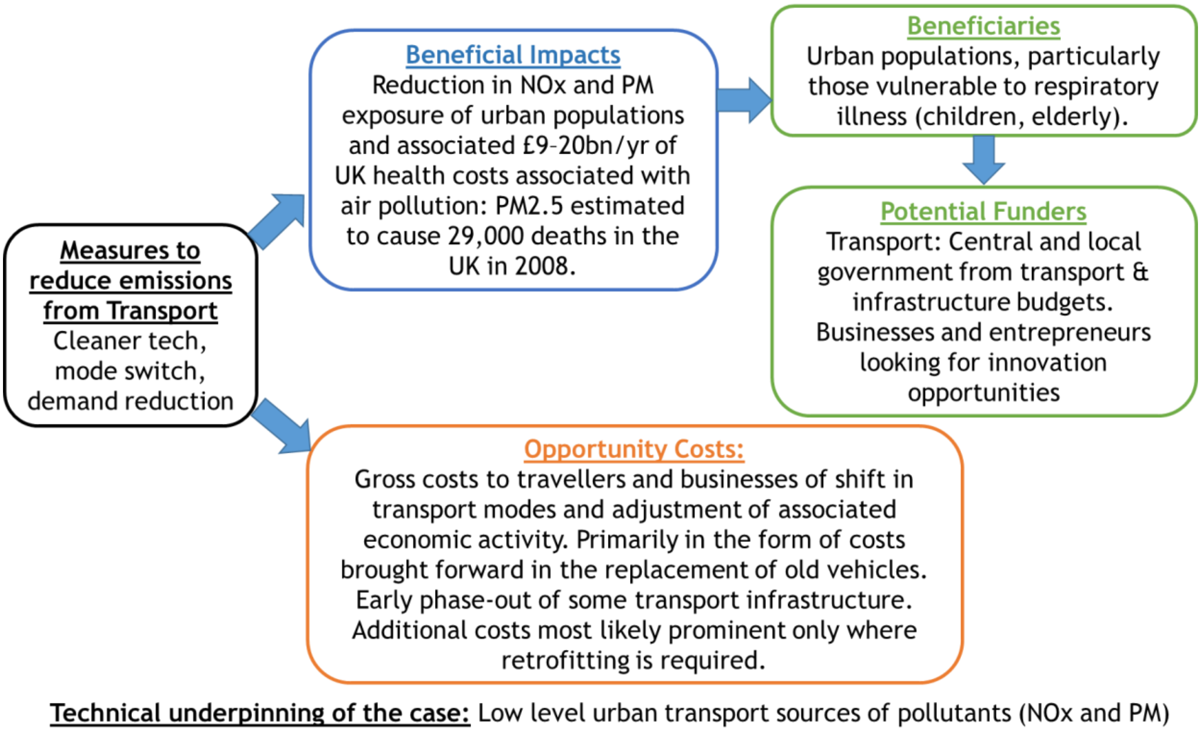
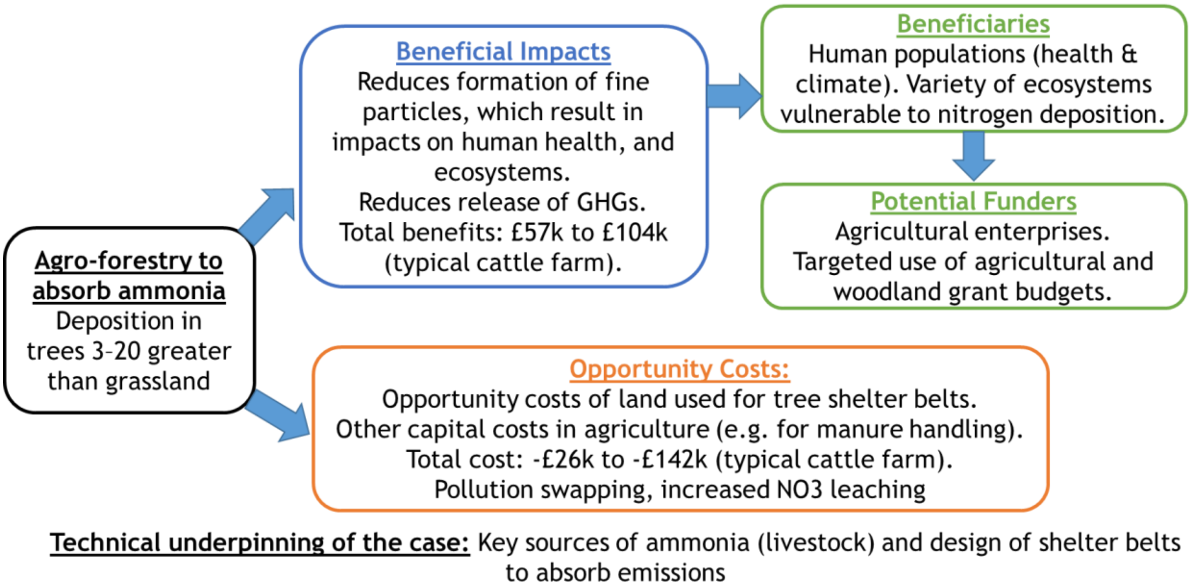


Figure 1.2: Air Evidence Value Chain - Ammonia



Sulphur dioxide and formation of ozone are also briefly considered. In the case of sulphur dioxide, historic and forecast reductions in emissions mean this pollutant is not a priority for further action. For ozone, the complexity of the processes that lead to ground level formation means that unilateral action in the UK will have only limited impact. In addition, metals (such as lead, arsenic and cadmium) are not considered due to uncertainties in attributing emissions to ecosystem impacts (RoTAP, 2012) and because a number of the metals already achieve the targets set by the regulatory standards (Defra, 2014a).

Three case studies are provide to illustrate the evidence base:

- The health impact of urban air emissions in Bristol;
- The London Ultra Low Emission Zone (ULEZ)[14]; and
- Mitigating ammonia emissions from agriculture.

These describe and quantify the impacts of air pollution, benefits of actions to reduce emissions and costs of these actions as much as data allow. These are detailed in Sections 4 and 5.

[14] This action is chosen as a case study as transport is the main source of emissions for nitrogen oxides (63%) and particulate matter (PM10, 52%) (TfL, 2014a).

2. UK REGULATORY CONTEXT

2.1. Air quality standards

Three primary air quality standards are set by the European Commission, which define the legal requirements for air quality in the UK:

1. Ambient Air Quality and Cleaner Air for Europe (Air Quality Directive/EU AQD, 2008): covers emissions of sulphur dioxide, nitrogen oxides, particulate matter (PM10 and PM2.5), lead, benzene, carbon monoxide and ozone;

2. The Fourth Daughter Directive: primarily relates to the metals arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons; and

3. The National Emission Ceilings Directive: targets pollutants responsible for acidification, eutrophication and formation of ground level ozone (sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia) in line with the Gothenburg Protocol.

The European standards set a limit value for each pollutant (for a specific period of time), based on medical and scientific understanding of their impact on human health and the natural environment (Defra, 2014a). The UK Air Quality Strategy (Defra, 2007) sets targets that are at least as stringent as the European standards (or more stringent, in the case of the ozone concentration limit value) for the following key air pollutants: sulphur dioxide, nitrogen oxides (particularly nitrogen dioxide), ozone, particulate matter, carbon monoxide, benzene, 1,3-butadienne, polycyclic aromatic hydrocarbons (PAH) and metallic pollutants (lead in particular).

The trends and non-compliance (exceedance) of the limit values informs the scope for potential action on air quality; i.e. where (ambient) levels of air pollution do not meet current standards, or are projected to fail to meet standards in the future, there is potentially a case for action (subject to weighing up the costs and benefits of such action).

2.2. Trends

Historic emissions of air pollutants by source sector (1970 – 2012) and projected future emissions are presented in Annex A.

Sulphur dioxide

Sulphur dioxide (SO_2) emissions peaked in the 1950s, largely due to emission controls (RoTAP, 2012), and have fallen by an average of 93% between 1970 and 2012 across the UK, according to the National Atmospheric Emissions Inventory (NAEI). These reductions are attributed to a switch from solid fuels to alternative, improved abatement technology and more stringent legislation on the sulphur content of some fuels (NAEI). This declining trend is projected to continue, falling a further 32% between 2012 and 2020 (EIONET, 2012), particularly due to reductions in emissions from shipping in the vicinity of the UK, following implementation of the MARPOL convention on emissions from international shipping (RoTAP, 2012).

Nitrogen oxides

There has been a 60% reduction in emissions of nitrogen oxides (NO_x) between 1970 and 2012 (NAEI) with nitrogen dioxide (the main component of nitrogen oxides) declining by an average of 50% between 1980 and 2007. Emissions are projected to continue to fall a further 31% between 2012 and 2020 (EIONET, 2012). However this declining trend has only resulted in a reduction of 23% in oxidised nitrogen deposition (RoTAP, 2012). Part of this pattern has been attributed to trans-boundary movements of pollutants, and another explanation is the increase in the oxidation of nitrogen oxides to nitric acid and aerosol nitrate, compared to the late 1980s (RoTAP, 2012). In urban areas, increases in direct emissions of NO_2 (as opposed to NO_x) have been attributed to the increasing share of diesel vehicles in the UK fleet and the implementation of measures to reduce particulate matter emissions from these vehicles, such as diesel oxidation catalysts (Defra, 2013).

Ammonia

Concentrations of ammonia (NH_3) have remained high and have changed comparatively little (RoTAP, 2012). Between 1980 and 2012, ammonia emissions fell by 22%, this is largely attributed to decreasing cattle numbers in the UK (NAEI). While nitrogen excretion with the pig and poultry sector is expected to decline, ammonia deposition is expected to rise slightly between 2012 and 2020 (EIONET, 2012) due to a rise in nitrogen excretion by cattle and direct soil emissions (RoTAP, 2012).

Ozone

For tropospheric (ground-level) ozone, there has been a 60% and 62% (respectively), reduction in emissions of the precursor compounds nitrogen oxides (NO_x) and non-methane volatile organic compounds (NMVOCS) between 1970 and 2012 (NAIE). NMVOC emissions are expected to rise slightly before falling 4% between 2012 and 2020 (EIONET, 2012). The impact of this fall has been on peak concentrations, which have declined by 30% in rural areas of the UK over the last 20 years. However, there has also been an increase in emissions of precursors from outside Europe (within the Northern Hemisphere), which have resulted in a rise in background ozone concentrations of approximately 10% in the UK between 1990 and 2010 (RoTAP, 2012).

Particulate matter

Particulate matter is classified as PM10 (particulate matter less than 10µm aerodynamic diameter) and PM2.5 (particulate matter less than 2.5µm). While both forms of pollutant can be localised, during episodic conditions, PM2.5 concentrations can largely be due to continental emissions. Furthermore, there is a difference between primary PM (which is directly emitted) and secondary PM (formed by atmospheric chemistry processes from precursor emissions of NO_x, SO_2 and NH_3). Between 1990 and 2012, UK emissions of PM10 fell by 59%, while emissions of PM2.5 fell by 67% (NAEI). There has recently been a small rise in PM10 emissions, primarily due to public electricity and heat production (NAEI). This is expected to be reversed in the coming years, due to reduced emissions from power stations, residential activities and the minerals industry (AEA, 2009). While PM2.5 emissions have slowly declined and are projected to decline into 2020 (EIONET, 2012), due to reductions from road transport, power stations and the mineral products industry (AEA, 2009).

2.3. Compliance with standards

To demonstrate compliance with European standards, the UK must present annual results of the national air quality statistics and indicators for the various pollutants. The UK is split into 43 zones (see Annex B), each of which is assessed for each pollutant, over a defined time period. Compliance is then based on whether the concentration level has exceeded the limit value (and the margin of tolerance) for that time frame.

Sulphur dioxide

For sulphur dioxide, two time frames are evaluated: the 1-hour mean and the 24-hour mean concentration. In both cases, all 43 zones complied with the limit value (Defra, 2014a). As can also been seen in Annex A (Figure A.1), sulphur dioxide has remained below National Emission Ceilings Directive (NECD) targets for a number of years, and is expected to continue to do so.

