Regional Index of Sustainable Economic Well-Being Development Project – Final Report

A joint report for the East Midlands Development Agency, North West Development Agency, Yorkshire Futures, Advantage West Midlands, the South West Regional Development Agency and the South East of England Development Agency

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Regional Index of Sustainable Economic Well-being

Development project – final report

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Executive summary

This report presents results from a development project carried out by **nef** (the new economics foundation) on behalf of ***emda*** (the East Midlands Development Agency) and Natural England, to improve the methodologies used in the calculation of the R-ISEW (Regional Index of Sustainable Economic Well-Being).

The R-ISEW is a measure of how much a region's economic activity contributes to, and detracts from, well-being, and how sustainable this activity is. It is an adjusted economic indicator which attempts to incorporate costs and benefits not traditionally measured in monetary terms. By monetising social and environmental issues, it brings them into a single analytic framework with economic ones, allowing us to explore trade-offs, and to assess whether economic well-being is really increasing sustainably in a given region. As a monetary figure, the R-ISEW can be compared with Gross Value Added (GVA), and other economic indicators. At the same time, exploring the R-ISEW's 20 separate components helps us to understand a fuller story of how economic well-being varies over time.

nef has been calculating the R-ISEW for all the English regions since 2006, with data going back to 1994. The methodology used is based on an earlier methodology developed by **nef** and Professor Tim Jackson at the University of Surrey to calculate a national ISEW for the UK in 2004.[1]

However, during the updates, potential improvements to the methodology have been discussed based on the emergence of new data and the identification of potential methodological innovations. In 2009, **nef** produced a scoping report highlighting some of the changes that could be made. The development work undertaken in 2010 enacts a subset of those changes identified by ***emda*, *Natural England*** and **nef** as taking priority.

Some of the development work was set back by delays beyond our control, most notably the postponement of the publication of the results of the National Ecosystem Assessment, which is central to the improvement of the natural habitats component. Nevertheless we have been able to make several proposals for changes to the R-ISEW methodology, and in most cases have been able to experiment with their implementation:

- Natural habitats: We use raw data from the Countryside Survey to calculate changes in habitat stocks at the regional level. We also review provisional results from the National Ecosystem Assessment to identify annual ecosystem service flows from a range of habitats. Combining these values with data from the Countryside Survey, and using a discounting model to estimate the net present value of future ecosystem services, we have been able to overhaul this component to include a full range of natural habitats, and calculate change year on year as opposed to cumulative loss. However, the unit values derived should be considered provisional pending the final publication of the National Ecosystem Assessment whereupon they should be reviewed. The new methodology means that this component now emerges as a small positive impact on the R-ISEW for all except one region, due to the recovery of natural habitats in most areas of England.

- Water pollution: New data on the status of river quality using the Water Framework Directive was not available to us during this project, nor has anyone calculated the benefits of improving water quality as assessed by the Directive on a per metre of river basis (as opposed to a per capita basis). As such, we are unable to modify the methodology of this component as we had intended. However, we have identified possible future sources for this data so future improvement should be possible.

- Long term environmental damage: We review a range of climate change models and assess them based on a set of agreed criteria. As a result, we adopt the PAGE09 model and its valuation of the social cost of a tonne of carbon at £166 per tonne in 2009 (£164 per tonne in 2008), which is almost double the valuation previously used of £70 per tonne in 2000 (£87 per tonne in 2008). We then incorporate this new value (together with an appropriate discount rate and rate of change over time) in both the old endowment fund model and a new model for calculating the present costs of climate change using an ecological debt metaphor. Both models see a substantial reduction in the size of this component, due to the lower discount rate that PAGE09 uses to reach its net present cost of £166 per tonne. The two models lead to very similar costs for the period 1994 to 2008, though differences would appear in the future. The decision on which model to use is left open. We also incorporate new data which attributes CO_2 emissions to regions according to their energy consumption, as opposed to the point of emission, which radically changes the distribution of the costs between regions.

- Public expenditure: We review the public expenditure statistical analyses to identify non-defensive expenditure beyond the health and education expenditure already included in the R-ISEW. Based on this review, we incorporate expenditure on science and technology, on recreation, culture and religion, and a proportion of that on transport, as positive impacts on R-ISEW.

- Net capital growth: We overhaul this component so as to better reflect national changes in capital expenditure over time, and lead to results that do not suffer large changes with each annual update, as is currently the case.

- Net international position: We modify this component slightly to improve its stability over time.

- Commuting: We make use of newly available data from the National Transport Survey to substantially simplify this component.

- Consumer durables: We propose removing this component, until such time as we have new data on lifetimes of consumer durables so as to better estimate true service flow from them.

The changes proposed:

- Bring the R-ISEW closer to a simple and consistent theoretical framework (the sum of net service flows and the net change in capital stocks, resulting from the productive activity in a given period);
- Utilise state of the art science (in the case of natural habitats and long-term environmental damage);
- Utilise new data sets (in the case of commuting and long-term environmental damage);
- Broaden components to include important elements hitherto ignored in our R-ISEW (natural habitats other than wetlands, more areas of public expenditure);
- Involve simpler calculations (in the case of long-term environmental damage, net capital growth and commuting), or remove components that were hard to interpret (in the case of consumer durables); and
- Are likely to be more sensitive to real year-on-year changes (in the case of long-term environmental damage, natural habitats, net capital growth and net international position).

After presenting changes to each component one by one, we present a revised set of results for the R-ISEW, using both the ecological debt model and the endowment fund model for calculating long-term environmental damage. In both cases, the new R-ISEW is around 20% higher than that calculated using the old methodology, though it increases over time at a marginally slower rate. The effect varies substantially by regions. For example, using the ecological debt model, London's R-ISEW only increases by 10% (for 2008), whilst that for Yorkshire and the Humber's increases by 70% as a result of the changes. Whilst London retains its top place in 2008, it only does so by a marginal amount, and the South West's value is higher for the five preceding years. Meanwhile, Yorkshire and the Humber is lifted from bottom place to seventh, with the East of England in bottom place.

