Health costs savings of West Yorkshire Low Emission Zone

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Summary of key findings

- Using results estimated as part of a health impact assessment regarding a West Yorkshire Low Emission Zone strategy, this paper quantifies cost-saving and health-improving implications of transport policy through its impact on air quality.
- The methods used are familiar to practitioners in pharmacoeconomics or health economics, but have less precedent in environmental economics.
- Cost savings considered are those affecting health and social care (NHS and PSS) budgets. They are calculated for each event using a lifetime horizon where possible. Future years are discounted and reported values are net present values.
- Health improvements are quantified using quality-adjusted life years (QALYs). These are also calculated for each event using a lifetime horizon where possible, with future years discounted and values reported as net present values.
- Averting an all-cause mortality death generates 8.4 QALYs. Each coronary event avoided saves £28,000 in costs and generates 1.1 QALYs. For every fewer case of childhood asthma there will be cost saving of £3,000 and a health benefit of 0.9 QALYs. A single term, low birthweight birth avoided saves £2,000 in costs. Preventing a pre term birth saves £24,000 in costs and generates 1.3 QALYs.

Introduction

How cost-effective are interventions – such as low emission zones – in generating health? This question underpins our analysis concerning the costs and benefits associated with emissions. It is particularly important to local decision making given the central role of local authorities in public health. There are competing uses for the local authority budget and each has a different cost and health effect. As a result, economic analysis can make a substantial contribution to deciding how to effectively spend this budget and generate the best possible outcomes.

Using estimates of emissions, Public Health England, Leeds City Council and Bradford Metropolitan District Council were able to produce estimates of exposure to poor air quality for each lower super output area (LSOA) in Leeds and Bradford (Cooper et al., 2014). This information was used to generate a range of health impacts of four different low emission zone scenarios for each LSOA in their health impact assessment (HIA). As a consequence, the extent to which an intervention impacts upon health is estimated and comparisons can be carried out between competing policies.

Economic evaluation is 'integral' to the analysis for public health interventions according to the National Institute for Health and Care Excellence (NICE, 2012). The key principle is that decision makers have access only to a finite, fixed budget, from which they are required to maximise an outcome or set of outcomes. For every investment made by the decision maker there will necessarily be disinvestment as the introduction of an intervention or expansion of its provision displaces the use of another intervention, given the fixed budget. Therefore decision making regarding investments should recognise these disinvestments as part of the opportunity cost or benefits forgone, that is in addition to accounting for competing investments that could have been chosen.

A key outcome in public health policy is health. Although inherently difficult to quantify, one method advocated for use in economic evaluation by NICE is the quality-adjusted life year (QALY) (NICE, 2013). This combines mortality effects through the number of life years, and morbidity effects by weighting each life year by its associated health-related quality of life (where a weight of one signifies perfect health and a value of zero represents death). In addition, since healthcare use imposes a cost to the NHS and Personal Social Services (PSS) budget, which is considered to be finite and fixed, displaced resources also have a health effect. It also follows that QALYs can be monetised into the amount of healthcare resources that would be required to generate the health benefit. This is typically done using a value of £20,000 per QALY following NICE (2013).

In addition to challenges common to all economic evaluations, those involving public health interventions face four further challenges as outlined by Weatherly et al. (2014). These are:

i. attributing outcomes to interventions,
ii. measuring and valuing outcomes,
iii. incorporating equity considerations and
iv. identifying and quantifying inter-sectoral costs and consequences.

In this paper, we are looking to apply the principles of economic evaluation of a public health intervention to air quality management strategies, beginning with valuing the health impacts estimated in the HIA.

Methods

Overview

The HIA for Leeds and Bradford (Cooper et al. 2014) gave the reduction in the number of the following health events associated with a given policy scenario, which were identified using guidance from COMEAP (2010) as well as by conducting a search of all relevant meta-analysis studies using PubMed:

Health event	Pollutant	Source	Type of effect	Range of impacts estimated for four scenarios if implemented separately
All-cause mortality death	$PM_{2.5}$	Pope et al., JAMA, 2002	Annual	16-20 deaths averted per year
Coronary events (Bradford only)	$PM_{2.5}$	Cesaroni et al., BMJ, 2014	Annual	24-45 coronary events averted per year
Cases of childhood asthma	NO_2	Takenoue, Paediatrics Int, 2012	One-off (effect is on prevalence, not annual events)	254-580 cases of childhood asthma averted
Term, low birth weight birth	$PM_{2.5}$ and NO_2	Pedersen et al., Lancet Respir Med, 2013	Annual	31-58 term, low birth weight births averted per year
Pre term birth	$PM_{2.5}$	Sapkota et al., AQAH, 2012	Annual	3.2-4.1 pre term births averted per year

