INCLUDING CARBON EMISSIONS IN THE ECONOMIC APPRAISALS OF ROAD SCHEMES

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ABSTRACT

Following the introduction of the climate change act in the UK the quantification and reduction of carbon emissions has become a major driver in the policy of large infrastructure owners. To deliver on the targets set by Government it will be necessary to consider the long-term implications in terms of Carbon emissions associated with investment decisions taken today.

In order to understand the full impact of investment decisions on carbon emissions a whole life approach is necessary, whereby carbon emissions from the initial construction and future operation and maintenance are taken into account in the appraisal process.

The research investigated a methodology for including carbon emissions within a whole life cost assessment, and looked at the impacts this had in developing a network road maintenance programme. The research had to addresses issues that included how the value of carbon emissions can be represented over time and how can the indirect costs (e.g. monetised cost of carbon emissions) can be compared alongside traditional direct costs (e.g. works costs).

Keywords: whole life cost, carbon, environment, economics, maintenance

1. INTRODUCTION

One of the key elements in developing a road maintenance programme is in selecting cost-effective treatment options for those lengths that need maintaining. If only the initial costs (i.e. of the planned maintenance) are used in the appraisal of different options, then the selected treatment may not yield an effective financial outcome over the longer term. In the economic appraisal of road maintenance schemes, the typical costs included are the works costs and user costs (the latter being a measure of the delay and accidents experienced by users during maintenance) and these have commonly been used in England to calculate the whole life costs of maintenance treatments over an analysis period of 30 or even 60 years. Whole life costing is an established technique that considers the costs incurred over the life of the asset, supporting the identification of the most cost-effective option.

In recent years the appraisal of road maintenance schemes has looked to incorporate a wider range of parameters (such as social and environmental measures). This has lead to a whole life value approach where it is not necessarily the lowest whole life cost option which is the most favourable, but the one that offers the best 'value' across the range of appraisal parameters over the analysis period.

Presently environmental impacts, including carbon emissions from the maintenance works, are rarely included within economic appraisal frameworks, since the cost of environmental damage and mitigation are difficult to monetise [1]. In spite of this Stern [2] said there is a desire to incorporate the cost of carbon emissions into the economic appraisal process, thereby bringing the cost of those emissions within standard economic appraisal frameworks.

The move to a whole life value approach allows additional parameters (e.g. carbon emissions, noise levels) to be included in the appraisal but therein is a fundamental problem. How can the 'value' of all the different parameters be measured and compared consistently and reliably? Unlike multi-criteria analyses (which score and weight the parameters individually) monetisation of the parameters enables a direct comparison across the range of value parameters. However, for many parameters (e.g. carbon emissions during maintenance) there is a lack of consensus on the most appropriate methodologies for monetisation.

This research aimed to investigate the impacts of including carbon emissions from road maintenance in the economic appraisal process and whether it may have an effect on the treatments selected in a maintenance programme. Although there are different ways to measure the effects of carbon, this study adopted one methodology to apply costs to carbon emissions from the maintenance activities to monetise their impact, allowing the costs to be included with the works costs and user costs already modelled.

2. MONETISING CARBON EMISSIONS

The quantification and monetisation of carbon has become the main driver of government policies to help mitigate the impacts of climate change. There are various methods and models available for assigning a monetary value to carbon. A detailed review of each method is presented in DECC [1] and DEFRA [3]. The methods considered in this study were:

- The social cost of carbon (SCC) - the marginal damage cost associated with an incremental unit of carbon, summed over its lifetime and discounted back to the year of emission [1].
- The marginal abatement cost (MAC) - an estimate of the future cost to reduce the next unit of carbon emitted.
- The shadow price of carbon (SPC) - the value of carbon at which MAC and SCC are equal. It is not the price paid for emissions reductions but a measure of willingness of society to pay to offset the effect of emissions [4].

In the UK the government has moved away from using the SPC, to the MAC that is consistent with UK adopted targets in the EU (i.e. European Trading Scheme – ETS) and International Levels such as the Kyoto Protocol [1].