Introduction

The English Regional Development Agencies (RDAs) are tasked with the challenge of encouraging sustainable development in their regions, with the ultimate aim of achieving high levels of social and economic well-being within environmental limits. Measuring progress towards that vision is no simple matter. Indicators exist for various aspects of this challenge, but without a cogent framework for bringing them together, assessing overall progress is difficult.

Three years ago, **nef** (the new economics foundation) produced the first complete set of Regional Indices of Sustainable Economic Well-Being (R-ISEWs) for the nine Government Office Regions of England. The R-ISEW is a measure of how much a region's economic activity contributes to, and detracts from, well-being, and how sustainable this activity is. It is an adjusted economic indicator which attempts to incorporate costs and benefits not traditionally measured in monetary terms. By monetising social and environmental issues, it brings them into a single analytic framework alongside economic issues, allowing us to explore trade-offs, and to assess whether economic well-being is really increasing sustainably in a given region. As a monetary figure, the R-ISEW can be compared with Gross Value Added (GVA), and other economic indicators. At the same time, exploring the R-ISEW's 20 separate components helps us to understand the fuller story of how economic well-being varies over time.

nef has been calculating the R-ISEW for all the English regions since 2006, with data going back to 1994. The methodology used is based on an earlier methodology developed by **nef** and Professor Tim Jackson at the University of Surrey to calculate a national ISEW for the UK in 2004.[2]

The R-ISEW is a complex tool and is still to some extent a work in progress. Some of this work is around updating unit costs and data sources. Other work is more fundamental and is required to better articulate the meaning of the R-ISEW and to ensure coherence. In 2009, **nef** prepared a scoping report for ***emda*** (the East Midlands Development Agency) and Natural England exploring possible avenues for the development of the R-ISEW, including:

- Developing the theoretical framework;
- Incorporating ecosystem services;
- Re-assessing the costs of long-term environmental damage, particularly in light of the *Stern Review*;[3]

- Assessing the contrast between costing consumption and production;
- Reviewing other possible component developments; and
- Assessing the feasibility of a scenario-modelling tool, including the development of spreadsheets with which to use it.

The scoping report identified a range of recommendations for next steps along these avenues, which are included here in full in Appendix 1. It also attempted to provide a theoretical framework for the R-ISEW as:

> The sum of net service flows and the net change in capital stocks, resulting from the productive activity in a given period.

Based on these recommendations, ***emda*** and Natural England agreed on a programme of development work including the following five strands, starting in February 2010:

1. Identifying unit values for natural habitats other than wetlands;
2. Re-evaluating the water pollution component;
3. Exchanging methodologies with other ISEW practitioners to inform LTED costing model decisions;
4. Updating costs of LTED in light of developments since the *Stern Review* and implementing the chosen costing model; and
5. Expanding the range of public expenditures in the Index.

Furthermore, this year's update highlighted a couple of other small technical changes that the R-ISEW could benefit from, which we will explore in the Section 5 of this report.

This report presents the conclusions of this development work. As well as presenting new methodologies, we have also used them where possible in Section 6 to calculate a revised R-ISEW which can be contrasted with the figures produced in the 2010 update.

Since the inception report produced in March 2010, circumstances have changed considerably. The change of government in May 2010 has led to the announcement of the abolition of the regional development authorities (RDAs). As a result, it was agreed between **nef** and ***emda*** that it is more important for progress to be made in terms of ensuring the R-ISEW legacy continues, within other relevant bodies, than to perfect and fine tune the methodology to the RDAs' requirements. This, combined with other realities, such as severe delays in the completion of the National Ecosystem Assessment (NEA), has forced us to reconsider our work plan, specifically omitting Strand 3. Instead, we propose to divert funds into dissemination work to be carried out by **nef** and ***emda*** to promote the R-ISEW.

1. Natural habitats

Summary

In this section we describe work done to integrate the R-ISEW environmental components (habitat loss and farmland loss) into one new category – change in natural habitats – as recommended in the scoping report.

The aim of this adapted component is to improve how natural habitats are accounted for in the R-ISEW in a way that is coherent with the overall framework. We propose doing this by calculating how much the total value of ecosystems changes from one year to the next for each region. In other words, we intend to calculate the change in natural stock.

Note that this is different from the approach used in the past, which looked at the loss of natural stock since 1930 for any given year. With such a methodology figures were also negative and stable. The new methodology, calculating change, means that figures can theoretically be either negative or positive and can vary considerably over time.

Despite the difference in theoretical framework, the data required is roughly the same:

- Change in stock of habitats per region from one year to the next; and
- Values of the benefits provided per habitat type.

The first of these is readily available from the Countryside Survey (CS) at a national level, though not at a regional level. We have overcome this obstacle following advice from the CS and using specialised software to convert national survey results into regional data, as described in the methodology section.

The second has been derived from preliminary results of the UK NEA (National Ecosystem Assessment), which aims at valuing the benefits that UK ecosystems generate for society. The NEA follows the CS habitats typology but the values are provided in different forms and are on a different level of detail and consistency, which has also created a few challenges.

The NEA is producing figures on the service flow, i.e. monetisable benefits, from ecosystems in one year. To calculate the value of those ecosystems as a stock, we therefore need to apply a utility function so as to estimate the total net present value in terms of future years of service flow. In other words, we calculate the

present value of a particular square kilometre of ecosystem based on the discounted value of the service flows that it will generate in future years.

The decision to rely on outputs from the NEA to generate a set of values per habitat was made in the initial phase of our research when it became evident that there was no point in creating new proxies for natural habitats when there was a big national programme working to do so.

The main benefit of this approach has been that the habitats component of the R-ISEW has been re-structured in a way that allows it to capture and integrate the latest developments in ecosystem service valuation – a rapidly evolving discipline. Indeed, many of the NEA results come from reviews of the literature, where certain academic articles have produced results that are appropriate to the aims of the NEA, such as scaling figures to national ecosystems. For the R-ISEW, therefore, the NEA has served to authoritatively filter and select the most appropriate figures for inclusion in such a project.