In order to attach valuations to each of these events, we apply published estimates of QALY losses associated with each health event, as well as the NHS and PSS resources used (given in 2013/2014 prices). All outcomes in subsequent years are discounted at 3.5% per year (given pre-discounted data relating to some of the health endpoints, this was used for consistency. It should be noted that this a subject of much debate – see for example Claxton et al., 2011 and indeed NICE (2012) advocate a discount rate of 1.5% per year for all outcomes).

The process of calculating QALY losses can be considered as two/three steps depending on the nature of the health impact:

1. Calculate health-related quality of life (HRQoL) decrement for each life year affected by the health impact.
2. If there is an effect on mortality, calculate which life years are lost (equivalent to assuming a health-related quality of life of 0 for affected years).
3. Where impacts on QALYs, from 1 or 2 (above), are not experienced in the present year, apply appropriate discount weight to determine the present value of these health impacts (years 1 +). This also applies to cost savings.

Since obtaining estimates of HRQoL and costs for each of these events was not always straightforward, some assumptions have been made, which are detailed in this paper. Where possible the valuations are based on data from Leeds and Bradford, but where this was not possible, data from elsewhere in the UK were used. A summary of the sources used is provided below.

Health event	Sources used for health cost calculation
All-cause mortality death	Kind et al. (1999), COMEAP (2010)
Coronary events (Bradford only)	Curtis (2014), Kind et al. (1999), ONS [census] (2011), ONS [life tables] (2014), Robinson et al. (2005), Sullivan et al. (2011)
Cases of childhood asthma	Curtis (2014), DH (2003)Gupta et al. (2004), Kind et al. (1999), ONS [census] (2011), ONS [life tables] (2014), Oswald et al. (1994), Peters et al. (2002), Sullivan et al. (2011)
Term, low birth weight birth	Curtis (2014), Petrou (2014)
Pre term birth	Colbourn et al. (2007), Curtis (2014), Kind et al. (1999), Mangham and Petrou (2008), Mangham et al. (2009)

Calculating health costs

All key cost savings are presented to the nearest £1,000 and key QALY gains are given to one decimal place. For each health endpoint we have given a combined value, where QALYs are monetised using £20,000 for each QALY. The spreadsheet containing all calculations is available upon request.

All-cause mortality

Pope et al. (2002) estimate that for every additional 10μg/m^3 PM2.5 there is a 6% elevated risk of all-cause mortality. They also estimate an elevated risk for cause-specific mortality, namely cardiopulmonary and lung cancer, although since these are necessarily a subset of all-cause deaths and no further information is provided on the circumstances of these deaths, we provide a valuation for all-cause deaths only (to avoid double counting). This estimate was generated on data where adults were aged 30 or above, which is assumed to be the only age group where this health effect is observed.

To convert these estimates into QALYs, we need to know how many years of life lost are averted due to an all-cause mortality, the HRQoL that these years of life lost would have been lived in and how many of the QALYs lost will not be in the current time period.

COMEAP (2010) – using the Pope et al. (2002) effect – estimate that exposure to particulate matter leads to a loss of approximately 340,000 life years in the UK from anthropogenic $PM_{2.5}$. In addition, they estimate that the same exposure results in roughly 29,000 attributable deaths. We therefore apply the same rate of life years per attributable death as implied by these estimates: 11.72.

There is much discussion in COMEAP (2010) as to how the life year loss is distributed amongst the population. They argue that it is unlikely that a specific person dies, on average, 11.72 years prematurely because of air pollution. We assume 2 life years lost per affected person, which equates to 5.86 people affected per attributable death. In order to provide a value for the HRQoL that these lost life years would have been lived in, they are assumed to be that experienced by 75+ year old in the UK (0.73, Kind et al. 1999) following COMEAP (2010) “mortality equivalent to nearly 29,000 deaths at typical ages of death”.

Our estimate of the QALY loss from an all-cause mortality death is 8.4 QALYs, which equates to £168,000.