2.1 Market price of carbon

At the European level, carbon targets are divided into two categories: traded carbon and non-traded carbon. The price of traded carbon applies to emissions deriving from fuels used by organisations covered by a cap on emissions and trade (of any unused allowance) systems such as the EU ETS. These systems have a limit on emissions (a cap), under which a set of allowances are traded based on the emissions coming from a source. If an emitter stays below the permitted allowance, the excess allowances can be sold or used in other areas of the business. Non-traded carbon derives from other sources such as fuel used in transport vehicles. There is a clear distinction of traded and non-traded sectors and therefore two sets of carbon price estimates have been developed. It was predicted by the Department of Energy and Climate Change that in 2030, when the global market of carbon begins, a single price of carbon will apply [5]. Table A1 (in Appendix A) shows the new carbon prices published by DECC for both traded and non-traded carbon up to 2050.

The costs are expressed in low, central and high estimates, with the ranges attempting to cover the outputs from the various models currently used [1].

3. DISCOUNTING THE FUTURE COST OF CARBON

To compare costs over a long period (e.g. the life of a maintenance option) all future costs are discounted back to a base year. The estimated present values show the equivalent current cost of all the future costs (e.g. to mitigate against the emissions of greenhouse gases (GHG) in the future [6]). However, one of the most sensitive parameters in project appraisal is the discount rate, particularly with long term impacts such as climate change.

Several studies on discounting have attempted to determine what discount rates should be applied for the future costs of carbon. Some studies recommend the use of a zero or close to zero discount rate[1], others have recommend a constant rate, use of dual-rate discounting [7], use of a declining rate of discounting[2] [8] & [9], use of exponential discounting[3], use of hyperbolic discounting [10][4] or simply discount rates similar to financial discounting [11].

The UK Government accepted the declining discount rates[5] and the recommended discount rates are incorporated into the HM Treasury Official Guidance the Green Book [12]. The recommended Department for Transport (UK) discount rate for transport investment projects such as the construction and maintenance of roads varies depending on the period in the project life cycle; 3.5%, 3.0% and 2.5% in the first 30 years, years 31 to 75 and over 75 years respectively [13].

Within this study the carbon costs were included with the maintenance works costs and the standard discount rate of 3.5% was used for the analysis of projects over a 30 year life. In addition the options developed in the analysis allowed a different discount rate to be applied to the costs of carbon emissions to investigate how the total maintenance costs (and, therefore, the selected treatments) may be influenced by the different contributions of the carbon costs (through different discount rates).

4. MODELLING APPROACH

To investigate the inclusion of carbon emissions in the economic appraisal of road maintenance schemes, data for a road network was modelled and the costs of carbon emissions for the maintenance treatment options were incorporated into analyses to look at the impact on the proposed road maintenance programme.

The model used in this research project was the ‘Network Whole Life Cost Model’ (NWLCM) that has been developed by TRL since the late 1990’s on behalf of the Highways Agency for use on the trunk road network in England. This model has been used for assessing the maintenance budget requirements as part of submissions for Government Spending Reviews and other Agency related tasks since 2000. The model uses network data (inventory, condition, traffic etc.) with algorithms developed specifically for the model to generate notional maintenance schemes. Two options are generated for each scheme; a ‘Do Minimum’ option which treats only the lengths that fall below safety thresholds, and a ‘Do Something’ option which is the engineering based selection of an appropriate maintenance treatment. Whole life costing is used to select schemes with the greatest economic benefit for a set of criteria or constraints (e.g. constrained budget, maintain steady state network condition).