The main disadvantage is that taking forward this task has been dependant on the timing of the NEA results and this has been later than expected. At the time of writing, the information provided by the NEA is still preliminary, with some values missing for certain habitats and others not directly comparable. This has affected the consistency of the results presented but as noted earlier, the value of the exercise lies not so much in the results but on re-framing the R-ISEW habitat components into a structure which can easily be updated once new and more consistent values become available. When these results do become available, however, the R-ISEW will be in a position to easily incorporate these values (since the CS values will not change) and will present the state-of-the-art in national ecosystem valuation. That said, even these results will be subject to major limitations and their interpretation and applicability should be cross-checked with the figures and methods of the NEA final report.

This section explains in more detail why we have made these changes, what changes have been made, and the impact they have on the results.

Introduction

In the scoping report we defined the R-ISEW as *the sum of net service flows and the net change in capital stocks, resulting from the productive activity in a given period* (page11). The scoping report noted that this definition precludes including ecosystem services in and of themselves in the R-ISEW, as it is the impact of productive activity that the R-ISEW intends to measure, not the sum of all service flows. Furthermore, one could argue that the value of ecosystem services in a given year is infinite – without the natural habitats around us, life on Earth simply would not exist.

As such, the R-ISEW should measure how stocks of ecosystems *change* over time, assuming that these changes are mostly attributable to human productive activity. If ecosystem stocks decline in a given year, we assume this to be a negative side-effect of human activity in that year, and subtract the loss of stocks from that year's R-ISEW. Conversely, if ecosystem stocks rise, we assume this to be a positive side-effect of human activity in that year (or perhaps the result of specific policy intended to increase stocks), and add it to that year's R-ISEW.

Measuring the value of ecosystem services requires information on the ecosystem as well as the value of the services they provide. This entails an enormous amount of complexity, as the ecosystems, their services and even their values are extremely dynamic and depend on innumerable variables. As such, the natural habitat element of the R-ISEW will not be able to capture the 'true' value of ecosystem services provided by different habitats, but it will provide an indication of their value, as well as providing a framework for how further work can improve accuracy, guide monitoring, and inform policy.

We can think of measuring an ecosystem's activity using natural sciences (ecology, topology, etc.), while the value of this ecosystem is measured using an economic approach. In this sense, the project relies on merging scientific and economic data. For the natural science part, we use CS data on land-cover estimates of different ecosystems. The caveats of this database for our purposes will be discussed in a later section. For the economic part we use the NEA, assigning values to different service flows for each ecosystem. The NEA and the CS use similar broad habitats, making the merging exercise more straightforward.

The NEA aims to assess the value of goods and services provided by the UK's natural environment. While it may be developing as state-of-the-art in this type of valuation, by its own admission it has significant limitations. For example, the categories of ecosystem mask the diversity of any single category, instead being taken as average or representative ecosystems of that type. Even a representative ecosystem is unlikely to have all of its services valued.

Differences to previous methodology

There are three key differences between the methodology developed here and how natural habitats and farmland were included in past R-ISEWs. First and most importantly, we have identified new unit values for a range of habitat types. In previous R-ISEWs, we only included wetlands as this was the only habitat for which we had a unit value. Even in the case of wetlands, the unit value was not entirely satisfactory, using land purchase prices which may not necessarily capture the full ecosystem value.

Secondly, we have reframed the component as *change in* habitats as opposed to *loss of* habitats. In the past, we used 1930 as a base year and calculated change in stock of habitats since then. Even where the amount of habitat increased in some regions in a given year, those regions were calculated to have a 'loss', as the loss is relative to 1930. In other words, until natural habitats revert to 1930 levels, this component would always be a cost to the R-ISEW. The clients for this work expressed an interest to change this, such that the natural habitats component could sometimes be a positive figure. For this to happen, we need to look at change year on year, rather than change relative to 1930. Doing so also makes the component more consistent with the definition of the R-ISEW from the scoping report, which refers to productive activity in a *given* year. If this activity has led to an increase in the amount of natural habitats in a region, this should be considered as a positive increase of value.

Having said that, the previous methodology of looking at cumulative loss can also be considered consistent with the R-ISEW. The logic behind it is this: What loss of ecosystem value has been necessary to sustain current economic activity? The implication is that the productive activity in a given year has only been made possible because we have gone below some ‘natural’ level of natural habitat. The problem then becomes choosing what that ‘natural’ level was – the choice of the year 1930 is somewhat arbitrary.

The third development emerging from our work on natural habitats has been to learn how to use the raw data from the CS to calculate regional stocks. The latest CS (2007) did not lead to the publication of regional stocks – only national values. In the last update, we assumed that all regions saw the same pattern of habitat change between 2000 and 2008. In this development work, we have been able to calculate regional stocks ourselves.

Sourcing data

The research was structured in two main phases. First we reviewed and gathered existing information and data. This included conversations with a few experts combined with a review of academic and grey literature. In the second phase, we analysed all the information and data gathered, to generate ‘reference values per habitat type’ and change in habitat type. This phase concluded with the estimation of the ‘change in natural habitats’ component for the R-ISEW.

Throughout the first phase we had conversations with a few experts to gather feedback on the methodology suggested and to get the latest available information on existing initiatives that might be similar or complementary to what we were trying to achieve. This also served the purpose of identifying additional data sources, literature, and contacts of relevance to our research. Experts consulted include:

- **Prof. Ian Bateman**, University of East Anglia. Prof. Bateman is working on the NEA initiative. He is drafting the economics chapter, which – among others – looks at how to integrate ecosystem services into national indicators.

- **Dr Mike Christie**, Aberystwyth University. Dr Christie has expertise in environmental valuation. He was involved in the ISEW Wales, looking at how to integrate natural environmental elements, and has recently been working on a project for Defra looking at the environmental benefits of UK Biodiversity Action Plans.

- **Gianni Ruta**, Economist, Environment Department at the World Bank. Gianni Ruta has been working on the Genuine Savings indicators for more than four years, and actively contributed to the *Where is the wealth of nations* report.

- **Paul Morling**, Senior Economist, The Royal Society for the Protection of Birds, also involved in the biodiversity chapter of the NEA.

- We also had the opportunity to discuss this research challenge through informal conversations with **Ian Dickie**, Consultant, EFTEC (Economics for the Environment Consultancy) and a few economists from the **Defra** Natural Environment Economists unit.