Nitrogen oxides

For nitrogen oxides, a critical level (concentration) set for the protection of vegetation, the annual average has been met in all 43 zones. However, for nitrogen dioxide (NO_2), the Greater London Urban Area failed to meet the limit value for the 1-hour mean concentration in 2013, while 31 zones similarly failed to meet the annual mean limit value[15]. In July 2014 the UK Government published revised projections based on 'business as usual', which show when each zone is expected to comply with the EU limit values. These show three zones, including the Greater London Urban Area, would not comply until after 2030. The limit values came into force in 2010, so the UK is in breach and is currently being infracted for non-compliance for 16 of the zones[16].

Ammonia

While compliance information was not available for ammonia in the latest UK air pollution assessment, emissions have been targeted within a number of the standards, and have already been met for the 2020 target of the Gothenburg Protocol (NAEI). However, ammonia still remains a pollutant of high concern, as controlled experiments have shown that the deposition of ammonia at low concentrations is more toxic than other forms of nitrogen deposition (RoTAP, 2012) and it plays a large role in health impacts and eutrophication (see Table 2.2).

In comparison to the NECD targets, nitrogen oxide and ammonia emissions have both remained below the ceiling for a number of years. However, ammonia levels are of some concern, as they have declined very little, and are forecast to show an upward projection into 2020 (EIONET, 2012).

Ozone

In 2013, all 43 zones achieved the target value based on the maximum daily 8-hour mean concentration. However, this daily mean is also used to compute a long-term objective for the protection of human health, and 33 (of the 43) zones failed this objective. Another statistic used to assess ozone is the AOT40[17] target value, which was met by all 43 zones. However, long-term objectives for the protection of vegetation, based on this statistic, were exceeded by 8 zones. Finally, 2013 saw three exceedances of the 1-hour limit ozone thresholds: once in the Brighton Preston Park and twice in Canterbury (Defra, 2014a).

[15] See figure A.3 in Annex A for the full list (Defra, 2014)

[16] Multiple reports highlighted this in the first half of 2014. See for example: http://www.airqualitynews.com/2014/02/21/unclear-who-would-pay-uk-air-quality-fines-say-experts/

[17] This is the sum of the difference between the hourly concentrations greater than 80 μg/m^3 and 80 μg/m^3 over a given period using only the hourly mean values measured between 0800 and 2000 CET each day.

Particulate matter

In 2013, all 43 zones achieved the daily mean and annual mean target for PM10. However, the Greater London Urban Area only achieved compliance because emissions of PM10 from natural sources and their contribution to ambient concentrations were deducted, in line with the definitions in the regulation.

For PM2.5, all zones achieved the annual mean targets for 2010 and the tougher target for 2015. In 2013, the Greater London Urban Area was the only one that failed to comply with the limit value, set to be met by 2020. This was after removing the natural contribution of sea salt in these figures. According to the EU AQD (2008), in instances where exceedance of particulate matter is due to natural sources, these can be ignored.

2.4. Sources of emissions

Table 2.1 below sets out the primary sources of emissions, based on breakdowns of emissions provided by the NAEI, and total emissions for 2012 have been noted next to each pollutant. Ozone is not included in the table as it is not directly emitted by any source, but is produced by the effects of sunlight on NO_x and volatile organic compounds (e.g. non-methane volatile organic compounds/NMVOCs). Therefore, the sources to tackle ozone are those for NO_x and NMVOCs.

2.5. Impacts of air pollutants

Table 2.2 provides a qualitative summary of the main human health and environmental impacts associated with the air pollutants of interest.

Table 2.1: Sectoral sources of emissions for key pollutants

Broad Sector	Sub-Sector		Sulphur dioxide (427t)	Nitrogen oxides (1062t)	Ammonia (274t)	NMVOC (757t)	PM10 (113t)	PM2.5 (77t)
Agriculture/ Waste/ Accidental fires	Agriculture/Waste		-	-	-	6%	15%	8%
	Cattle		-	-	41%		-	-
	Direct Soil Emissions		-	-	23%		-	-
	Poultry		-	-	10%		-	-
	Other Livestock		-	-	8%		-	-
	Waste		-	-	12%		-	-
	Production Processes/Waste		6%	-	-	-	-	-
Production Processes				1%	-	-	19%	12%
	Solvent & Other Product Use		-		-	46%		
	Extraction & Distribution of Fossil Fuels		-		-	20%		
	Public Electricity and Heat Production		-	27%	-	-	8%	6%
	Combustion & Production Processes		-		6%	14%		
Combustion in Industry/ Commercial/ Residential			-	28%			33%	45%
	Combustion in Industry	Combustion in Energy and Transformation Industry	66%		-	-		
		Combustion in Manufacturing Industry	14%		-	-		
		Stationary Combustion	-	-	-	7%		
	Other		10%	-	-	-		
Transport	Road Transport		4%	-	-	8%	20%	21%
	Passenger cars			15%	-	-	-	-
	Heavy duty vehicles			11%	-	-	-	-
	Other Transport			18%	-	-	6%	8%

Source: National Atmospheric Emissions Inventory (NAEI), 2012. Volumes are available from: http://naei.defra.gov.uk/overview/pollutants.

Table 2.2: Summary of impacts from key air pollutants

Pollutant	Sulphur dioxide	Nitrogen oxides	Ammonia	Ozone	PM10	PM2.5
Human health	Respiratory irritant Very rapid impact on health	Respiratory irritant for ST exposure above 200 μg/m^3 Increase susceptibility to respiratory infections and allergens Potential mortality and morbidity effects	Mortality effects (cerebral haemorrhage, severe liver damage etc.) Eye and throat irritation Precursor to formation of fine particles (see PM2.5)	Respiratory irritant Short-term, high exposure can cause respiratory irritation, irritation of eyes, nose and throat High levels may exacerbate asthma attacks/trigger attack High levels may cause chest discomfort	Respiratory illness, cardiovascular illness etc. Mortality No threshold known below which it is safe	Long-term exposure linked to respiratory effects, cardiovascular effects etc. Estimated 340,000 years loss of life across population
Environmental	Harmful to plants at high concentrations Loss of sensitive species (e.g. mosses and lichens) Ecosystem acidification Loss of (freshwater) aquatic species (e.g. Atlantic salmon) Reduction in acid neutralisation capacity (ANC) of lakes and streams Precursor to secondary sulphate particles NB: there are also losses of benefits when emissions are reduced (e.g. to crops)	Results in Nitrogen deposition In sunlight can form photochemical pollutants (e.g. ozone) Direct toxicity to plants at very high gaseous concentrations High levels of nitrate can harm plants Ecosystem acidification and eutrophication Lower diversity of plants	Results in Nitrogen deposition Direct toxicity to plants at high gaseous concentrations Animals also affected by respiratory effects Ecosystem acidification and eutrophication Precursor to formation of fine particles (see PM2.5)	Can cause damage to plants and cause reduced carbon sequestration in plants Loss of yield and quality of crops, e.g. estimated reduced national production of wheat in 2000 by approximately 1.2 mil tonnes Reduced forest yield Changes in species composition Greenhouse Gas	Black carbon (in PM) contributor to climate change Secondary PM (e.g. nitrates, sulphates) leads to acidification and eutrophication	Secondary PM (e.g. nitrates, sulphates) leads to acidification and eutrophication

Sources: COMEAP (2010), Defra (2014a); RoTAP (2012); Smith et al. (2011); and WBK (2004).

3. OUTLINE OF NATURAL CAPITAL EVIDENCE BASE

The overall trend for the air pollutants in the UK is declining emissions, even though despite this, a number of targets have not been met. These targets have primarily been set to mitigate human health impacts (Table 2.2), but also account for a number of environmental factors.

The current air quality policy targets, even if met, should be implicitly assumed to represent the 'socially optimal' level of pollutant level. For example, the World Health Organisation's (WHO) target values for PM2.5 are 10 µg/m^3, which is substantially lower than the current UK limit values. While, recent evidence, including from the ESCAPE EU research project[18], goes as far as to suggest that some health effects continue to occur even at very low levels of exposure. Therefore, there remains a strong case to target the pollutants that remain above their limit values, and also to examine the case for achieving air quality levels beyond current target levels.

Table 3.1 summarises the case for evidence on tackling the different air pollutants. These conclusions are based on the information presented in Sections 2 and 3, as well as the growing scientific and economic evidence base. Overall, the evidence is clearest in relation to tackling the effects of NO_x and PM emissions in urban areas (particularly transportation), and ammonia from agriculture closer to urban areas. In particular, these represent the pollutants which can be most impacted by unilateral action by the UK. Sections 4 and 5 look in more detail at the evidence on urban transport emissions and ammonia emissions from agriculture, respectively.

[18] See: http://www.escapeproject.eu/

Table 3.1: Summary of Evidence on Air Pollutants

Pollutant	Evidence	
	Summary	Conclusion
Sulphur dioxide	There are potential benefits to coastal areas from taking a targeted approach to shipping emissions. However, the impact of SO_2 on human health is marginal, and there could be costs associated with reduced air pollution levels. Costs include sulphur deficiency in crops and reduced suppression of methane emissions in wetland (Gauci et al., 2004).	Lower priority
Nitrogen oxides	There are potential benefits to be gained from targeting NO_x emissions from transport, particularly in urban areas. This will have secondary benefits to the environment as a result of reduced eutrophication and impacts on biodiversity.	High priority
Ammonia	Contribute to secondary aerosol formation resulting in human health concerns, and impacts on ecosystems and biodiversity via eutrophication, acidification and direct toxicity effects. Therefore, NH_3 emissions are a key area for action.	High priority
Ozone	A toxic substance to humans causing respiratory problems; causes significant crop yield losses, and damage to natural ecosystems. Actions are required to address the precursors to the formation of ground level ozone (NO_x, Ammonia, NMVOCs etc.).	Priority through action on other pollutants
PM10	While not as harmful as PM2.5, PM10 remains a pollutant of concern, due to health impacts. Hence, there are potential benefits to be gained from targeting emissions from transport, particularly in urban areas.	Priority behind Ammonia, NOx, and PM2.5, but correlated to latter two.
PM2.5	Health impacts imply PM2.5 is a primary concern. There are potential benefits to be gained from targeting emissions from transport, although this is likely to be limited to urban areas since the regional background level of PM2.5 is understood to be the main contributing factor.	High priority

4. URBAN TRANSPORT EMISSIONS (NO2, NOX AND PM2.5)

4.1. Potential measures

Road traffic is a key source of emissions in urban areas. Actions to improve urban air quality would need to reduce local traffic emissions (particularly to tackle impacts from NO_2, NO_x and PM2.5), while still meeting the need for mobility.

At the national level, the main policy drivers are the vehicle emissions standards, set by the European Commission to define acceptable limits for exhaust emissions of new vehicles. These standards have different regulations depending on whether the vehicle is a light-duty vehicle (cars and light vans) or heavy-duty vehicle (trucks and buses). Light-duty vehicles are currently regulated by the Euro 5 emission standard, defined by regulation 715/2007; the latest in a series of standards that have gradually tightened the emissions allowance since 1992. Recent standards have targeted particulate emissions from diesel cars and tightened NO_x emissions (28% reduction compared to Euro 4)[19]. The Euro 6 (the next standard, under the same legislation) is applicable to cars that are registered from September 2015 onwards[20]. This standard will impose even further reductions on NO_x emissions from diesel engines (a 67% reduction compared to Euro 5) and will establish similar standards for petrol and diesel vehicles. According to the AA, these standards have imposed reductions in some pollutants of 96%, compared to their 1992 limits[8]. The standards on heavy-duty vehicles have followed the same approach: the Euro VI emission standard came into effect in 2013/2014, as defined by regulation 595/2009. The standard introduced particle number emission limits, stricter on-board diagnostic requirements and a number of new testing requirements. The impact of these standards on heavy-duty vehicles is believed to have resulted in a reduction of UK wide NO_x and PM10 emissions of 128kt and 5kt (respectively) between 2001 and 2010[21]. However, further emission standards have not yet been defined.

Although some of the cost of the applying these standards could be passed on to customers, it is the manufacturers that are directly impacted by the regulation. As they are required to meet the emission limits of the standards as well as ensure that the devices fitted to control pollution are able to last for a distance of 160,000 km[22].