NWLCM currently uses the direct costs of the maintenance works and the indirect user delay costs in the prioritisation of schemes. For this study, the estimated carbon emissions costs for the maintenance activities were included with the works and user costs. By including the carbon emissions costs in the analyses, the Economic Indicator values (used for prioritising the maintenance schemes) were calculated not just from the works and users costs, but the works, user and carbon costs. Using those total costs, the Economic Indicator for adopting treatment option 1 over treatment option 2 is:

$$\frac{\text{Whole life cost (of option 2)} - \text{Whole life cost (of option 1)}}{\text{First year cost (of option 1)} - \text{First year cost (of option 2)}}$$

The first year cost is defined as the works cost, or the works and carbon cost, depending on the scenario being modelled. In order to calculate the value for an Economic Indicator, the first year cost of option 1 must be greater than the first year cost of option 2. A positive Economic Indicator value implies that treatment option 1 presents economic benefits over treatment option 2, the basis of the Indicator being the reduction in whole life cost achieved by spending money now. If the Indicator value is negative then there is no long term benefit from the investment. Do Minimum

[1] Zero discount rates mean present value and future value are the same.
[2] Declining rate of discounting is also known as hyperbolic discounting.
[3] Minimises extreme positive and magnifies extreme negative.
[4] Hyperbolic discounting provides a balanced treatment of positive and negative time preference.
[5] The declining discount rate is for economic appraisal. However, environmental impacts such as climate change are included in quantifying the Net Present Value (NPV) of a project to be appraised. Therefore, the rate is applicable if carbon cost is included in the project economic appraisals.

schemes do not have Economic Indicators calculated because by their nature, they are the minimum required to maintain safety standards and must be completed.

4.1 Maintenance scenarios investigated

For the purpose of this study the "asphalt Pavement Embodied Carbon Tool", asPECT [14] was used to generate CO_2 emissions for three common maintenance treatments used on the trunk road network in England. This is a specific methodology developed for conducting life-cycle GHG assessments of asphalt pavements.

All three treatments included milling of the old pavement surface to the required depths and replacement with new asphalt. The type of asphalt varied according to layer and maintenance treatment type. The typical depths (based on experience of maintenance treatments used on trunk roads in England) and types of asphalt used in each layer are shown in Table 1. The thin surfacing and resurfacing treatments can be triggered as either Do Minimum or Do Something options from surface distresses, whereas the full reconstruction is only a Do Something treatment, triggered from the remaining structural life of the pavement.

Table 1: Treatments investigated

Treatment	Layer	Typical depth (mm)	Type of asphalt (% bitumen content)
Full reconstruction	Surface	30	Asphalt Concrete (6.0%)
	Binder	60	Asphalt Concrete (6.0%)
	Base	110	Asphalt Concrete (6.0%)
Resurfacing	Surface	50	Hot Rolled Asphalt (7.0%)
Thin surfacing	Surface	30	Stone Mastic Asphalt (6.6%)

5. CALCULATING GHG EMISSIONS

The CO_2 emissions per tonne of treatment were calculated using the asPECT methodology to create an average, based on previous carbon footprinting studies undertaken for the different types of materials. The previous studies provided batch compositions and heating and mixing energy consumptions. Average distances were used for the journey for material transported from quarry to plant and plant to site (42 km each way and 20 km each way respectively; [15]). An average density for asphalt of 2.3 t/m^3 was used to convert kgCO_2e/t values to kgCO_2e/m^3. The calculated figures from the analysis are presented in Table 2.

Table 2: Calculated CO_2e values for treatments investigated

Treatment	CO_2e content (kgCO_2e/m^3)
Full reconstruction	147
Resurfacing	160
Thin surfacing	161

5.1 Transforming carbon costs into model format

The advice given in DECC [1] was that for appraising policies not covered by the EU Emissions Trading Scheme, the non-traded price of carbon should be used. It should be noted that from 2030 onwards, the non-traded and traded costs for carbon converge to the same values (see Table A1). NWLCM requires that costs are related to the area of the maintenance treatment, and the following process converted the costs into the required format.

- For each maintenance treatment, the carbon emitted was calculated (Table 2);
- For each year the cost of CO_2e/ m^3 was calculated for each treatment;
- For each treatment, the average treatment thickness was used to calculate the cost/m^2 rate for use in the model; based on the treatment thicknesses:
    - Strengthening: 200 mm;
    - Resurfacing: 50 mm;
    - Thin surfacing: 30 mm.

Using the above process the costs were calculated for use in the model for each carbon cost band (low, medium and high) for each treatment (thin surfacing, resurfacing and full reconstruction) up to the year 2050.