Early in the research phase it became evident that the NEA initiative had lots to offer in terms of providing information on values per habitat type and, rather than developing our own proxies for a few habitat types (agriculture, forest, wetlands, coastal, etc.), it was worth using the information from the NEA.

This resulted in devoting the main bulk of our research efforts in tracking and obtaining the latest information and state-of-the-art from the NEA. Because of delays in the publication of the final NEA results, it became apparent that we would only be able to incorporate preliminary results in this development work. To gain access to these results, we obtained 'reviewer' status to the NEA.

A similar process took place to review all the data available from the CS and to identify options to convert it from national data into regional data.

About the National Ecosystem Assessment (NEA)

The UK NEA is the first analysis of the benefits to society provided by the UK's natural environment. It originated with the 2005 Millennium Ecosystem Assessment, which aimed to show the value of ecosystems to human well-being. As part of the Living with Environmental Change (LWEC) project, it aims to fulfil Defra's Action Plan for Embedding an Ecosystem Approach, the UN's Convention on Biological Diversity (CBD), and the EU's Water Framework Directive (WFD). It is being developed by government (Defra), academic institutions, and key stakeholders such as the Royal Society for the Protection of Birds.

The NEA divides ecosystem services into a number of categories, including cultural, provisioning, regulating, and supporting. The valuation process is illustrated in Figure 1.1.

The process of developing economic values for different habitats is itself designated to different teams working virtually independently. For example, there are teams valuing cultural services, others focusing on biodiversity services, and others on urban landscapes.

At the time of writing, the NEA was a work in progress and final results had not been published. However, final results are scheduled to be published soon.

It is important to note that, whilst the NEA represents the most robust review of ecosystem evaluations to date, even these final figures will involve an extensive range of assumptions and that policy-makers must remain fairly cautious about taking the results too literally. As with all aspects of the ISEW, it is not only the final net effect on the R-ISEW of any given policy that is important, but also the effect on different components taken separately.

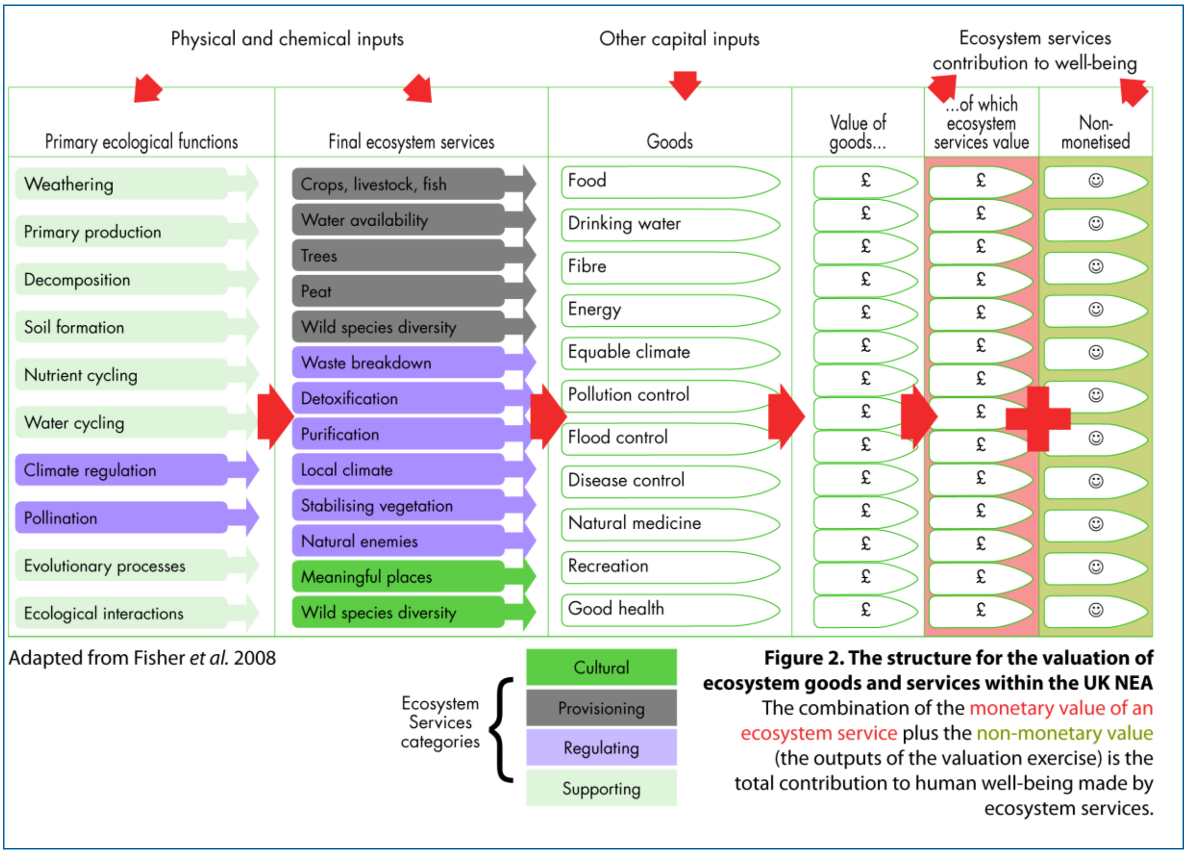

Figure 1.1. Conceptual framework of the NEA.[4]

About the Countryside Survey (CS)

This is a survey of the UK's natural resources carried out at regular intervals since 1978. The CS therefore offers a way to measure changes in the natural environment over time. There are two parts to the CS, one being the Field Survey and the other the Land Cover Map. The Land Cover Map uses satellite data to map land cover and vegetation categorised according to land classes. Meanwhile, the Field Survey samples 1 km^2 areas across the UK with the aim of obtaining representative samples for each land class and determining changes in their make-up in terms of broad habitat. Note that the NEA does not provide different values for different land classes – what we are ultimately interested in is the distribution of broad habitats by region.

Methodology and challenges

It is probably fair to say that this development work would have been a lot easier had we set out to carry it out a year or two later. We faced huge challenges in terms of obtaining the required data in time, as noted below. The approach used was the best possible at the time of writing. Further improvements may be possible in the future.