Overall, urban air quality has improved over the past decade due to the implementation of these more stringent emission limits for passenger cars, light- and heavy-duty vehicles and buses. This has led to reductions in particulate matter, as well as nitrogen dioxide from petrol cars[23]. However, local hotspots near busy roads and junctions (in particular) continue to show high concentrations of ambient air pollutants, specifically nitrogen oxides (NO_x) and fine particulate matter (PM2.5). A key source of these pollutants (particularly NO_x) is believed to be from diesel-powered cars, which have grown from approximately 15% of the UK market in 2000 to 50% by 2012 (SMMT, 2014). Given that diesel engines emit greater volumes of NO_x than new petrol vehicles[24] implies that diesel cars are a primary source of concern for emission abatement of NO_x. For example, Carslaw et al. (2011) find that overall, urban areas have experienced an 18% increase in NO_x emissions between 2002 and 2009 from diesel vehicles.

[19] See: http://www.theaa.com/motoring_advice/fuels-and-environment/euro-emissions-standards.html.
[20] See: http://www.smmt.co.uk/industry-topics/environment/intro/european-engine-emission-standards/.
[21] See: https://www.tfl.gov.uk/cdn/static/cms/documents/lez-impacts-monitoring-baseline-report-appendix-1.pdf.
[22] See: http://europa.eu/legislation_summaries/environment/air_pollution/l28186_en.htm.
[23] Nitrogen dioxide emissions from diesel cars have not fallen.
[24] See: http://www.dft.gov.uk/vca/fcb/cars-and-fuel-options.asp

The current situation is summarised in the UK report (Defra, 2014a) and the European Commission on compliance with air quality limit values for 2013 (Defra, 2014b). However, the definition of larger zones used for the assessment of compliance does not fully account for local effects. In the same way, the number and spatial distribution of the Automatic Urban and Rural Network (AURN[25]) monitoring sites may not account for all local hotspots in urban and suburban areas.

Locally focused measures implemented to improve air quality include the introduction of Air Quality Management Areas (AQMAs[26]), within which specific actions in relation to NO_2, and in some cases for PM2.5. Note that currently there is no binding legal limit value for PM2.5 concentrations; a limit value of 25 µg/m^3 has to be attained by 2015 and 20 µg/m^3 by 2020 (EU AQD).

In a 2004 report (Defra, 2004), evidence has been compiled on the effectiveness of specific local measures, stating that *"… schemes that are directed at emissions improvements, such as low emission zones, scrappage schemes and motorway speed restrictions, lead to the biggest emissions improvements, and have the largest air quality and health benefits"*. Defra supports local authorities that choose to implement Low Emission Zones (LEZs) and other local transport measures, providing guidance for Local Air Quality Management (LAQM[27]) and Action Planning[28].

Current examples of LEZs are found in Norwich[29] and London[30], while further cities in the UK have plans for the implementation of LEZs (for example Edinburgh[31]).

4.2. Outcomes

Health effects of urban air pollution contribute to both acute and chronic health impacts (e.g. exacerbation of asthma, respiratory illness, cardio-vascular and cardio-pulmonary diseases). For the most acute effects, reductions in air pollution will have immediate benefits, by reducing the exposure of the general public and particularly vulnerable groups (e.g. patients suffering from asthma or chronic obstructive pulmonary disease). In the case of chronic diseases, recovery may not be measurable, but reductions in symptom days may be observed.

The rate and type of recovery of state will vary for the different health effects and individual exposure/susceptibility is not easily determined on an aggregate level. Overall, reductions in emissions will improve the resilience of people in urban areas to morbidity effects from air pollution.

The success of local urban transport measures will be affected by the proportion of local concentrations that are due to regional/long-range transport of pollutants. At locations where ambient air pollution primarily originates from local sources, local measures will have a more direct effect. As local air quality measures may require substantial planning and their implementation relies on profound changes in transport behaviour of the urban population, they are typically not effective in achieving short-term benefits. For instance, improvements of urban public transport schemes, support for active transport (cycling, walking) and low- or zero emission public transport options can only be implemented on a time scale of 10-25 years. This is due to the long planning

[25] See: http://uk-air.defra.gov.uk/networks/network-info?view=aurn.
[26] See: http://uk-air.defra.gov.uk/aqma/.
[27] See: http://laqm.defra.gov.uk/.
[28] See: http://laqm.defra.gov.uk/action-planning/action-planning.html.
[29] See: http://laqm.defra.gov.uk/documents/Norwich_lez.pdf.
[30] See: https://www.tfl.gov.uk/modes/driving/low-emission-zone.
[31] See: http://www.edinburgh.gov.uk/info/20153/maintaining_and_enhancing_the_quality_of_life_in_edinburgh/710/pledge_51.

cycles for fleet and infrastructure investments and the time necessary for human behaviour to change.

4.3. Economic impacts of measures

Costs for the implementation of local air quality measures may include: costs of national regulation to implement stricter vehicle emissions standards; costs of road and transport infrastructure (bus or bike lanes, new public transport fleet etc.); support for local scrapping schemes for the most polluting vehicles, etc. The scope of these activities is linked to the extent of expected improvement in air quality, but in general, local-level schemes can be implemented across a wide range of urban environments. However, their effectiveness may vary due to local conditions and the composition of urban transport modes.

As a result, when considering the feasibility of the different local measures, there are some constraints to scaling up actions to improve air quality. Some are linked to the structure and composition of cities; e.g. old, walled cities and city quarters only providing limited options for traditional infrastructure changes, such as the introduction of physically separated cycle paths. Further research is needed to produce a more systematic evaluation of approaches to engage with urban populations, to induce lasting behavioural changes to support transport mode shifts, as well as engagement with citizens on urban transport planning to improve local support and buy-in of the population.

4.4. Case studies

Two case study examples are provided. Box 4.1 provides a summary of the costs associated with emissions in the Bristol urban area, and the impact of this on health. Box 4.2 presents the estimated costs and benefits of the establishment of an Ultra Low Emission Zone in London.

Box 4.1: Health impacts of urban air emission in Bristol

This example provides a summary of results presented in Air Quality Consultants (2014). The study concluded that an additional 188 premature deaths of Bristol residents (over the age of 30) were attributable to air pollution in 2010 (with a sensitivity range of 65 – 328 additional premature deaths). Twenty four of these were attributable to local road traffic emissions. There were also 52 respiratory hospital admissions and 42 cardiovascular hospital admissions attributable to air pollution in Bristol.

Morbidity impacts

A significant proportion of the morbidity costs to the health services and to society are from the hospital admissions. Unit values for these are presented below.

Summary of Inter-Departmental Group on the Costs and Benefits of Air Quality (IGCB Recommendations on health valuation for morbidity effects

Health Effect	Valuation (2004)	
	Central Value	Range
Respiratory Hospital Admissions	£1,900 - £9,100	£1,900 - £9,600
Cardiovascular Hospital Admissions	£2,000 - £9,200	£2,000 - £9,800

Source: Defra (2006)

Converting these values to 2013 prices and multiplying the number of hospital admissions with the respective central value, the annual human health morbidity costs in Bristol due to air pollution are: £0.2 – 1.1 million/year (in 2013 prices).

Mortality impact

Air Quality Consultants (2014) estimate the value of mortality impacts based on the value of a statistical life year (VoLY). Defra (2006) advises that the VoLY for mortality due to long term exposure to air pollution is £29,000 (in 2004 prices), which is £37,300 (in 2013 prices). Following COMEAP (2010), it is possible to estimate unit values for the mortality.

The calculation of the mortality costs is outlined as follows:

- Upper: COMEAP (2010) estimates that 28,861 deaths were attributable to PM2.5 exposure in the UK and that this represents 340,000 life years lost. Therefore, the value of lost life years (in 2013 prices) is £12.7 billion (=340,000 x £37,300). This implies a value of statistical life (VoSL) of £439k (£12.7billion/28,861). Estimated mortality costs of urban air emissions in Bristol are therefore approximately £82.6 million per year, in 2013.
- Lower: COMEAP considers it very unlikely that 28,861 represents the number of individuals affected. Instead it suggests that air pollution, acting together with other factors, may have made some smaller contribution to the deaths of up to 200,000 people. This implies a VoSL of £63k (12.7billion/200,000). Giving mortality costs of approximately £11.9 million per year, in 2013.

Conclusions

Mortality costs far outweigh morbidity costs to air pollution in Bristol. The reasoning being that:

- The value of a statistical life used far outweighs the value of morbidity due to both respiratory hospital admissions and cardiovascular admissions.
- The number of hospital admissions are smaller than the number of deaths. According to Air Quality Consultants (2014), this is likely to be because the hospital admissions are based on studies on the short term response to daily changes in air pollution, while the number of deaths are from studies assessing long-term exposure. Short term exposure figures tend to be lower than long term exposure, particularly in the case of studies of mortality.

Combined mortality and morbidity costs to society are estimated to be between £12.1 and £83.7 million. This figure demonstrates the potential scale of the importance (particularly of health effects) of air pollution in just one city. The valuation of impacts is considered an underestimate of the total impact relative to the estimates of national impacts of air pollution. It provides an acceptable estimate for of the value of impacts, and context for the impacts of reducing emissions.

Box 4.2: London Ultra Low Emission Zone

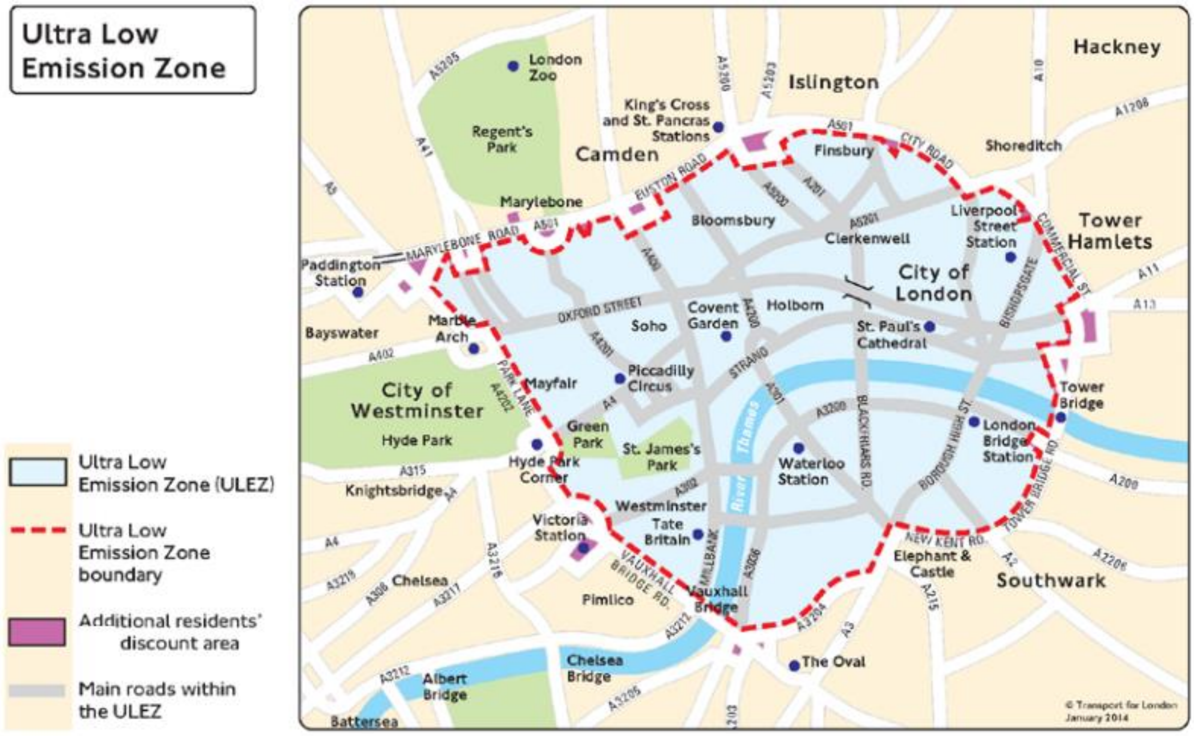
Background

The Greater London Area has failed to achieve the targets for NO_2 and (to a lesser extent) PM2.5 for future restrictions. Transport is a primary source for these pollutants. Based on COMEAP (2010) guidance on the relationship between concentration and mortality rates, there was an equivalent of 4,300 premature deaths attributed to air quality related illnesses from fine particulate matter in London, in 2008. Following the same methodology set out in Box 4.1, this amounts to (annual) mortality costs to society of approximately £0.27 - £1.9 billion in 2008.