5.2 Modelling options

In order to model the impact of including carbon emissions in the appraisal of road maintenance options for the development of a maintenance programme, the following scenarios were used in NWLCM:

- Turn on or off the inclusion of carbon costs;
- Select low, medium or high estimates for carbon costs;
- Add the carbon costs to either:
    - Works costs (i.e. directly included within the annual maintenance budgets) (i.e. in the Economic Indicator in Section 4, carbon costs are included in the first year costs and the whole life costs); or
    - User costs (e.g. not directly included within any yearly budgets, but considered within prioritisation) (i.e. in the Economic Indicator in Section 4, carbon costs are included only in the whole life costs);
- Specify the discount rate to be applied to the carbon costs.

6. MODEL ANALYSES: SINGLE YEAR ANALYSES

All the scenarios used condition data from the Highways Agency trunk road network in England (December 2010) and are shown in Table 3. The analyses included combinations for all the different modelling options specified in Section 5.2. In these initial analyses two discount rates of 3.5% and 0% were modelled.

The trunk road network is managed in 12 Areas and this study used one typical Area for the analyses. The analysis year was 2010 with the treatment options assessed over a 30 year whole life cost period. In these analyses the discount rate applied to all future costs within the 30 years treatment evaluation period. Following completion of the first unconstrained analyses, a value for the constrained budget was set at a level that would inhibit all preferred scheme options being completed from the unconstrained analyses (the constrained budget was set at a value of £8M, just over 50% of the total year 1 cost in the unconstrained analysis).

Table 3: Matrix of analysis types

<table>
<tr><th>Carbon/No Carbon</th><th>Budget</th><th>Carbon Cost Level</th><th>Carbon Cost Included with Works/User Costs</th><th>Carbon Annual Discount Rate (%)</th><th>Scenario</th></tr>
<tr><td rowspan="2">No Carbon</td><td>Unconstrained</td><td></td><td></td><td></td><td>1</td></tr>
<tr><td>Constrained</td><td></td><td></td><td></td><td>2</td></tr>
<tr><td rowspan="24">Carbon</td><td rowspan="12">Unconstrained</td><td rowspan="4">High</td><td rowspan="2">Works</td><td>3.5</td><td>3</td></tr>
<tr><td>0</td><td>4</td></tr>
<tr><td rowspan="2">User</td><td>3.5</td><td>5</td></tr>
<tr><td>0</td><td>6</td></tr>
<tr><td rowspan="4">Central</td><td rowspan="2">Works</td><td>3.5</td><td>7</td></tr>
<tr><td>0</td><td>8</td></tr>
<tr><td rowspan="2">User</td><td>3.5</td><td>9</td></tr>
<tr><td>0</td><td>10</td></tr>
<tr><td rowspan="4">Low</td><td rowspan="2">Works</td><td>3.5</td><td>11</td></tr>
<tr><td>0</td><td>12</td></tr>
<tr><td rowspan="2">User</td><td>3.5</td><td>13</td></tr>
<tr><td>0</td><td>14</td></tr>
<tr><td rowspan="12">Constrained</td><td rowspan="4">High</td><td rowspan="2">Works</td><td>3.5</td><td>15</td></tr>
<tr><td>0</td><td>16</td></tr>
<tr><td rowspan="2">User</td><td>3.5</td><td>17</td></tr>
<tr><td>0</td><td>18</td></tr>
<tr><td rowspan="4">Central</td><td rowspan="2">Works</td><td>3.5</td><td>19</td></tr>
<tr><td>0</td><td>20</td></tr>
<tr><td rowspan="2">User</td><td>3.5</td><td>21</td></tr>
<tr><td>0</td><td>22</td></tr>
<tr><td rowspan="4">Low</td><td rowspan="2">Works</td><td>3.5</td><td>23</td></tr>
<tr><td>0</td><td>24</td></tr>
<tr><td rowspan="2">User</td><td>3.5</td><td>25</td></tr>
<tr><td>0</td><td>26</td></tr>
</table>

7. MODELLING RESULTS

7.1 Overview

From analysis of the results for maintenance lengths and costs there was only a small difference in total treatment costs and lengths when central or high carbon costs were included in the model and combined with works costs or with works + user costs. When using the low carbon costs there was no change in the total maintenance lengths and treatment options selected by the model.