Regional land cover maps

The first step is to use the land cover maps provided by the CS to determine the percentage of each land class type (not actual broad habitats) per region. To do this, we used Geographic Information System (GIS) software which allows the land cover maps to be overlaid on maps incorporating regional boundaries.[5] Whilst we were provided with maps for 2000 and 2007, the amounts of each land class barely change from year to year and should be treated as static.

Change in broad habitat areas

The next step is to determine the proportions of broad habitat per land class and how these changed between 2000 and 2007. The necessary data comes from the CS Field Survey. A few examples are shown in Table 1.1.

Table 1.1. Changes in coverage of habitat type for selected habitat types and land classes.[6]

Land Class	Broad habitat	Broad habitat name	% in 2000	% in 2007	Change
1	1	Broadleaved Mixed and Yew Woodland	12.7%	12.6%	- 0.1
1	2	Coniferous Woodland	3.6%	3.5%	- 0.1
1	21	Littoral Sediment	0.0%	0.0%	0.0
2	1	Broadleaved Mixed and Yew Woodland	13.1%	14.5%	1.4
2	2	Coniferous Woodland	1.4%	1.4%	- 0.0

The following example will help illustrate the approach. If we assume that land class 1 makes up 500 km^2 of region X, then the amount of the broad habitat Coniferous Woodland can be seen to have dropped from 18.2 km^2 (3.6%) to 17.7 km^2 (3.5%) – a drop of 0.5 km^2 or 0.07 km^2 per year over the seven years.

To find the area of any particular habitat in a region and how much it has changed, we must sum up the product of all land classes (in area terms) with the respective broad habitat proportion (as a percentage – see Equation 1). There are 45 land classes, and for each land class there are up to 44 broad habitats (though only 21 main broad habitat categories). While the land class is not itself directly relevant, it predicts the proportions of broad habitats. The full list of broad habitats is shown in Appendix 2.

Formally, this is, for any given broad habitat type in a region:

$$A_{bh,r} = \sum_{lc=1}^{45} P_{bh,lc} \times A_{lc,r} \qquad (1)$$

where r is the region, lc is the land class, bh is the broad habitat, P is the proportion of a given land class that a broad habitat contains and A is an area.

It is important to note that this methodology relies on assuming that changes to the proportions of each broad habitat within each land class apply across the UK as a whole equally.

Table 1.2 shows the change in area for each broad habitat type for each region of England and Wales between 2000 and 2007. As can be seen, the picture is generally positive but mixed, with increases for some types of grassland, broadleaved forests, littoral sediment, and dwarf shrub heath, but decreases for some wetland types. The biggest change is actually a loss of farmland (around 250,000 hectares across England), but this is dealt with in the farmland component. At this stage, it is not yet clear why this pattern is very different from that found in the June Agricultural Survey (the data used in the farmland component), which reported farmland *increasing* by 190,000 hectares in the same time period. In future, one could consider building the June Agricultural Survey data into this component as a way to correct estimates of farmland, and so adjust amounts of other habitats accordingly.

Table 1.2. Change in habitat areas between 2000 and 2007 (hectares), from Countryside Survey.

Broad Habitat category	North East	North West	Yorkshire	East Midlands	West Midlands	East of England	London	South East	South West	Wales
Broadleaved Mixed & Yew Woodland	3285	4858	8800	4498	5737	2486	374	10923	13870	-11831
Coniferous Woodland	-5226	1478	-750	663	477	240	-100	-651	-238	19142
Boundary and Linear Features	-894	-803	-1863	-1978	-475	1451	129	2659	819	-4883
Arable and Horticulture	-13328	-19573	-47851	-38938	-33101	-63322	-4280	-91026	-87285	30718
Improved Grassland	9797	-37500	12097	13849	5615	31978	2381	48735	61519	-46001
Neutral Grassland	1381	47118	25464	26563	17366	20868	102	22807	-4323	7641
Calcareous Grassland	-193	-136	-187	33	-359	-67	-107	-1021	-1065	-38
Acid Grassland	4743	655	-385	-863	-1042	1461	86	1056	-7643	35977
Bracken	285	-2491	-3032	-3110	-3832	-344	16	-103	-6169	-55677
Dwarf Shrub Heath	1137	4980	4949	3696	5424	2189	59	852	23041	8664
Fen, Marsh, Swamp	-507	59	561	-646	-885	-738	-269	-1505	-2794	-1373
Bog	-873	-2578	1180	-649	-129	-1887	-140	-916	-334	1333
Standing Open Waters and Canals	138	193	489	582	397	2281	94	1250	728	552
Rivers and Streams	-109	-422	-376	29	68	92	28	122	206	292
Montane	4	27	26	1	1	0	0	0	1	-23
Inland Rock	-669	0	-37	-313	-105	-1071	-65	-958	-519	771
Urban	2369	4425	1475	-3933	4971	2571	1219	5030	7301	14596
Supra-littoral Rock	-497	-357	-513	-98	-278	-109	-58	-378	-824	157
Supra-littoral Sediment	282	88	240	15	11	14	-2	110	484	-113
Littoral Rock	17	87	196	90	148	101	36	189	220	17
Littoral Sediment	-1142	-108	-480	510	-9	1806	496	2824	3006	80
Sea	0	0	0	0	0	0	0	0	0	0

Ecosystem service unit values

After determining the change in area for each habitat for each region across all land classes, the next step is to identify unit values per hectare for each habitat. Our intention from the outset has been to use the NEA to derive appropriate values; however, as we have noted, this has led to problems during the course of this project. The NEA reporting process has been delayed a number of times. At the beginning of this project (in March 2010), the NEA was due to report some data by mid- to late-2010. Currently, the estimated date for final reporting is in mid-2011.

Of particular importance, the economic chapter of the NEA has been delayed, as has the merging of economic and natural science data. Only after obtaining reviewer status were we able to access the relevant findings.