Approach

The Mayor of London and Transport for London (TfL) have developed a proposal for an Ultra-Low Emission Zone (ULEZ) in central London (TfL, 2014b; Jacobs, 2014). It requires that all vehicles entering central London (see map) meet new exhaust emissions standards from the September 2020, with additional requirements for TfL busses, taxis (black cabs) and private hire vehicles. Those vehicles that are within this zone, 24 hours a day and 7 days a week, will have to pay a charge that depends on the vehicle type, as outlined in the table below.

Map of proposed London ultra low emission zone (ULEZ)



Source: TfL (2014b)

Daily charges according to vehicle type

Vehicle class	Emissions standard and charge per day
Cars	£12.50, if not Euro 6 compliant (diesel) or Euro 4 compliant (petrol)
Motorcycles, moped etc.	£12.50, if not Euro 3 compliant
Coaches and non TfL buses	£100, if not Euro VI compliant
Vans and minibuses	£12.50, if not Euro 6 compliant (diesel) or Euro 4 compliant (petrol)
Heavy good vehicles (HGVs)	£100, if not Euro VI compliant

Source: TfL (2014b)

In combination these measures to implement the ULEZ are expected to reduce the level of emissions of NO_x emissions by just over 50% by 2020 (Jacobs, 2014). This is largely based on expectations of emissions standards that will be achieved by new vehicles, some of which have already been in place for a number of vehicle classes.

Estimated benefits

Limited information is provided on the impact of the ULEZ in terms of the reduction in emissions. However, reductions of NO_x, PM10 and PM2.5 emissions are estimated to result in £101 million benefits in the first year of operation, i.e. 2020 (Jacobs, 2014). These benefits are calculated based on the health benefits from the implied reduction in emissions of these pollutants, relative to a baseline condition where the ULEZ does not exist. The main effect of the policy is to shift forward in time the replacement of the London fleet towards lower emission vehicles, which would still happen, but at a slower pace. As a result of this 'falling' baseline from a growing expected number of low emission vehicles on the road, annual benefits are estimated to fall to £32 million by 2025. Additional benefits are recognised though, in terms of CO_2 reductions (£7.6 million) and journey time savings (£31.7 million) that are also anticipated in the first year.

Estimated costs

One-off policy development, consultation and marketing costs are expected to be approximately £30 million. Expected annual operating costs are summarised in the table below.

Annual operating costs (from 2020)

Annual Costs	Costs (£)
Operational costs: handling enquiries, registrations and payments, on-going enforcement of the scheme and maintenance of the website	6 million
Additional operation costs for TfL	8 million
Cost of additional bus services	14 million

Source: TfL (2014b)

Costs of complying with the measures by road users or paying the charge (a transfer from private road users to the public budget) are expected to be around between £120 and £250 million in the first year. This is likely to largely impact small to medium sized enterprises (Jacobs, 2014). The overall cost to the London economy (currently valued at approximately £565 billion[32]) is estimated to be around 0.03% - 0.08%. Some offsetting may occur, however, with costs of compliance representing income to other London businesses, and the impact is expected to fall over time as the level of compliance rises.

Conclusions

The available evidence is limited, and hence it is challenging to provide a complete summary of the costs and benefits of proposed London ULEZ in monetary terms. Upfront costs appear to be of a similar magnitude to estimated benefits. However, the longer term profile of costs and benefits is not explicitly considered, meaning it is not possible to assess the net present value of the proposal.

[32] Source: http://www.uncsbrp.org/economicdevelopment.htm accessed 11/11/14.

5. AGRICULTURAL AMMONIA EMISSIONS

The main source of ammonia (NH_3) emissions is the agriculture sector. While emissions have been falling slightly in the UK (Figure A.4, Annex A), deposition of compounds of reduced N (NH_y) has changed little. Cattle remains the largest emission source, with other livestock (poultry, pigs and sheep - in descending order of importance) also emitters. However, non-agricultural sources are also relevant, mainly through industrial and combustion processes (Webb et al., 2002). Historically, petrol vehicles fitted with catalytic converters were also a significant source, but successive European standards have steadily decreased the emissions for new vehicles, to levels as low as those for pre-catalyst vehicles (Carslaw and Rhys-Tyler, 2013).

Ammonia flows in the atmosphere are described in more detail in Annex C. Gaseous emissions of ammonia can be deposited within precipitation over a large spatial radius from the source, with dry deposition primarily occurring close to the sources (Bealey, forthcoming). It is typically difficult to differentiate the environmental effects of reduced forms of N from other (oxidised) forms of nitrogen deposition (RoTAP, 2012). However, in the UK, ammonia is responsible for roughly two thirds of all N deposition.

5.1. Potential measures

Currently, specific air quality measures targeting ammonia from agriculture include the Integrated Pollution, Prevention and Control (IPPC, as part of the EU Industrial Emissions Directive[33]), which regulates emissions from large, intensive pig and poultry farms through a system of permits. Animal housing and the spreading of manure on land represent the main land management activities that give rise to ammonia emissions (Webb et al., 2002). To date, measures to target these emissions have included: low emission manure spreading and handling techniques; modifying livestock diet through low-protein feeds; decreasing the surface area fouled by manure; ‘scrubbing’ ammonia from the exhaust air of livestock housing; and improving manure storage through covering and encouraging crusting. The key mitigation measure that has been the focus of recent research are shelter-belts. This involves planting tree shelter belts in order to decrease ammonia concentrations downwind from sources (potentially a 15% - 45% reduction under realistic conditions) and a net decrease in emissions to the atmosphere (Bealey, forthcoming).

5.2. Outcomes

Ammonia is of concern for two reasons: it contributes to secondary aerosol formation of fine particles, which result in impacts on human health; and as a component of nitrogen deposition it affects the environment and therefore biodiversity through eutrophication, acidification and direct toxicity (Jones et al. 2014). With respect to human health, in addition to the effects from fine particles, ammonia can also alter the uptake of oxygen by haemoglobin due to an increased pH within the blood (Issley and Lang, 2001), while ammonium hydroxide can cause various forms of tissue irritation (Zumdahl, 1997).

Annex D outlines the impact pathway for eutrophication and direct toxicity effects of ammonia. As a nutrient, nitrogen promotes plant growth. As nitrogen is dissolved in the water environment or leaches through the fertilisers in soil, it results in excessive plant growth and decay, which can lead to a lack of oxygen in the water, suffocating fish and other aquatic species. Ammonia is also toxic to vegetation at high concentration, with potential impacts on plant growth, provisioning services (e.g. growth), and species composition.

[33] Directive on IPPC is officially designated Directive 2008/1/EC.

Finally, as nitrogen deposition (and so ammonia deposition) results in the release of the greenhouse gas nitrous oxide (N_2O), climate regulation is another potentially key area of concern (Smart et al., 2011).

5.3. Economic impacts of measures

Costs for implementation of agricultural measures vary according to the form of the mitigation. In many cases, this could simply be a change in the procedures taken within the farm, which may not result in a cost. However, larger measures such as scrubbing ammonia from exhaust air will require investments in technologies and periodic maintenance. This document discusses one potential measure 'tree shelter belts' in detail which has significant potential for application to large-scale point sources such as intensive animal husbandry units. However, it is noted that other measures such as improved manure management are also applicable to this type of source. Improved handling measures can substantially reduce ammonia emissions resulting from other ammonia sources, such as slurry or fertiliser application to agricultural land.

The cost for this 'shelter-belt' measure can be broader than one-off start-up costs. Setting aside plots of land for planting trees implies an opportunity cost in terms of reduced production. For poultry farming, the quality of the land might be negligible, but in lowland farms, the value of alternative uses may be significant (e.g. arable land or pasture). While these measures also entail maintenance costs, they will also potentially yield benefit (revenues) from felling of the trees periodically.

Further costs arise from the unintended consequences of pollution swapping, primarily the increase in nitrate leaching that will occur due to N saturation of the soil below tree shelter belts. High nitrate leaching in groundwater or streams adjacent to the site can cause additional impacts on the environment and have associated economic costs. However, the risks of such leaching depend on the location of the shelter-belt and can be managed by other measures (e.g. runoff controls).

While certain changes in agricultural practices could be implemented within a few years, tree shelter belts typically take over 10 years to become effective, and the changes in storage or housing of livestock depend on the lifetime of the existing infrastructure.

5.4. Case Study

Box 5.1: Illustrative dairy farm shelter-belt example

Background

Trees are effective scavengers of both gaseous and particulate pollutants from the atmosphere (Beckett et al., 2000; Nowak, 2000). There is a potential benefit of converting grassland and arable land to forests, as the dry deposition rates[34] of forest typically exceed those of grassland by a factor of 3–20 (Gallagher et al., 2002; Fowler et al., 2004).

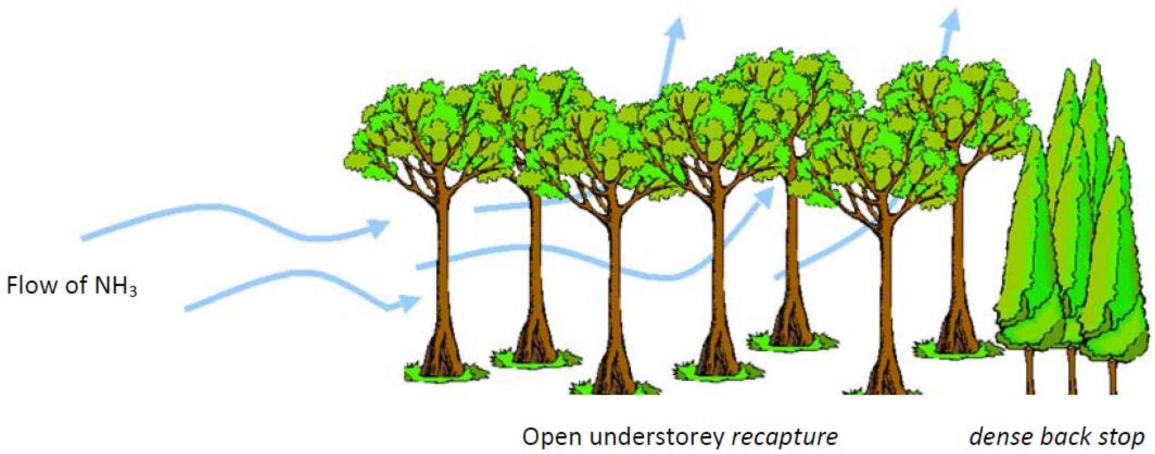
Beneficiaries

[34] Deposition is the process by which aerosol particles (like ammonia) collect/deposit themselves. Through dry deposition, ammonia particles/gas are transported on wind, while wet deposition involves the particles being dissolved in water particles in the air and deposited through rain, fog and snow.

Ammonia's toxicity effects are primarily local to large point sources, meaning that beneficiaries will also be on the local scale, both in terms of the human health and environmental effects. Hence, benefits are likely to be greatest where there are significant human receptors and/or sensitive natural habitats. Benefits in relation to conversion of ammonia to ammonium and its impacts on the environment through nitrogen deposition exceeding the critical loads may be distributed on a wider spatial scale (and range in scale from local to UK-wide) as fine particles travel further than ammonia. Therefore, the spatial scale of human health benefits is more dependent on the ambient conditions (e.g. other particles in the atmosphere required to create ammonium) and the meteorological conditions. Climate change regulation benefits are global in scale.

__Quantifying ecosystem services__

The following sets out an illustrative example in relation to a dairy farm, based on reporting by Bealey et al. (forthcoming). This outlines an shelter-belt measure for mitigating ammonia emissions. This is achieved by creating an open understorey in the tree shelterbelt to recapture the ammonia, preventing it from passing over the woodland, and then a dense backstop at the downwind edge to force the ammonia up through the canopy. This process is illustrated below:



Bealey et al. test the impact of three livestock production systems, including a waste storage system from a slurry lagoon for pig/dairy farming. For each system, the recapture efficiency of tree planting around these sources is estimated under different canopy structure scenarios, lengths and differing leaf densities. Overall 20% ammonia capture efficiency is estimated for waste storage systems, based on a 10 meter tall tree canopy with a 25 meter long main canopy and 25 meter dense backstop canopy.

__Private benefits and costs__

Following Sandars (forthcoming), the net private impacts (to the farm) can be estimated for a beech wood and spruce wood understorey and backstop (respectively). Taking a 25-year time horizon, this is calculated to be a cost of £26k in present value terms (2010 prices), following Green Book guidance for discounting (HM Treasury, 2011). This is based on the depth of the woodland of 50 metres (for 25m understorey and 25m backstop) and assumes only 50 meters distance from the emission source, as this requires the smallest area for planting trees.