Coronary events

Cesaroni et al. (2014) find an elevated risk of coronary events for adults of 19% for adults for every increase of 5µg/m^3 of PM2.5 (where levels of PM2.5 are reasonably low – exposure below 15µg/m^3 – such as found in West Yorkshire). They consider all events with ICD-9 codes 410 and 411 to capture "acute myocardial infarction" and "other acute and sub-acute forms of ischemic heart disease" and all deaths from ischemic heart diseases (ICD-9 codes 410-414). The authors exclude respondents with history of cerebrovascular events or acute coronary events in order to capture incident cases only. The effect is estimated using data from 11 European cohort datasets, which contain adults only. It seems unlikely that coronary events are equally likely to result from particulate matter for all people aged over 18 years old. Indeed, the authors test for effect modification with age. For those under 60 years old the effect of particulate matter on coronary events is not significant at the 5% level (hazard ratio 0.91, 95% confidence interval 0.71 to 1.15). As a consequence, we assume that only those aged 60 or over have increased risk of a coronary event from exposure to PM2.5.

In terms of the population of Leeds and Bradford, the average age of those aged over 60 is 71 years old. Therefore we assume that the coronary event affects a 71 year old person. A non-fatal coronary event leads to a loss of health-related quality of life experienced by the patient and – in addition – will lead to usage of NHS and PSS resources. These effects are not one-off effects, but rather continue until the death of the patient. For the purposes of this example we assume that there is no loss of life expectancy, thus use national average life expectancy at 71, which is a further 16 years for women and 14 years for men.

In order to establish the health-related quality of life decrement resulting from a coronary event we used figures from Sullivan et al. (2011) for ICD-9 codes 410, 412 and 414 and compared against the UK population norms (Kind et al., 1999). These do not exactly match the ICD-9 codes analysed in the source paper by Cesaroni et al. (2014) and so some inaccuracy may result here. ICD-9 code 410 is acute myocardial infarction (MI), which was used for the year in which the MI was experienced. ICD-9 code 412 is old myocardial infarction, which was used for MI patients in years following the MI itself. ICD-9 code 414 is for other chronic ischemic heart disease and was used to provide information on the health-related quality of life losses from non-MI coronary events, in the absence of the appropriate figure for ICD-9 code 411.

The resource uses associated with a coronary event were used in Robinson et al., 2005, where data was obtained for members of the Nottingham Heart Attack Register cohort. Resource use was inflated to 2013/2014 prices using the HCHS Pay and Prices Index (Curtis, 2014). For MI patients, the cost is greater in the year in which the MI is experienced and lower thereafter. Non-MI coronary event patients are assumed to have a constant cost to NHS and PSS each year for the rest of their lives resulting from their coronary event.

Coronary event type	Health-related quality of life	NHS and PSS cost per annum
MI (year 1)	0.605	£5,579.29
MI (all subsequent years)	0.671	£2,232.56
Non-MI (all years)	0.651	£1,999.03

Our estimate of the resource use and QALY loss from a non-fatal MI is £31,000 and 1.0 QALYs, which equates to a total value of £51,000. The resource use and QALY loss from a non-fatal non-MI coronary event is £25,000 and 1.2 QALYs, which equates to a total value of £49,000.

For application to the HIA, the value of each estimated coronary event averted is required. To do this, we take the average of MI and non-MI costs saved and QALYs gained. As a result each estimated coronary event averted is associated with a NHS/PSS cost saving of £28,000 and a QALY gain of 1.1. The combined value is therefore £50,000.

Cases of childhood asthma

Takenoue et al. (2012) estimate that for an 18.8μg/m^3 increase in nitrogen dioxide there is a 13.5% elevation in the risk in developing childhood asthma. The studies forming the basis of their meta-analysis contain data pertaining to children aged between 0 and 18 years old. Since the effect is measured over the whole childhood period, this effect is not considered to be an annual effect, but rather a one-off reduction in prevalence. It is elsewhere reported that poor air quality can exacerbate symptoms of asthma and this relationship could be a further development of this work going forwards.

There are two elements to our valuation of cases of childhood asthma. Firstly, there is a health-related quality of life decrement for sufferers of either persistent or frequent asthma relative to the UK population norm. Secondly, asthma causes greater utilisation of GP and hospital services as well as significant costs in the form of community prescriptions. We do not consider mortality from asthma, since this is likely to be fairly low, but this could be investigated in future work. In particular, by identifying the effect of poor air quality on exacerbating symptoms associated with asthma this may be more closely related to potential mortality effects. Further it is also likely that cases of severe asthma will impose costs upon the educational system and have adverse effects on the child's educational outcomes, but these are considered beyond the scope of this document.