The process has also been made difficult by mixed messages of what the NEA will report. Our initial understanding was that the NEA would report the current changes to the environment in economic terms. Instead, however, some teams at the University of Nottingham were charged with scenario analysis using a (probabilistic) Bayesian framework, rather than actual annual changes. While we had hoped to follow the methodology of the NEA for calculating annual changes, we had to direct this ourselves instead. The NEA had intended to evaluate current changes in the environment by tying the natural science and economic findings, much as we have done here, but there was substantial confusion over who was to do this (the team charged with this were instead doing future scenario analysis on our last contact).

NEA values were assessed using a number of criteria. First, we were looking for values per unit area. These would allow us to tie in the values to changes in land use in the UK.

Second, the NEA economic values had to be able to be readily connected with the databases we were using for changes to the natural environment. The data we used from the CS was of land cover of different habitat types. While this serves as a good macro indicator for changes in the UK's environment, it lacks some important environmental information. For example, biodiversity itself was not measured in land area cover although it does provide an ecosystem service with an NEA value. Likewise, bird densities in farmland, while having an NEA assigned value, are not covered by the CS land class data. Water quality is another example. We value wetlands by other ecosystem services, but these are insensitive to the quality of the water body.

Third, values had to be relatively easily extracted and applied. Given our time and resource restrictions, we could not employ some of the more complex value functions in the NEA.

The NEA listed 33 broad habitat types, categorised into eight habitat types. Values were presented for the broad habitats. We reviewed the values mentioned in the report, identifying those that fit the above criteria. Table 1.3 lists each of the broad habitats from the CS, and the values which we identified to correspond. There are two types of value here. The first column shows values that represent annual service flows, which can be assumed to continue into the future. The second column, used for coastal defences, represents one-off replacement costs. The final column combines these two values to generate an overall value of the land as capital (explained in the following section).

Table 1.3. Unit values for each broad habitat, from the NEA.

Broad habitat		Annual service flow (£/ha/yr)	One-off replacement cost (£/ha)	Total (£/ha)
1	Broadleaved Mixed and Yew Woodland	279		9267
2	Coniferous Woodland	279		9267
3	Boundary and Linear Features			
4	Arable and Horticulture			
5	Improved Grassland			
6	Neutral Grassland	387		12852
7	Calcareous Grassland	387		12852
8	Acid Grassland	387		12852
9	Bracken	366		12148
10	Dwarf Shrub Heath	366		12148
11	Fen, Marsh, Swamp	2165		71911
12	Bog	2385		79219
13	Standing Open Waters and Canals	2165		71911
14	Rivers and Streams	2165		71911
15	Montane	6		193
16	Inland Rock	6		193
17	Urban			
18	Supra-littoral Rock	7100	545000	780829
19	Supra-littoral Sediment	7100	545463	781293
20	Littoral Rock	3550	272500	390415
21	Littoral Sediment	3550	272732	390646

The biggest values are for coastal defence areas, with wetlands lower by a factor of 10. As can be seen, we have not included a value for farmland as this is covered in the farmland component

Deriving stock values from flows

The values from the NEA represent annual ecosystem service flow – how much value a given habitat produces in one year. However, for the purposes of the R-ISEW, we need change in value of stock, which is a different matter. Our proposal is to use discounted net present value of future service flows to value a given stock. This is consistent with economic theory. When an individual purchases an item (e.g. a consumer durable), the assumption of classic economics is that they feel the price they have paid is equal to (or below) the net present value of service flows they expect to derive from it, present and future.

Whereas the model of climate change costs chosen in Section 3 will use a fixed discount rate of 1%, here we have chosen to use a more sophisticated discount model taken from the World Induced Technical Change Hybrid (WITCH) climate change model.[7] This model has the advantage that it has the property of a time-varying discount rate, which offers lessons from behavioural economics regarding hyperbolic discounting, a phenomenon where people employ a discount rate which falls over time. While this is time-inconsistent, it reflects our value for environmental services further into the future than a standard exponential discount rate. We chose the WITCH model over the more common DICE model (Dynamic Integrated model of Climate and the Economy) because, amongst other reasons, it uses 5-year periods, rather than DICE's 10-year periods. The model uses a starting discount rate of 3% per annum, which then decreases by 0.25% over time. We calculate the net present value of service flows from ecosystems for 100 years. This is, of course, an arbitrary figure which can be increased or decreased, but intends to reflect the fact that aside from the preference for the present implicit in discount rates, there is an added factor here related to the uncertainty of the value of ecosystems in the future, as the annual flows calculated in the NEA are specific to a given context – i.e. the UK in 2010. Future service flows from habitats will vary as a result of population changes, climate changes, the size of the economy, technology, and preferences. We exclude the first year from the total value, partly to avoid the risk of double-counting.

The final column of Table 1.3 presents the unit stock values for each habitat type. These values are sensitive to the discount rate used and the number of years of service one includes in the model. For example, only including service flows for the next 50 years instead of the next 100 years reduces the values by a factor of 50%.

The unit values for different types of wetlands are almost 14 times higher than those used in the old R-ISEW.

Results

Table 1.4 shows the annual changes in stocks of natural habitat calculated for each region for the period 2000 to 2007.

Table 1.4. Annual change in value of natural habitats for each region.

Region	Annual change (£m)
North East	-91
North West	38
Yorkshire	34
East Midlands	72
West Midlands	12
East	139
London	20
South East	183
South West	143
England	**550**

All regions with the exception of the North East enjoy a positive annual change in natural habitat value year-on-year from 2000 to 2007, with the largest increases seen in the South. As a whole, the value of natural habitats in England increased by £550 million a year, mostly due to increases in littoral and supra-littoral sediment in the South, and neutral grassland in the North. The biggest negative aspect is a decrease in supra-littoral rock, costing England £347 million a year.

As has already been discussed, changes to the theoretical basis of this component mean the overall figures are very different to in the previous R-ISEW. The previous methodology calculated the cumulative loss relative to 1930. Given the long-term declining trend, this figure is inevitably negative and also unlikely to change much over time. The new methodology calculate year-on-year *change*, which can of course be positive or negative (and indeed is different from region to region). This is because, in recent years, natural habitats have actually been recovered in England. In the old methodology, this manifested itself as a marginal reduction in the size of the cumulative loss. In this methodology, it is seen as a plus in itself. However, as of course, change in any given year is much smaller than the cumulative change over 70 years, the values calculated are smaller. The previous R-ISEW produced a cost of around £2,400 million for England overall for each year.