When either central or high estimates for carbon costs (with no discounting) were used there was a difference in the length treated (and subsequently the works costs). This resulted in an increase of approximately 1% and 10% of the length treated for the central and high carbon costs respectively in the unconstrained budget analyses, with a subsequent improvement in network condition due to the additional lengths treated; the network length in poor condition[6] decreased from 9.08% to 9.05% and 8.72% for the central and high costs analyses respectively (i.e. for high carbon costs there was a reduction of 0.36%).

The changes for the constrained budget analyses were less than for the unconstrained budget analyses, but by the nature of analysis types that would be expected (i.e. when operating at a reduced budget it is unlikely to be able to significantly change the total amount of maintenance undertaken, although the treatment types could change).

7.2 Scheme option selection

NWLCM works by creating schemes from all the lengths of network that are in potential need of maintenance in the given year. Each scheme has two options evaluated for it (i.e. Do Minimum and Do Something options) and one of those is marked as the preferred option based on the Economic Indicator value for the Do Something option. The preferred option for each scheme is then prioritised and selected to form the maintenance programme, subject to the constraints of the analysis (e.g. constrained budget). Where constraints (e.g. budget) prevent implementation of a preferred Do Something option, the Do Minimum option for that scheme is included in the maintenance programme.

The results from the unconstrained and constrained budget analyses showed changes to the maintenance predicted (e.g. preferred scheme option, treatment type, length treated etc.). The biggest differences in the costs and length treated were in the analyses with no carbon and high carbon costs (with no carbon discounting); scenarios 1 and 4 respectively. The comparison of the unconstrained analyses for the no carbon and high carbon cost analyses showed some differences in the scheme options selected in the two analyses.

For two of the differences, the Do Something was the preferred option and selected in the ‘carbon’ analysis but the Do Minimum was the preferred option and selected in the ‘no carbon’ analysis. When carbon costs were added to the works costs without any discounting, the change in costs was large enough to switch a negative Economic Indicator value into a positive value, resulting in the Do Something option becoming the preferred option. With both of these differences the Economic Indicator (the ratio of the whole life cost savings from carrying out the Do Something option compared to the Do Minimum option and the additional scheme cost of the Do Something option over the Do Minimum option) value was close to zero so only a small change in the costs meant a change from a negative to positive economic return. For options that had a large negative Economic Indicator value there was an improvement to the economic benefit of carrying out the scheme, but not necessarily a change from an overall negative to positive return. The same changes were not seen in the analyses where carbon costs were discounted because the changes in the savings were not large enough to trigger a change from a negative to a positive economic return.

The third difference between the scenarios with and without carbon costs was for a scheme selected in both analyses, but it was a Do Minimum option selected in the ‘no carbon’ analysis and a Do Something option selected in the ‘carbon’ analysis. The causes of the changes were similar in that an increase in total costs (from the included carbon costs) changed the Economic Indicator value from negative to positive.

A comparison of the constrained analyses for scenarios 2 (‘no carbon’) and 16 (‘carbon’), given in Table 3, showed that out of the selected maintenance programmes in the analyses, there were differences in two of the schemes. Effectively the two schemes were swapped in and out of the two different analyses. The preferred option for both schemes switches between the two analyses so that when the preferred option of one is a Do Something, the preferred option of the other is a Do Minimum, and vice-versa. When the preferred option was the Do Minimum there were no costs in 2010 (due to none of the scheme exceeding minimum safety thresholds) and so it is not selected in that year. So by including or excluding carbon costs, the Economic Indicator value changes so that the two selected options move in or out of the ‘selected scheme list’ for the maintenance programme.