Private costs include planting trees and maintenance, whilst private benefits primarily relate to potential grants for the development and upkeep of a shelterbelt. Costs are potentially over-estimated as the upper limit for the opportunity costs of land for dairy farming are assumed. In addition, potential timber harvesting revenues and costs are omitted, implying an underestimate of private benefits. External costs include those arising from pollution swapping, primarily resulting from higher risks of nitrate leaching below tree shelter belts.

If the distance from the emission source is increased to 400m (which requires the largest area for planting), the net cost increases to £142k. In practice, the ideal distance will depend on the conditions of the farm and the exact requirements for dairy farming.

External benefits and costs

Unit value (net) benefits estimates are summarised below:

	Unit values (2010, £)	Source
Human health *Chronic mortality effects, morbidity effects and health impacts from secondary particulate matter*	£1,633/t	IGCB damage costs estimates[35]
Climate regulation effects *Reduction in nitrogen dioxide release from soil*	£660/t	DECC (2009)
Net environmental effects* *Impacts on provision of (other) ecosystem services*	Not available	-

Notes: *net benefit per tonne ammonia emission excluding nitrogen dioxide sequestration

Unit value estimates for human health and climate regulation benefits associated with reduced/mitigated ammonia emissions are available from established sources (IGCB and DECC). Equivalent £/tonne estimates are not available for the (net) effect on the provision of (other) ecosystem services. However, Jones et al. (2014) identify a number of effects of nitrogen deposition on ecosystems, including: reductions in timber production and livestock production from a fall in nitrogen deposition, which contributes to plant growth and reduces the carbon sequestration ability of the plant life. The reduced eutrophication of water results in benefits to recreational fishing; and reduced loss of biodiversity from acidification translates to benefits which can be estimated through society's willingness to pay for the appreciation of biodiversity. Damage costs for NH_3 impacts on the environment have been calculated, but are not yet available (Jones et al. forthcoming).

The calculation of the external benefits is outlined as follows:

- The average size of a commercial dairy farm in 2013 was approximately 134 cows[36], and the average emission is 28 kg of ammonia per animal per year (AEIG, 1998). Therefore, the 'average' dairy farm in the UK emits approximately 3.75 tonnes of ammonia annually.
- A shelter-belt for a slurry lagoon is estimated to result in 20% ammonia capture efficiency. This implies the 'average' dairy farm would see a reduction of 0.75 tonnes of ammonia emissions annually.

[35] See: https://www.gov.uk/air-quality-economic-analysis.

[36] See: http://www.thisisdairyfarming.com/discover/dairy-farming-facts/how-many-cows-are-there-on-the-average-farm/.

- Estimated benefits are presented as a range. The high estimate is based on immediate mitigation and low is based on mitigation only starting in 10 years from planting:
    - Benefits in terms of human health (IGCB damage costs) are estimated to be £15k - £26k in present value terms over 25 years.
    - For climate regulation, NO_2 release can vary depending on the habitat (Skiba et al., 1999; Horvath et al. 2003). Mid-range estimates of climate regulation benefits are estimated to be £42k - £78k in present value terms over 25 years. These estimates are the arithmetic average of the following upper and lower estimates:

Upper: taking that the global warming potential of NO_2 is 310 times that of CO_2 (Houghton and Keller, 2001; DECC, 2009) and that nitrogen dioxide released from the soil represents 5% of nitrogen deposition (Smart et al., 2011), a tonne reduction in nitrogen deposition (and so ammonia deposition) is equivalent to a 15.5 tonne reduction in CO_2e. Based on DECC guidance (DECC, 2009), the upper estimate of the present value of climate regulation benefits (over 25 years) is estimated to be £71k-£131k.

Lower: the global warming potential of NO_2 is approximately 290 times that of CO_2 (Forster et al., 2007) and taking that nitrogen dioxide release represents only 1% of nitrogen deposition (IPCC, 2006), this represents a lower estimate of £13k - £24k in present value.

- The estimated range of the present value of human health and climate regulation benefits over 25 years for the shelter-belt example is £57k - £104k[37].

The main caveats for these illustrative estimates are:

- There are a number of assumptions regarding the farming practices. AEIG (1998) was produced as a guide for Europe as a whole, and therefore may not necessarily reflect the typical conditions in England. A constant farm size is assumed for the period 2010-2035, and the amount of ammonia emitted is assumed constant as a result.
- It is estimated that maximum mitigation benefits will be experienced in 10 years. However, benefits are also assumed constant from year 10 onwards, and are more likely to gradually increase to their maximum level.
- Human health benefits are uplifted by 2% per annum, to reflect the fact that willingness to pay for human health and environmental benefits rises with economic growth (Defra, 2011).
- The climate regulation benefits are based on the assumption that a tonne of ammonia emissions results in a tonne of nitrogen deposition, an approach that has been taken in previous studies (Smart et al., 2011). Also, further impact pathways of nitrogen deposition are not considered, such as the potential effect of a reduction in plant growth and the resulting reduction in carbon sequestration.
- Net environmental benefits are not included in these estimates.
- The human health unit (damage) costs are derived using the Photochemical Trajectory Model (Defra, 2008), by considering the change in population weighted particulate concentrations from a 30% reduction in ammonia emissions. As most of the UK population currently live in urban areas, there is likely to be a larger weight placed on the health effects on the urban population than the rural area. Therefore, these benefits might be overestimates for the rural area, and are better suited for application to locations close to population hubs.

Calculated benefit-cost ratio

[37] Present value calculation follows the Green Book guidance (HM Treasury, 2011) on the use of a discount rate of 3.5% over the 25 year period.

The table below reports a range of benefit-cost ratios based on the estimated private and external costs and benefits.

Cost/Benefit (description)	Central value (range)	
	No lag	10-year lag
25 Year BCR (low cost)	4.0: 1 (6.1: 1 – 2.0: 1)	2.2: 1 (3.3:1 – 1.1: 1)
25 Year BCR (high cost)	0.7: 1 (1.1: 1 – 0.3: 1)	0.4: 1 (0.6:1 – 0.2: 1)

The central value estimates are based on the (arithmetic) average of the upper and lower estimates of the climate regulation benefits. The reported range reflects the upper and lower bounds.

Comparing Costs and Benefits

The calculated BCRs do not incorporate a monetary valuation for some environmental effects. However, Jones et al. (2014) suggest these may be significant. They estimate a net benefit to ecosystem service provision as a result of declines in nitrogen emissions (including ammonia) for the period 1987 - 2005. This is based on a net reduction in average UK deposition to 17.6 kgN/ha/yr (2005) from 20.2 kgN/ha/yr (a decline of 2.53 kgN/ha/yr) (1987). The aggregate net benefit is estimated to be £65.8m in equivalent annual value (EAV) terms, with a sensitivity range of £5.1m to £123.2m (EAV). It is estimated that reduced nitrogen deposition results in a net loss for provisioning services (timber and livestock) but a net gain for cultural services (appreciation of biodiversity and recreational fishing). Regulating services also show a net loss as the nitrogen dioxide sequestration benefits are offset by reduced carbon sequestration (see caveats above).

Jones et al. suggest ranges for the net environmental benefits, and the discussion above identifies ranges for other benefits (e.g. health). The range of total benefits overlaps with the range of costs developed for the two scenarios. Therefore, as the choice of figures used can result in a benefit-cost ratio of either <1 or >1, it is informative to calculate a 'switching value', where the value of all benefits (including net environmental benefits) for the dairy farm shelter-belt example exceed the costs from the high-cost scenario. The net environmental benefit would need to be equivalent to £3,411/tonne (no lag) and £13,050/tonne (10-year lag) per year in 2010, to give BCRs equal to 1. Based on these unit values, the present value of net environmental benefits over 25 years would be £43k and £90k (respectively)[28]. These net environmental benefits are 0.4 and 1.6 times the value of the benefits for human health and climate regulation.

These results imply that to obtain a BCR > 1 for the high-cost shelter-belt measures, health, climate regulation and net environmental benefits need to be realised. This will only be the case in specific locations:

- Where measures benefit sensitive habitats (and more so if human health benefits are also relevant). This particularly includes ecosystems that are naturally adapted to small supplies of nitrogen; e.g. montane systems, heathland and moorland, blanket bogs, and some grassland (Hornung et al., 2002); and
- Where they mitigate emissions sources that are in proximity to population centres, and therefore are likely to lead to human health benefits.

Therefore, as the case for lower cost measures is less reliant on achieving the full range of benefits, it is also less dependent on location. Meaning that they may have net benefits where only one of the above location criteria are met.

Conclusion

This illustrative case study considers a narrow example in relation to the impact of the mitigation of ammonia. Bealey et al. also considered the impact of measures on housing emissions (20% emissions efficiency) and emissions when livestock are grazing (45% emissions efficiency). Depending on livestock patterns (for example, between housing and pastures), this could result in a fall in the ammonia efficiency factor (for dairy, which is largely situated in the housing) or a rise. Bealey et al. primarily consider the impact of poultry and pigs. Pigs have lower annual emissions, with only 6 kg of ammonia emitted (AEIG, 1998), but larger numbers and the largest grazing period (Bealey et al.). Poultry has even lower annual emissions, of only 0.37 kg emitted (AEIG, 1998), even larger numbers of livestock and a slightly lower period grazing. Therefore, there is scope for future research into understanding how farm specific conditions impact the balance of costs and benefits for various forms of livestock.

The feasibility of this measure is likely to be dependent on public subsidies to incentivise farmers to take on such action. Although private net benefits have been under-estimated in this case, as the potential revenue from periodic tree felling is omitted, shelter-belt measures would appear to represent an opportunity cost. Therefore, grant schemes would be required to transfer some of the external benefits to farmers, in order for measures to be implemented.