However, the pattern of regions is relatively similar. The North East, which had the highest per capita costs using the old methodology, is now the only region to retain a negative figure. Other northern regions, such as the North West and Yorkshire and the Humber, also retain a low position – having had high costs before, and low benefits now. The regions with the highest per capita values are now the South West and the East of England.

Discussion

Caveats with Countryside Survey data

The CS data on change in broad habitats is provided at country level, not at regional level. If a certain land class is reported to have changed in terms of its broad habitat composition, then we must assume that that change is uniform across the country. Of course this is not ideal –there may be very different processes taking place in different regions and, indeed, the starting compositions of each land class might be different as well. The only way we are able to model differences between regions is in terms of their land class structure, but this may not be too bad. Some land classes only occur in one or two regions, whilst there are many regions that don't have a particular land class. As such, there is some certainty regarding the regional distribution of the impacts of changes to the proportions of broad habitats in some cases.

But it is clear that the estimations are not perfect. For example, because of our methodology, we estimate the presence of 258 hectares of coastal margin in landlocked West Midlands. Similarly, as we have noted there are some differences between the estimates we have generated for farmland and those produced by the June Agricultural Survey. A particular area of concern is the increase in the amount of littoral rock across England from 3km^2 in 2000 to 1,087km^2 in 2007. Sources at the CS say that this may a by-product of the methodologies they use in calculating broad habitat cover. Indeed, the Countryside Survey website summary data reports 0 hectares of littoral rock in England in 1998. It is not clear at this stage how this problem can be compensated for.

Also problematic is the fact that we only have CS data using this methodology for two years – 2000 and 2007. All changes between 1994 and 2008 must be estimated assuming a linear trend anchored by these two data points.

Caveats with National Ecosystem Assessment data

The economic values we used are not sensitive to stock and flow issues. The value of an ecosystem depends on its size differently to its flow. Conventional economic theory predicts that the larger the stock of a resource, the less valuable it becomes per unit area. The use of static proxies assumes that unit areas of a stock have non-changing values. We also assume that these values apply for all points in time in the future.

Some of the values were also provided at the marginal level, but this was not always the case, making their use more inconsistent. The change of ecosystem land cover could have been valued using marginal values, which tend to be higher (sometimes by three times or more), and which may have offered more accurate measures of the resource's value. By mixing values for marginal changes to a stock with other values for the stock, we are assuming that the average and marginal values are equal, which is rarely the case.

Another issue is the distribution of sub-habitat types within a given NEA habitat type which could not be used with the CS data. That is, some habitats, such as dry dunes, had significant values (for carbon storage, for example), but these could not be applied to the CS data as it did not contain the coverage of these habitats. This mismatching of habitats meant a number of values could not be applied. Indeed, many other NEA values could not be used because they were not given in per area units – instead given in per capita values (such as enclosed farmland carbon storage), or aggregated over the UK (such as peat bogs for carbon storage – and area peat bogs are not given regionally or provided by the CS).

Finally, we did not adjust economic values for population (essentially assuming uniform distribution) or income, and some values were adjusted by the NEA to recent years (e.g. 2004) not corresponding to either 2007 or 2000. We did not, in this section, adjust the values for either of these dates, but assumed that they had not changed greatly. It is well established that values are sensitive to population, anthropogenic uses, income levels, service types, and so on. these adjustments, however, were beyond the scope of this study because, for the most part, our GIS methodology using the CS data did not map on population densities. With that said, there were only a few instances in the NEA where values were declared with any clear sensitivity to population densities.

When the NEA is complete we recommend a further review to ensure that all relevant values have been included.

Conclusions and next steps

This section outlines the methodology – and challenges encountered – to estimate the natural habitats component of the R-ISEW. It highlights several issues with regards to the robustness of the data used. Key elements worth highlighting that affect the robustness of the results include:

- simplification of many habitats into a few types;
- heterogeneity of values (static versus marginal values);

- lack of adjustments for changes in values over time and population; and
- low quality data on changes in land cover over time.

As noted earlier, this is a first attempt to lay out a structure to help convert the generation of new information on valuation of ecosystem services into changes in stocks of natural capital of each region over time. This is a work in progress, and it will need to be tested and modified.

Below we outline a few ideas for future action to help strengthen the methodology and results:

CS data

- Ensure that land cover estimates are statistically robust. Could do so possibly by combining with the European Environment Agency (EEA) CORINE land cover maps. The most recent EEA land cover maps are from 2000, but the 2007 data sets will be released soon.
- Apply more sensitivity analysis.
- Cut up the areas more to try to get them closer to what the NEA values are looking at, although this may not always work well, considering the NEA values are actually quite crude and not highly specific to small special habitats.
- Complement CS data with more detailed data on biodiversity, bird numbers, livestock, etc.

NEA data

- Derive values from value functions rather than relying solely on static proxies, ignoring the dynamic nature of stock and flow issues. While we also used average values, there could be some scope to use marginal values (though these were less developed in the current NEA version).
- Better attribution of market values to ecosystem services (obviously not exhaustive, but could have some good case examples like pollination).
- Complement the NEA values with a literature review of other proxies. Some NEA values are quite difficult to apply, yet it is not ideal to assign a zero value instead.
- Explore ways to value the ecosystem other than through ecosystem services, which exclude important intrinsic values.

2. Water pollution

Background

When we started calculating the R-ISEW in 2004, the UK published annual updates on water quality levels under the General Quality Assessment (GQA) scheme. We were able to combine these data with unit values derived from a paper by Defra in 1999 on the economic benefits of improving water quality.[8] This paper uses willingness to pay analyses and a classification of rivers into six quality classes, which we assumed to be equivalent to the classes reported by the GQA.

In recent years, however, it has become apparent that there will be changes to the reporting of water pollution levels so as to comply with the EU Water Framework Directive (WFD). If the UK were no longer to report water quality according to the GQA, then new unit values would be needed. Furthermore, the 2010 update of the R-ISEW highlighted difficulties in sourcing new data at the regional level. As such it was necessary to revisit this component.