[6] The network in poor condition is defined as the lengths which exceed the investigatory thresholds limits from the DMRB [16]

7.3 Prioritised scheme order

Section 7.2 described two schemes swapping over in the constrained budget analysis and this prompted a further look into the order of the prioritised schemes from the two analyses. Table 4 shows the order of the schemes, with all the Do Minimum options grouped together at the top (because they don't have an Economic Indicator). The rest are the Do Something options and have been ordered in descending order of their Economic Indicator value (i.e. top of the list has highest Economic Indicator value, representing the best return and will be the first Do Something considered).

Over 50% of the schemes don't change their position in the prioritised list between the two analysis types, as shown by those with the horizontal arrows. The remainder of the schemes however can be seen to move, but only within relatively few positions in the prioritisation lists, as shown by the shaded cells. For example, the schemes 41, 69 and 67 stay in the same block, but move their relative positions. The same is true of the other blocks.

Table 4: Prioritised list of scheme options

No Carbon		**Carbon**
All 'Do Minimum' scheme options (which have no Economic Indicator).		All 'Do Minimum' scheme options (which have no Economic Indicator).
All 'Do something' schemes then ordered by the Economic Indicator, in descending order (i.e. scheme 51 gives the best return)		
51	⟷	51
49		65
16		11
11		23
23		32
44	⟷	44
25	⟷	25
32		16
52	⟷	52
42	⟷	42
48	⟷	48
31	⟷	31
72	⟷	72
34	⟷	34
37	⟷	37
41		67
69		41
67		69
13	⟷	13
17		24
70		14
14		70
24		17
57	⟷	57
21	⟷	21
64	⟷	64
59	⟷	59

Schemes in each of the shaded groups have very similar Economic Indicator values, but noticeably different to others in the list. When the scheme cost changes through the inclusion or exclusion of carbon costs the change may be enough to update the Economic Indicator value and change the order of the scheme within its own group, but not enough to move it out of its group (with the current level of carbon costs). Therefore, if the constrained budget cuts across one of the groups of similar Economic Indicator values, then a change in the schemes selected can occur with the inclusion of carbon costs in the analysis. Conversely when the budget does not cut through one of these groups there is a change in the prioritisation order of the selected schemes, but the overall programme of schemes remains unchanged.

7.4 Increase in carbon costs

The previous single year analyses suggested that the current carbon prices do not lead to significant changes in the selection of the maintenance programme. Therefore further analyses were completed that uplifted the base (high) carbon costs by multiples of two, five and ten respectively, to assess at what point noticeable differences in the network outputs can be seen. These analyses were completed under a constrained budget, with a 0% discount rate for carbon.

The results in Table 5 showed that in the base analysis (scenario 16) there was a total of 33km of maintenance completed in 2010. A ten-fold increase in the carbon costs leads to a drop in maintenance lengths of just over 18%, and a subsequent worsening in network condition. For each case where the costs are increased there is a worsening of condition for all analysis years.

Table 5: Reduction in 2010 maintenance as a result of an increase in the carbon costs

Carbon Costs	Total Maintenance in 2010 (km)	Percentage reduction in length treated from base analysis (%)	Network condition (% of network in poor condition)
Base (High costs)	33	-	10.40
Base x2	32	-2.1	10.45
Base x5	30	-8.1	10.56
Base x10	27	-18.2	10.79

Analysis of the breakdown of treatment types for the different scenarios showed the amount of thin surfacing remained fairly constant, being made up largely of the Do Minimum options that have to be completed. The reductions in maintenance are almost solely a result of the reductions in the amount of resurfacing and strengthening.

7.5 Discount rate analysis

From earlier analyses it was apparent that the biggest difference in schemes selected was seen with undiscounted costs for the carbon (but with the works costs discounted as standard at 3.5%). In addition, within the literature there are some arguments that say a negative discount rate reflects the future cost of carbon mitigation rising, because the cheapest mitigation measures are usually implemented first, and so this was also investigated. In practice this could also be modelled through amending the carbon costs accordingly and using a standard discount rate. Therefore, in addition to single-year analyses, analyses over a 5 year programme period were undertaken to look at the longer-term effects on the maintenance programme of different discount rates. These analyses used discount rates of 3.5%, 0% and -3.5%.