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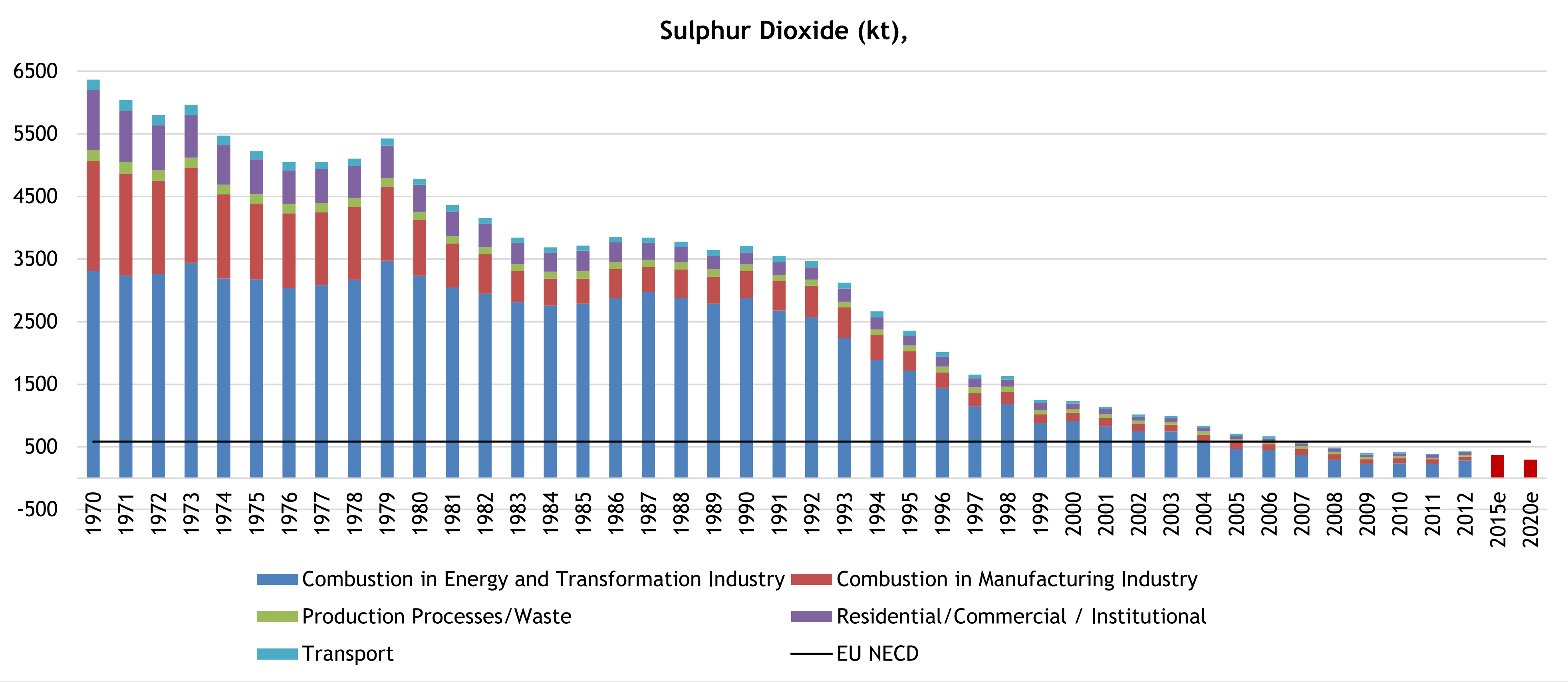
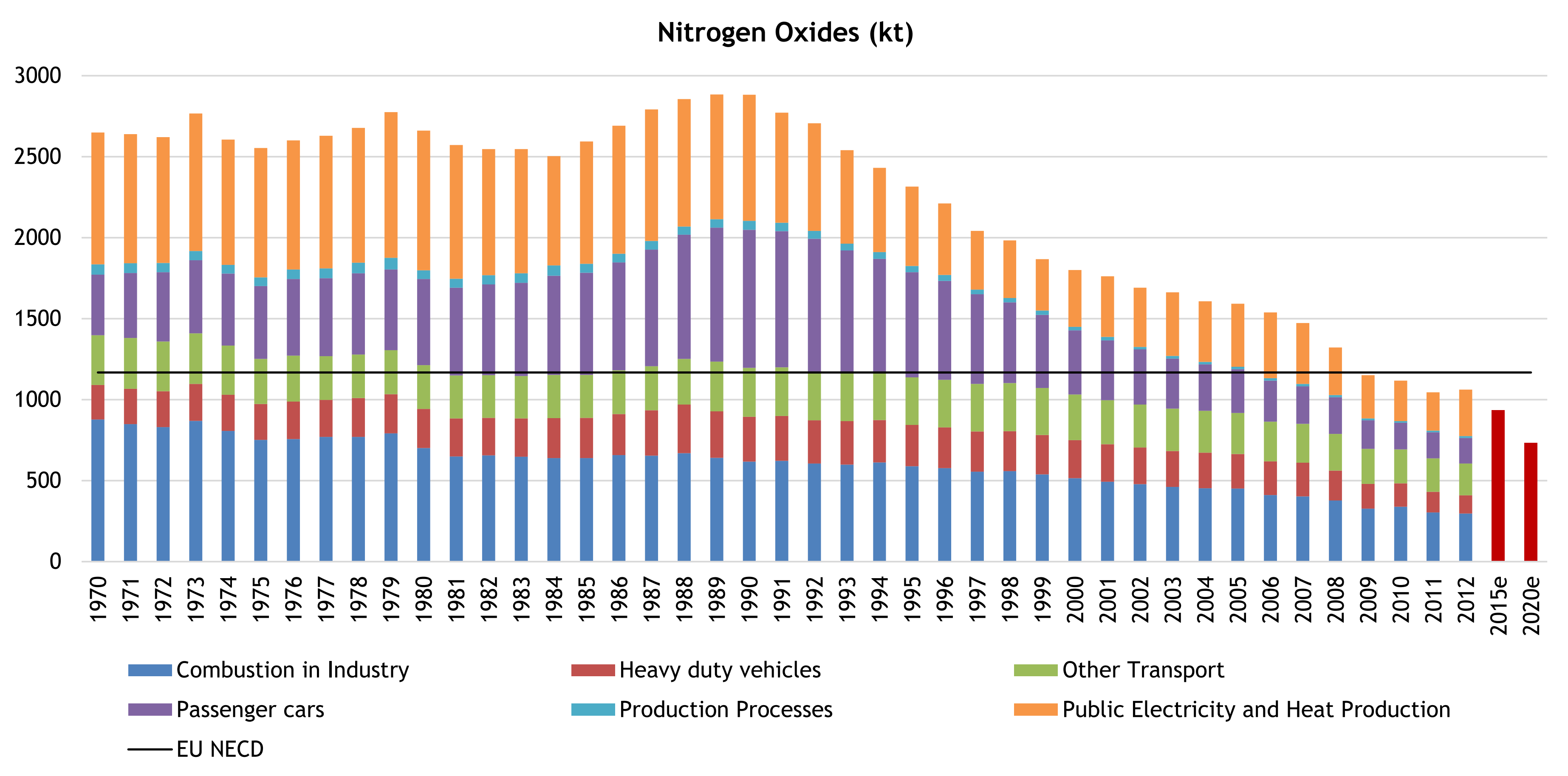
ANNEX A: HISTORIC AND PROJECTED EMISSIONS

Figure A.1: Emissions of Sulphur Oxides (1970-2012; predicted emissions for 2015 and 2020)



Sources: Emissions data from National Atmospheric Emissions Inventory (NAEI), 2012. Available at: http://naei.defra.gov.uk/overview/pollutants. Predicted emissions from: EIONET (2012) UK 2012 Submission to the UN Convention on Long-Range Transboundary Air Pollution (LRTAP), European Environment Information and Observation Network, Central Data Repository. Available at: http://cdr.eionet.europa.eu/gb/un/cols3f2jg/envtzp7xq.

Figure A.2: Emissions of Nitrogen Oxides (1970-2012; predicted emissions for 2015 and 2020)



Sources: Emissions data from National Atmospheric Emissions Inventory (NAEI), 2012. Available at: http://naei.defra.gov.uk/overview/pollutants. Predicted emissions from: EIONET (2012) UK 2012 Submission to the UN Convention on Long-Range Transboundary Air Pollution (LRTAP), European Environment Information and Observation Network, Central Data Repository. Available at: http://cdr.eionet.europa.eu/gb/un/cols3f2jg/envtzp7xq.

Figure A.3: List of UK Zones that have passed/failed Limit Value for Nitrogen Dioxide, 2013

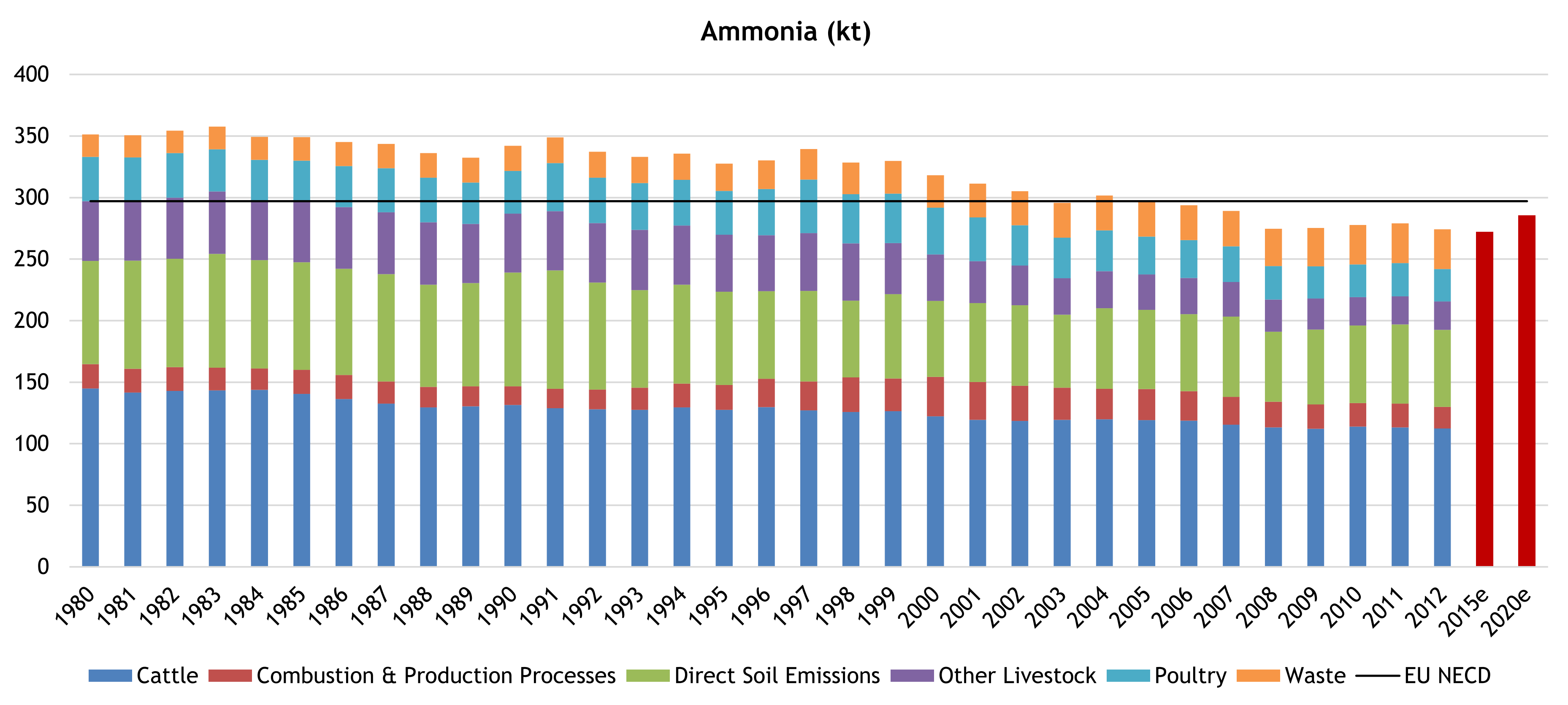
Zone	Zone code	NO_2 LV for health (1hr mean)	NO_2 LV for health (annual mean)	NOx critical level for vegetation (annual mean)
Greater London Urban Area	UK0001	> LV	> LV	n/a
West Midlands Urban Area	UK0002	OK	> LV	n/a
Greater Manchester Urban Area	UK0003	OK	> LV (m)	n/a
West Yorkshire Urban Area	UK0004	OK	> LV	n/a
Tyneside	UK0005	OK	> LV	n/a
Liverpool Urban Area	UK0006	OK	> LV (m)	n/a
Sheffield Urban Area	UK0007	OK	> LV (m)	n/a
Nottingham Urban Area *	UK0008	OK	> LV + MOT (m)	n/a
Bristol Urban Area	UK0009	OK	> LV (m)	n/a
Brighton/Worthing/Littlehampton	UK0010	OK	> LV (m)	n/a
Leicester Urban Area *	UK0011	OK	> LV + MOT (m)	n/a
Portsmouth Urban Area *	UK0012	OK	≤ LV + MOT (m)	n/a
Teesside Urban Area	UK0013	OK	> LV (m)	n/a
The Potteries	UK0014	OK	> LV (m)	n/a
Bournemouth Urban Area	UK0015	OK	> LV (m)	n/a
Reading/Wokingham Urban Area	UK0016	OK	> LV (m)	n/a
Coventry/Bedworth	UK0017	OK	> LV (m)	n/a
Kingston upon Hull	UK0018	OK	> LV (m)	n/a
Southampton Urban Area	UK0019	OK	> LV (m)	n/a
Birkenhead Urban Area *	UK0020	OK	≤ LV + MOT (m)	n/a
Southend Urban Area *	UK0021	OK	≤ LV + MOT (m)	n/a
Blackpool Urban Area	UK0022	OK	OK	n/a
Preston Urban Area *	UK0023	OK	OK	n/a
Glasgow Urban Area	UK0024	OK	> LV	n/a
Edinburgh Urban Area *	UK0025	OK	≤ LV + MOT (m)	n/a
Cardiff Urban Area *	UK0026	OK	> LV + MOT (m)	n/a
Swansea Urban Area *	UK0027	OK	≤ LV + MOT (m)	n/a
Belfast Metropolitan Urban Area	UK0028	OK	> LV (m)	n/a
Eastern	UK0029	OK	> LV (m)	OK
South West	UK0030	OK	> LV	OK
South East	UK0031	OK	> LV	OK
East Midlands	UK0032	OK	> LV	OK
North West & Merseyside	UK0033	OK	> LV (m)	OK (m)
Yorkshire & Humberside	UK0034	OK	> LV (m)	OK
West Midlands	UK0035	OK	> LV (m)	OK (m)
North East	UK0036	OK	> LV (m)	OK (m)
Central Scotland *	UK0037	OK	≤ LV + MOT (m)	OK (m)
North East Scotland	UK0038	OK	> LV	OK (m)
Highland	UK0039	OK	OK	OK (m)
Scottish Borders	UK0040	OK	OK	OK
South Wales	UK0041	OK	> LV (m)	OK
North Wales*	UK0042	OK	≤ LV + MOT (m)	OK
Northern Ireland *	UK0043	OK	OK	OK (m)

LV = limit value, MOT = margin of tolerance, (m) indicates that the compliance or exceedance was determined by modelling.