In Peters et al. (2002) the authors describe childhood asthma as three types [prevalence in parentheses]: infrequent episodic (75%), frequent episodic (20%) and persistent (5%). With appropriate medication some cases of asthma can be relatively symptom-free, but in other cases asthma has a substantial impact on health-related quality of life. Our estimate assumes that the decrement of health-related quality of life is applicable only for the 25% of asthmatic children who have either persistent or frequent episodic asthma. The estimate for health-related quality of life is taken from Sullivan et al. (2011), which gives a value of 0.722 (compared to population norm for children of 0.94). The Sullivan et al. (2011) estimate is based on asthmatics of all ages and hence may not be entirely accurate for the 0-18 years old population, but was the best available in the absence of a more specific estimate. The average age of a child from Leeds or Bradford which 9 years old. This is then extrapolated by assuming at age 18 that there is a 58.2% probability of asthma continuing into adulthood and that life expectancy of asthmatics is equal to the general population, which is a further 72 years from the age of 9 according to ONS life tables (Oswald et al., 1994; ONS, 2014). The net present value health loss due to childhood asthma is 0.92 QALYs. In sensitivity analysis where the health-related quality of life decrement is applied to only the 5% persistent asthma sufferers the net present value of the total QALY loss is 0.19 QALYs.

The cost of asthma to the healthcare sector is taken from Gupta et al. (2004). This is then divided by the total number of asthmatics in the UK in 2001, which is roughly 8.57 million, given a prevalence of 14.5% (DH, 2003). The costs of asthma per asthmatic per year in 2013/2014 prices are then:

	Cost per year per asthmatic (2013/2014 prices)

Hospital admissions	£10.88
GP costs	£16.63
Community prescriptions	£102.60

Using these figures we can estimate the present value of healthcare costs over the lifetime of someone developing asthma in their childhood. Community prescriptions costs are based on net ingredient cost, although actual costs to NHS and PSS budgets may vary according to discounts and costs borne by patients.

Our estimate of the resource use and QALY loss from a case of childhood asthma is £3,000 and 0.9 QALYs, which equates to a total value of £21,000.

Term, low birth weight births

Pedersen et al. (2013) estimate that there is an elevated risk of low birth weight (<2500g) babies born at term (37 weeks gestational age) by 18% and 9% for an increase of PM2.5 exposure by 5μg/m^3 and an increase of nitrogen dioxide exposure 10μg/m^3 respectively. The estimate is taken from a study involving 14 European cohort datasets.

The outcome used here has been difficult to value using existing studies. Many studies consider low birth weight, but not just for term births and so may be linked to pre-term birth (which should be captured in the next section). Another potential source of valuation is the use of the small for gestational age ICD marker, but this would also include pre term births. As such, while there are many studies identifying associations between low birth weight and later outcomes, these were confounded by other factors and not applicable to this estimate. Future work could seek to identify health effects of term, low birth weight births. We were able to get an estimate of the additional NHS and PSS costs for a term, low birth weight birth over the first two years of life relative to a term non-low birth weight birth, using data regarding the East Midlands of England provided by Prof Stavros Petrou, University of Warwick (personal communication), in his 'Secondary economic analyses of the LAMBS cohort study'.

The estimate of the additional resource use from a case of term, low birth weight is £2,000.

Pre term births

Sapkota et al. (2012) find a 15% elevation of risk of pre term birth for an increase in PM2.5 exposure of 10μg/m^3. The meta analysis features studies from a number of countries, but mainly from USA.

Since gestational age is thought to be a good predictor of neonatal and childhood health outcomes, more information was available on this outcome resulting from air pollution compared to term, low birth weight birth. The incremental probability of neonatal mortality for a pre term birth relative to a term birth is 4.9% (Mangham et al., 2009). Pre term birth is also associated with higher risks of mild, moderate and severe disability among survivors. The health gains from averting pre term birth are comprised of both these factors. Regarding the QALY loss among survivors, there are HRQoL effects of mild, moderate and severe disability with values taken from Colbourn et al. (2007). In addition, while mild disability only affects HRQoL in early years, moderate and severe disability are assumed to reduce life expectancy as well as health-related quality of life, with this assumption also taken from Colbourn et al. (2007).