With the unconstrained budget, when the carbon costs were included and the discount rate decreased, the total works costs increased, as would be expected. There were some slight variations however, such as in 2014, where it can be seen, in Figure 1, that the annual budget for the 0% and -3.5% discount rate decreased, compared with a discount rate of 3.5%. This is likely to be a result of the increased maintenance completed in the earlier years meaning that the network is in a better condition by 2014 and requires less maintenance in that year, demonstrated by the fact that across all 4 analyses the total maintenance length over the 5 years only varies by 2%. On the whole, the analyses behave as expected with the works costs increasing as the discount rate is reduced, because the lower discount rate leads to an effective increase in the carbon cost being added to the total works costs, and inevitably, some Do Something schemes will get substituted in a Do Minimum scheme following a change in the scheme savings (as in Section 7.2).

Although the total maintenance lengths showed little difference, the spread of the maintenance within the analysis period can be seen to vary and this change in the timing of the maintenance resulted in the network condition improving for the 0% and -3.5% carbon discount rates (from 10.51% of the network in poor condition to 9.85% and 9.89% respectively) but with little difference between those two results.

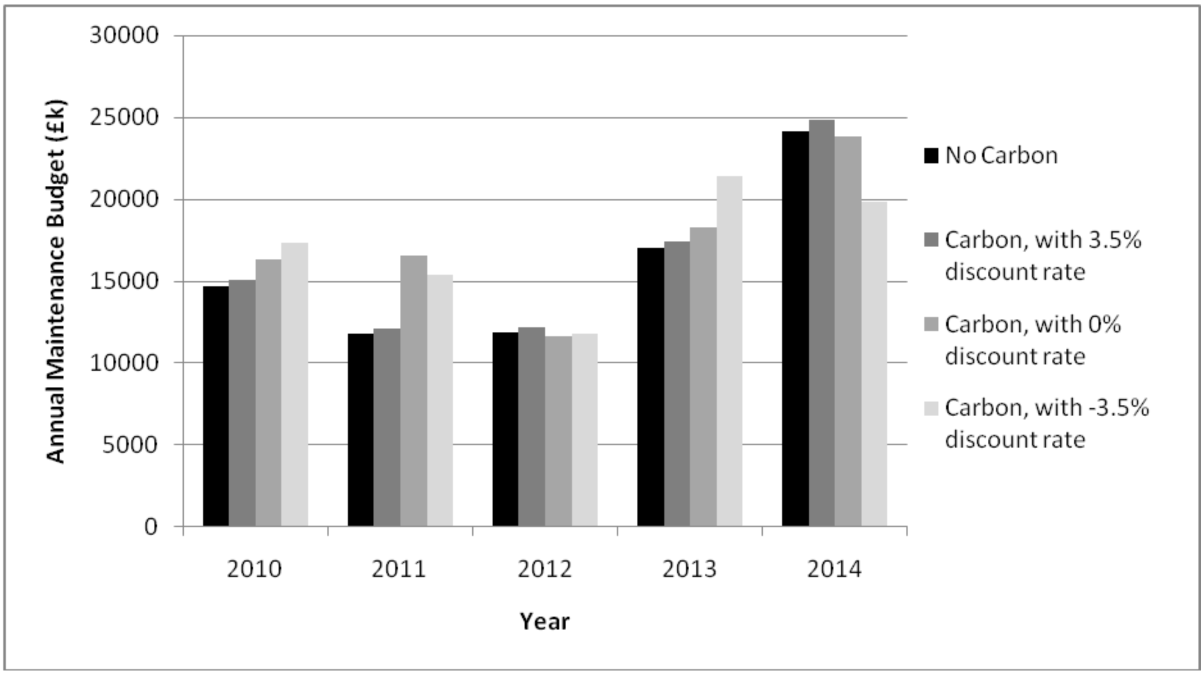

Figure 1: Change in annual budgets (including carbon costs where stated) from a variation in carbon discount rate

With the constrained budget, there is obviously limited variation to the total works costs. Due to the analysis always trying to generate the optimal works programme within the funding available, it selects a different number of schemes, and, therefore, the overall network condition showed little difference between the scenarios.