Asterisk (*) indicates a time extension in place during 2013.

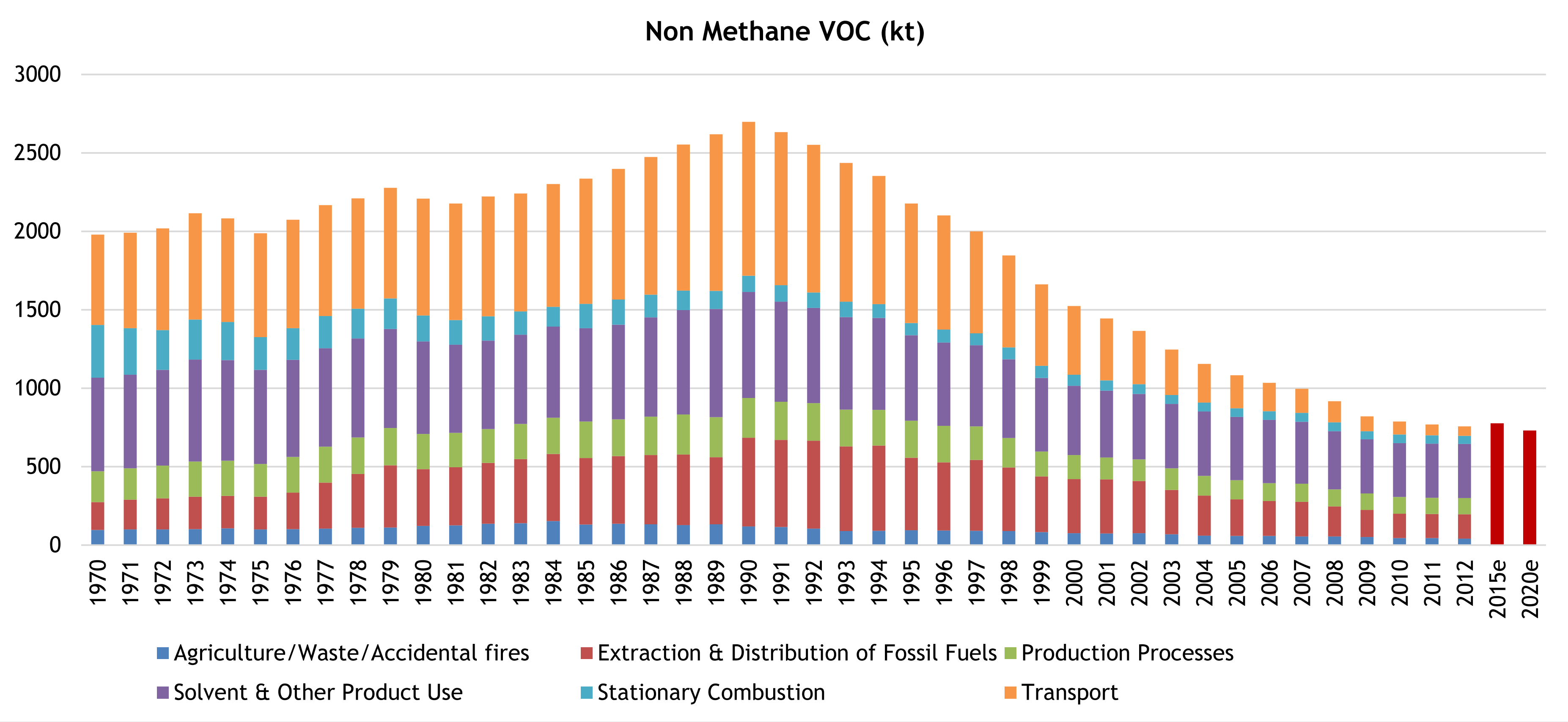
Source: Defra (2014)

Figure A.4: Emissions of Ammonia (1980-2012; predicted emissions for 2015 and 2020)



Sources: Emissions data from National Atmospheric Emissions Inventory (NAEI), 2012. Available at: http://naei.defra.gov.uk/overview/pollutants. Predicted emissions from: EIONET (2012) UK 2012 Submission to the UN Convention on Long-Range Transboundary Air Pollution (LRTAP), European Environment Information and Observation Network, Central Data Repository. Available at: http://cdr.eionet.europa.eu/gb/un/cols3f2jg/envtzp7xq.

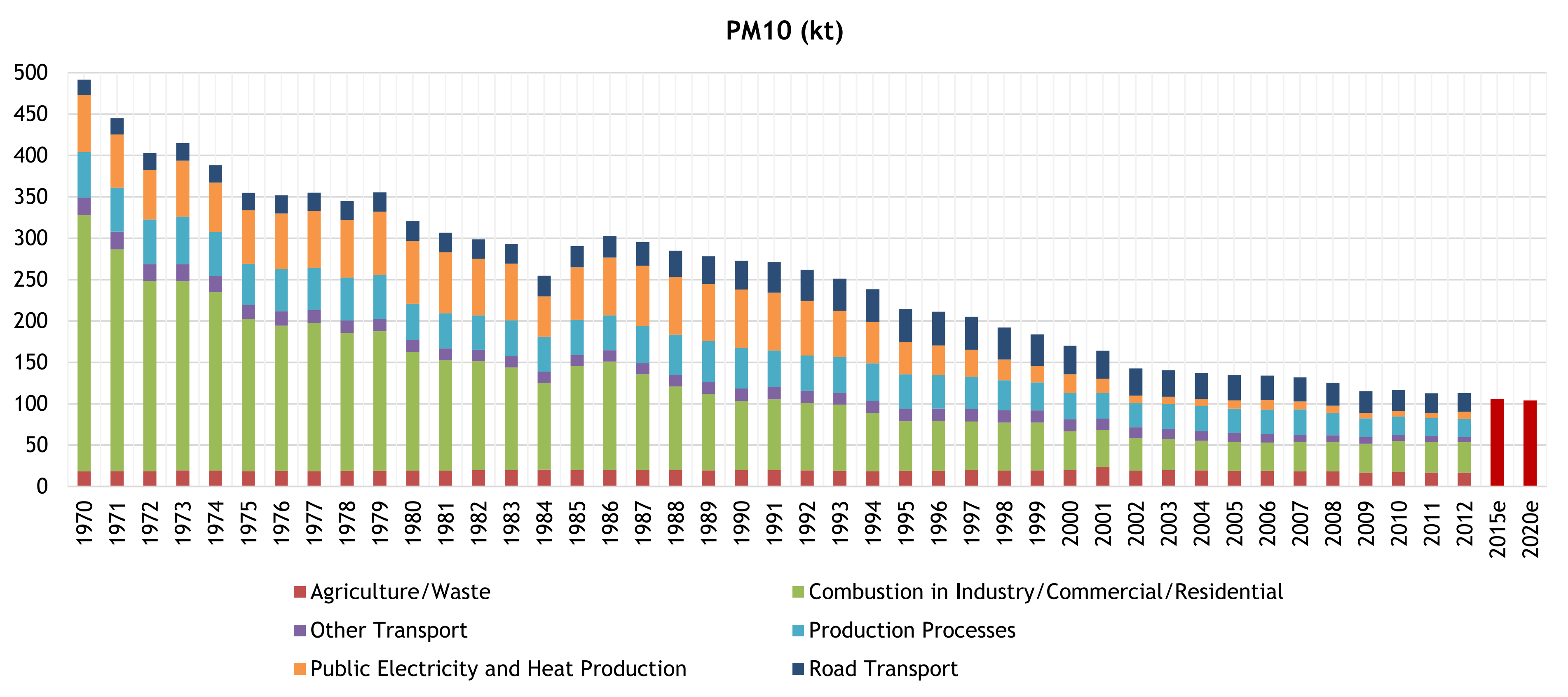
Figure A.5 : Emissions of Non-Methane VOCs (1970-2012; predicted emissions for 2015 and 2020)



Sources: Emissions data from National Atmospheric Emissions Inventory (NAEI), 2012. Available at: http://naei.defra.gov.uk/overview/pollutants. Predicted emissions from: EIONET (2012) UK 2012 Submission to the UN Convention on Long-Range Transboundary Air Pollution (LRTAP), European Environment Information and Observation Network, Central Data Repository. Available at: http://cdr.eionet.europa.eu/gb/un/cols3f2jg/envtzp7xq.

Emissions targets for the NECD are not presented as targets are set for VOCs in general, not specifically NMVOCs.

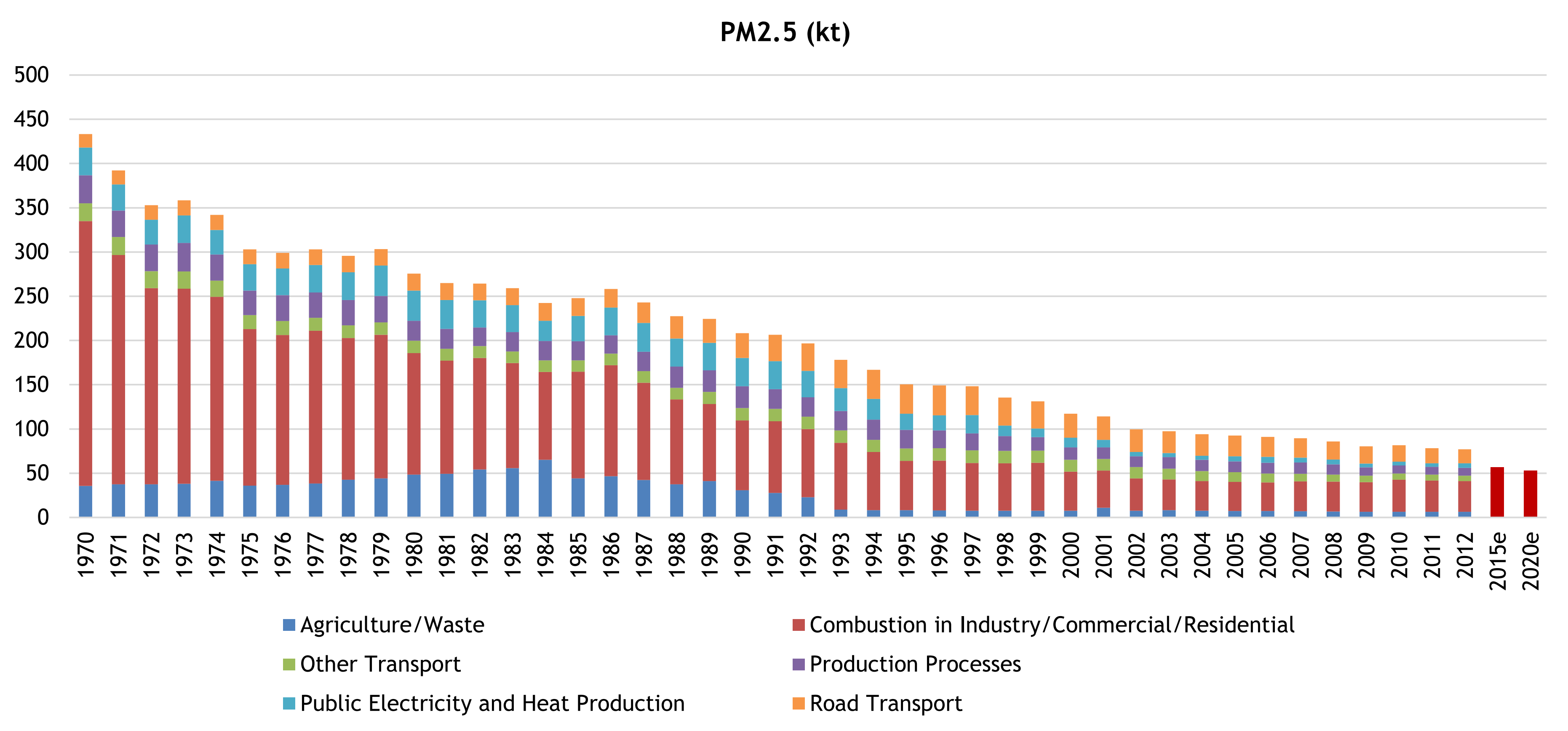
Figure A.6: Emissions of PM10 (1970-2012; predicted emissions for 2015 and 2020)



Sources: Emissions data from National Atmospheric Emissions Inventory (NAEI), 2012. Available at: http://naei.defra.gov.uk/overview/pollutants. Predicted emissions from: EIONET (2012) UK 2012 Submission to the UN Convention on Long-Range Transboundary Air Pollution (LRTAP), European Environment Information and Observation Network, Central Data Repository. Available at: http://cdr.eionet.europa.eu/gb/un/cols3f2jg/envtzp7xq.