Disability level	Health-related quality of life	Life expectancy
No disability (UK population norm)	Varies with age (initially 0.94)	79

Mild disability	Varies with age (initially 0.85)	79
Moderate disability	0.645	68
Severe disability	0.47	26

Pre term births are also more costly to the NHS and PSS in terms of resource use. Over the first 18 years of life the incremental cost per survivor to NHS and PSS is £25,908.93 (updated to 2013/14 prices), a lot of which is from inpatient neonatal care, which is estimated by Mangham and Petrou (2008, received in personal communication - published results in Mangham et al., 2009). It is assumed that the cost of not surviving is the same between term and pre term births and the expected cost is calculated on a per birth rather than a per survivor basis, which yields an expected incremental lifetime cost of £24,071.21 per birth.

A pre term birth leads to an additional £24,000 cost to NHS and PSS budgets. In addition, it leads to a loss of 1.3 QALYs, which gives a combined loss equal to £50,000.

Summary of results

For the purposes of illustration, we summarise these results using a scenario modelled as part of the health impact assessment (Cooper et al., 2014). The scenario entails upgrading all pre Euro 4 buses and HGVs to Euro 6 emission standards by 2016. The net present value of the cost of implementing this scenario – for within the outer ring roads only – according to Ricardo-AEA (2014) is £6.3 million, including enforcement costs (71.4% of this cost is for Leeds and the remainder for Bradford). This can be considered when health effects are valued for a districts-wide policy implementation relative to a 2012 baseline, see table below:

Health event	**Pollutant**	**Number averted per year**	**NHS/PSS costs saved per year, nearest £10,000**	**QALYs gained per year**	**Total value, nearest £10,000 (combining resource use and monetary valuation of QALYs)**
All-cause mortality death	$PM_{2.5}$	16	-	134.4	£2,690,000
Coronary events (Bradford only)	$PM_{2.5}$	24	£670,000	26.4	£1,200,000
Term, low birth weight birth	$PM_{2.5}$	12	£20,000	-	£20,000
Term, low birth weight birth	NO_2	19	£40,000	-	£40,000
Pre term birth	$PM_{2.5}$	3.2	£80,000	4.2	£160,000
Total annual effect		n/a	**£710,000****	**160.2**	**£3,920,000**
Cases of childhood asthma	NO_2	254*	£760,000*	228.6*	£5,330,000*

*assumed to be one-off effect
** does not follow from data in table because of rounding

Discussion

Comparison to Interdepartmental Group on Costs and Benefits (IGCB) damage costs

DEFRA's recommended damage costs consider certain non-health outcomes, such as damage to natural and built environments that are not captured among the effects from the HIA. The HIA, however, considers more health outcomes including neo-natal complications arising from air pollution as well as costs of childhood asthma cases (not stemming from respiratory admissions).

Discussion of results and future work

The valuations presented in this paper represent a preliminary step toward conducting an economic evaluation in the area of air quality improvement. They build upon the results from a HIA of potential low emission zones in West Yorkshire conducted by Public Health England, Leeds City Council and Bradford Metropolitan District Council and are informative for a wide range of interventions where PM2.5 or nitrogen dioxide concentrations are expected to be affected.

The value of preventing bad health events through improving air quality needs to be weighed against the full opportunity costs of implementing strategies. These costs are also not analysed as part of the HIA, but are an essential component of any economic evaluation.

Whilst the objective of these valuations was to provide estimates of health loss and resource use caused by a health event that is appropriate for the affected population (in this case Leeds and Bradford), in some cases it was necessary to make assumptions to the effect that a national estimate was a sufficient approximation. This is likely to be inaccurate in certain cases, since for example life expectancy at birth in Leeds and Bradford is one year shorter than that of England as a whole. Further, in the case of the cost of treating coronary events, our estimates are from all cases of coronary events and not only incident cases. The uncertainty associated with estimates arising from these – and – other factors should be acknowledged when they are used for aiding decision making.

In future work some methodological changes could be incorporated into the estimation of health effects. One key example is that exposure to PM2.5 is thought to cause all-cause mortality not in year one of exposure, but to varying degrees with delays between exposure and effect (COMEAP, 2010). In addition, evidence from all studies – not limited to meta-analysis – should be considered and synthesised appropriately to capture all health effects and their associated uncertainties. Finally, non-health effects and the distribution of health effects could be valued to compare against the opportunity costs of strategies to improve air quality.

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