8. CONCLUSIONS

In the one year budget analyses the inclusion of carbon costs as part of the main scheme works costs was shown to increase the Economic Indicator values of some schemes from negative to positive values, which with an unconstrained budget, resulted in 10% more maintenance in one analysis. In the constrained budget analyses fewer differences were noticed. However, further investigation showed that although the overall lengths treated and subsequent condition may not change greatly, the order of schemes in a prioritised list can move within groups following recalculation of the Economic Indicator value (see Section 7.3). If the analysis has any constraints on the analysis (e.g. budget limits) and if that constraint means the budget is used in a group of schemes that have changed order then a change in the selected programme of maintenance can occur.

The biggest influence in these analyses was in varying the discount rate for the carbon costs. In the multi-year analyses this was seen through maintenance being brought forward in the programme period. A discount rate of 0% produced the biggest differences in maintenance lengths and total costs, although this could have been influenced by the length of the programme period chosen for analysis.

One of the inherent issues with the carbon costs is the level at which they should be set and how they increase over time. Throughout the analyses in this study the level of costs did not prevent any 'Do Minimum' schemes being selected. If the carbon costs were increased such that they had an effect on the 'Do Minimum' schemes selected, it would result in much greater changes in the resultant maintenance programmes.

Within these analyses the carbon cost element as a proportion of the works costs varied from less than 1% when using low carbon costs to approximately 3% when using high carbon costs. At these current levels it is not surprising that the introduction of carbon costs has a small impact on the programme of maintenance works within road maintenance appraisal, and a pure monetisation of carbon costs in the appraisal is currently of limited use. In order for the GHG emissions to have a significant impact on recent maintenance programmes, there would need to be an extra weighting applied to these costs, and this would then align more with a multi-criteria analysis where their influence can be adjusted appropriately.

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APPENDIX A Carbon Prices

This Appendix shows (in Table A1) the costs associated with carbon for each year (2008 to 2050). The traded and non-traded costs become the same, and remain the same, in 2030.

Table A1: Carbon prices, 2008-2050 [1]

Year	**Traded prices (£/tCO_2e in 2009 prices)**			**Non-traded prices (£/tCO_2e in 2009 prices)**		
	Low	Central	High	Low	Central	High
2008	12	21	26	25	50	75
2009	12	21	27	25	51	76
2010	12	22	27	26	52	78
2011	12	22	27	26	52	79
2012	13	22	28	27	53	80
2013	13	23	28	27	54	81
2014	13	23	29	27	55	82
2015	13	23	29	28	56	84
2016	13	24	29	28	57	85
2017	14	24	30	29	57	86
2018	14	24	30	29	58	87
2019	14	25	31	30	59	89
2020	14	25	31	30	60	90
2021	16	30	39	31	61	92
2022	18	34	46	31	62	93
2023	20	39	53	32	63	95
2024	23	43	61	32	64	96
2025	25	48	68	33	65	98
2026	27	52	76	33	66	99
2027	29	57	83	34	67	101
2028	31	61	90	34	68	102
2029	33	66	98	35	69	104
2030	35	70	105	35	70	105
2031	38	77	115	38	77	115
2032	42	83	125	42	83	125
2033	45	90	134	45	90	134
2034	48	96	144	48	96	144
2035	51	103	154	51	103	154
2036	55	109	164	55	109	164
2037	58	116	173	58	116	173
2038	61	122	183	61	122	183
2039	64	129	193	64	129	193
2040	68	135	203	68	135	203
2041	71	142	212	71	142	212
2042	74	148	222	74	148	222
2043	77	155	232	77	155	232
2044	81	161	242	81	161	242
2045	84	168	251	84	168	251
2046	87	174	261	87	174	261
2047	90	181	271	90	181	271
2048	94	187	281	94	187	281
2049	97	194	290	97	194	290
2050	100	200	300	100	200	300