No emission targets exist for PM10 within the NECD (not a transboundary pollutant).

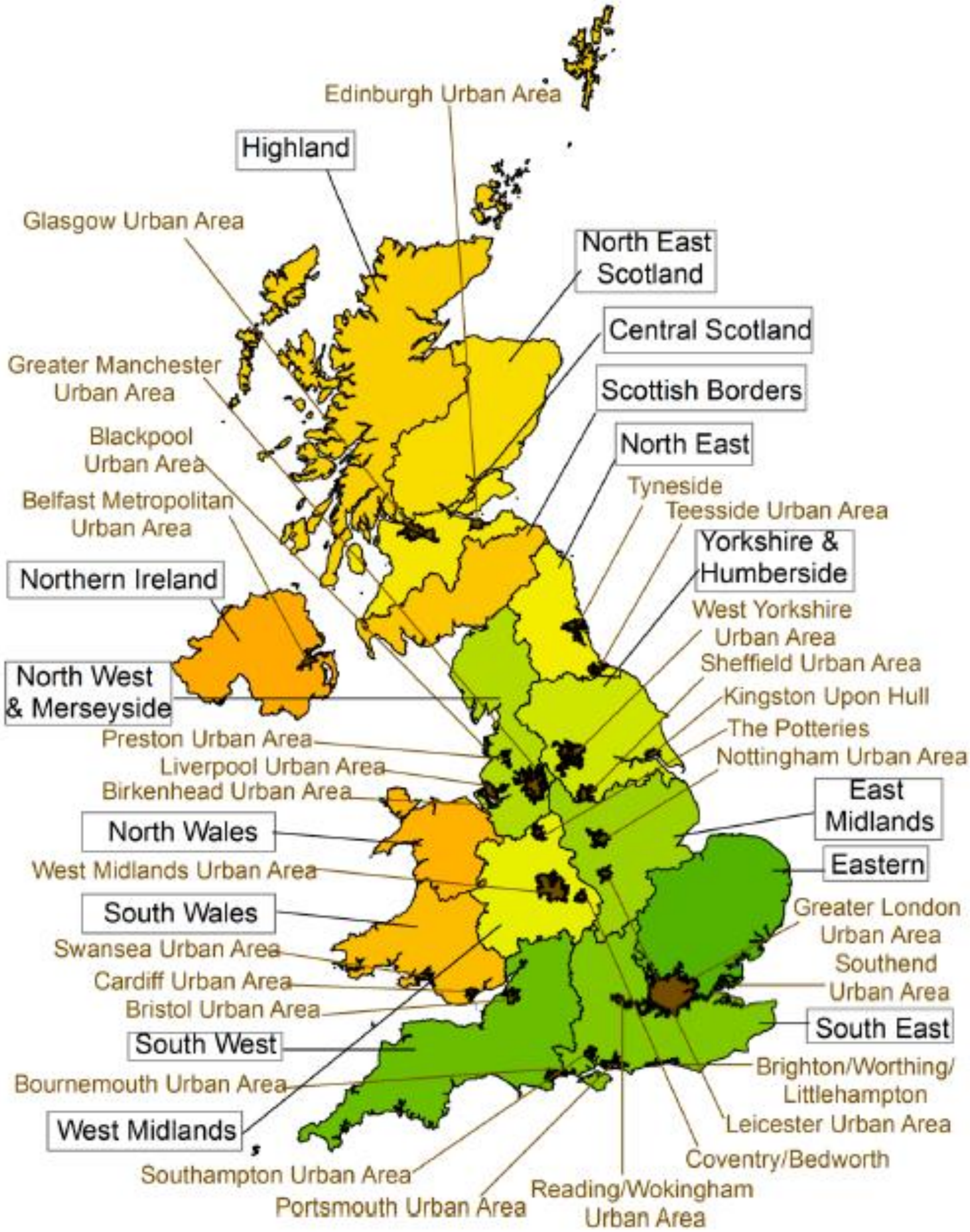
Figure A.7: Emissions of $PM_{2.5}$ (1970-2012; predicted emissions for 2015 and 2020)



Sources: Emissions data from National Atmospheric Emissions Inventory (NAEI), 2012. Available at: http://naei.defra.gov.uk/overview/pollutants. Predicted emissions from: EIONET (2012) UK 2012 Submission to the UN Convention on Long-Range Transboundary Air Pollution (LRTAP), European Environment Information and Observation Network, Central Data Repository. Available at: http://cdr.eionet.europa.eu/gb/un/cols3f2jg/envtzp7xq.

While concentration targets have been established for PM2.5, in the latest NECD, there is no equivalent emissions target.

ANNEX B: MAP OF ZONES AND AGGLOMERATIONS WITHIN THE UK



Agglomeration zones (brown)
Non-agglomeration zones (yellow/green)

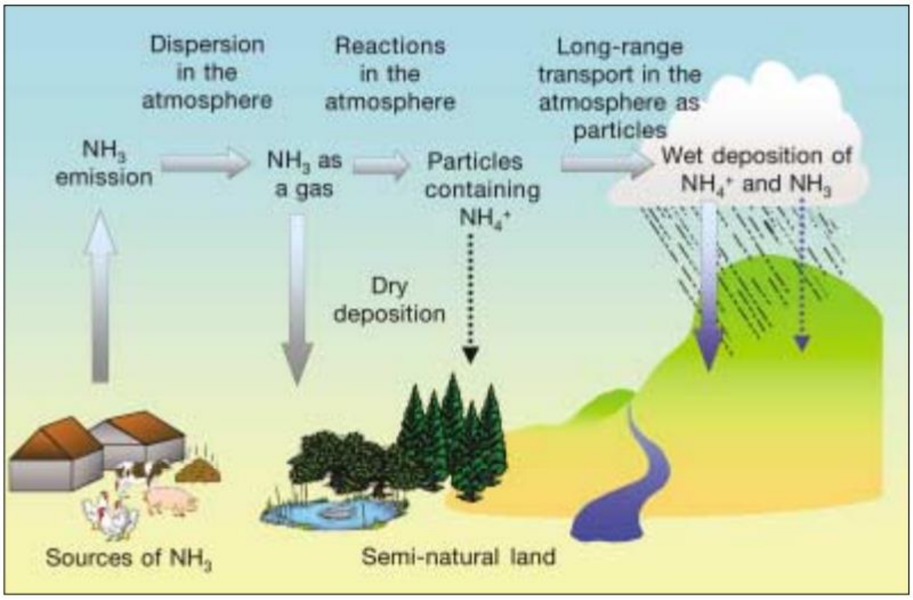
Source: Defra (2014)

ANNEX C: IMPACT PATHWAYS FOR AMMONIA EMISSIONS

Ammonia is released from sources in gaseous form and disperses into the atmosphere before being deposited (Figure C.1). This can occur in a large spatial radius from the source and can be absorbed by land and water surfaces (dry deposition) or be dissolved in rain/snow to fall (wet deposition). The effects of dry deposited ammonia, however, primarily occur close to the sources (Bealey, forthcoming). Ammonia can also react with other particles in the atmosphere to form fine particle ammonium (NH_4^+, a type of PM2.5), which can travel further and can similarly be absorbed through dry or wet deposition (Sutton and Fowler, 2002).

Deposition of ammonia is a form of nitrogen deposition, and it is typically difficult to differentiate it from other (oxidised) forms (RoTAP, 2012). The evidence is mixed on whether the impact of ammonia (relative to nitrogen dioxide, for example) is more or less toxic to the ecosystem, as it depends on the habitat exposed (Jones et al., 2014). Due to this, most studies assume that there is an equal environmental impact from ammonia and nitrogen oxides (Jones et al., 2014; Smart et al., 2011).

Figure C.1: Ammonia flows in the atmosphere

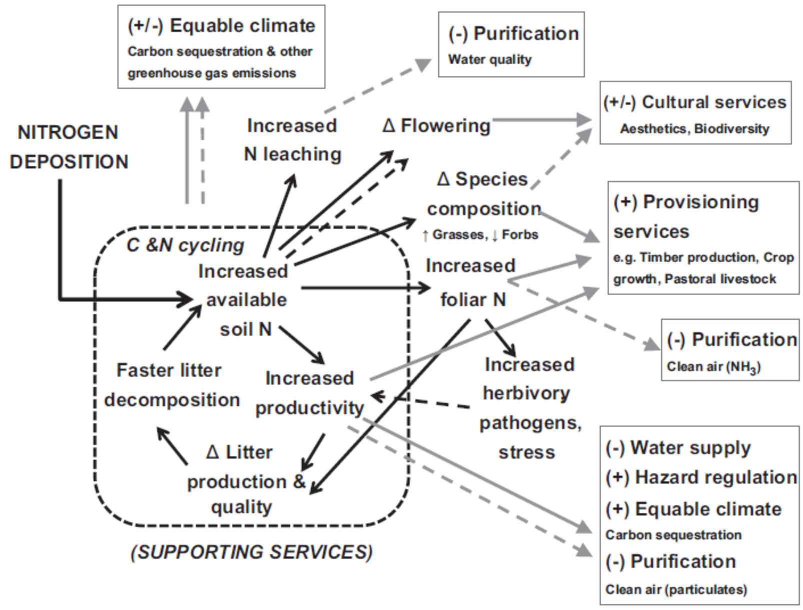


Source: Sutton and Fowler (2002)

Nitrogen (ammonia and nitrogen oxides) deposition remains a concern in relation to impacts on ecosystems, as it is estimated that by 2020, 48% of sensitive habitats in the UK will still exceed the critical load for nutrient nitrogen (Hall et al., 2006; Halsworth et al., 2010). This implies the potential for toxic levels of deposition, which can result in eutrophication in the water environment.

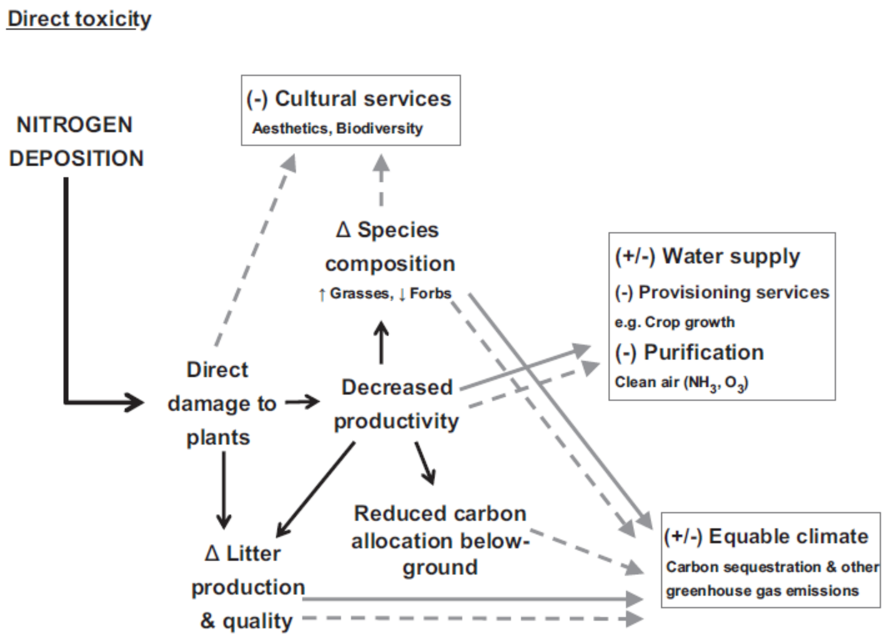
ANNEX D: IMPACT PATHWAYS FOR NITROGEN DEPOSITION

Figure D.1: Process-based impact pathway for eutrophication



Source: Jones et al. (2014)

Figure D.2: Process-based impact pathway for direct toxicity



Source: Jones et al. (2014)