Approach

We attempted to pursue parallel avenues with this component. On the one hand we looked to see if updated data would be reported in line with the GQA in the future, and whether any new economic values had been calculated since 1999. On the other hand we attempted to determine the reporting schedule for the WFD and whether any unit values had been generated based on it. We also attempted to identify any publications relating the two frameworks.

Our research was guided by consultations with a number of experts:

- Anna Maria Giacomello, Environment Agency;
- Ralph Underhill, Water Policy Officer, Royal Society for the Protection of Birds (RSPB);

- Emma Comerford, Economist, Royal Society for the Protection of Birds (RSPB);
- Professor Joe Morris, Cranfield University; and
- Professor Ian Bateman, University of East Anglia (UEA).

Findings

GQA

The GQA is a framework used to assess water quality in terms of chemistry, biology, and nutrients. It has been used by the Environment Agency to report on water quality in the UK for the last 20 years. The main shortfall of such a measure is that it does not assess the whole water environment, which the WFD aims to rectify.

According to the Environment Agency website,[9] 2010 was the last year for which water quality will be reported using the GQA. From 2011 onwards, quality will only be reported using the WFD. Furthermore, we were unable to obtain any new data beyond 2007 on the state of rivers in England, either at regional level or for the country as a whole. In summary, it seems that the R-ISEW will have to switch to using the WFD.

Furthermore, our attempts to find updated economic valuations based on the GQQ since the 1999 Defra study were unsuccessful. A review of the literature, and the Aquamoney database, uncovered several useful economic studies that valued water bodies, but none that reported figures compatible with the GQA measurement framework.

WFD

The WFD (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000) is a European Union directive that seeks to achieve good water quality status in all EU member states' water bodies by 2015. The WFD takes a river basin as a single system, using natural boundaries rather than administrative or political ones. Good ecological status is defined in terms of the three criteria: biological community, hydrological characteristics, and chemical characteristics. The baseline status of any given body is assumed to be approximately equivalent to that which might be expected under conditions of minimal anthropogenic impact.[10]

A problem that we identified with using the WFD for this component is that it only requires reporting once every seven years. The most recent public report was in 2007, meaning that the next will not be due until around 2014. Clearly, this prevents us making any estimates of changes under the WFD for several years.

Late in the project, however, we found that the Environment Agency had released annual WFD figures for 2008 and 2009 to the Royal Society for the Protection of Birds. It is likely that the government will report annually on the WFD, though this has yet to be confirmed. In the short term, the greater barrier for this project was to identify an economic valuation of river quality based on the WFD.

The state-of-the-art of economic valuation of water quality related to the WFD comes from a Defra-led Collaborative Research Programme producing several economic studies to inform the implementation of the WFD in the UK, including studies on pollution costs from different sectors (i.e. agriculture, industry, etc.) and willingness to pay for water quality improvement in different locations (www.wfdcrp.co.uk). We specifically looked at a Defra[11] report that estimates economic values of improvements in water quality under the WFD. The study used three elicitation methods to help provide incremental and average estimates, all based on people's willingness to pay (WTP) for water quality improvements either locally or nationally. Values were for an improvement of 95% of water bodies under a number of different scenarios. These scenarios were all variations of the rate of water quality improvement up to good or high overall status by 2015, as directed under the WFD.

However, these results suffer a number of drawbacks. For our purposes, the two major ones are that incremental values were not given scaled to changes in WFD status (e.g. the value of improvement from 'moderate' to 'good'), and that the values were in household units instead of by water quantity. For the second of these, values in household units are implicitly based on the quantity of water in the locality and nationally, but for the average values it was not known what quantity of water was referred to. This meant that any results derived using these values would only be sensitive to population, and would ignore any changes to water quantity in a region.

At the end of the project, however, we found that some conversions of these WTP values had been made to a per quantity unit, rather than per household, and that incremental estimates had also been made using the WTP values. These, however, have not been made public. There is the possibility that either they are released or that we might be able to obtain them, but we have been advised by members of the NEA (specifically Joe Morris at Cranfield University who worked on the freshwater component of the NEA) that this would be a very slow and bureaucratic process. That said, these estimates may not be entirely reliable for our study either. The figures would have to be used with great caution because of the high likelihood that water quantity causes the results to show a greater impact for high land cover areas, such as lakes, than linear features, such as rivers, which have very small areas.

In sum, our study is interested in year-on-year changes in water quality for each water body in England, but we were unable to get year-on-year estimates of WFD water quality status, we could not find the value of any incremental change, and we could not make these sensitive to how much water of a given quality there actually was in a region.

Reconciling the two frameworks

There is currently no published information relating these two frameworks. As such, we have no way of converting proportions of rivers of different quality levels according to one framework to proportions according to the other. Having said that, the Environment Agency website reports that it has been collecting data using the two frameworks simultaneously between 2008 and 2010 precisely for the purpose of allowing conversion in the future.

In relation to the economic valuation, we still have no way of determining the economic values produced by Defra in relation to the GQA to values appropriate for the WFD.

Action taken

Our initial plan was to update GQA economic values which would either a) be more accurate measures of quality improvements or b) incorporate a broader range of environmental values than the older GQA values. However, we found no updated GQA economic figures, and this is primarily because of the replacement of GQA with the WFD. The use of WFD data had its limitations: most significantly that currently available economic values were not appropriate for our use and that we could not obtain WFD water body data for the years of interest.

Due to the problems associated with the GQA and WFD approaches outlined above, we decided to employ the ecosystem approach taken by the NEA. An outline of the methodology for the CS and the NEA data is provided in Section 1.

The value used in the R-ISEW is the middle of the range provided by the NEA. Several estimates are provided in the NEA, based on whether the wetlands are lowland or upland and whether the services are extractive or not, and whether the values are average or marginal. We use only average values, and values derived by the NEA to merge lowland and upland values, which means £1700 for non-extractive services and £2630 for extractive services. We take the average of these, or £2165, to estimate a general wetland value. Marginal values tend to be much higher (£11,200-£17,300 for lowlands and £5,630-£8,680 for all wetlands, with population or GDP/capita changes of +/-10% altering these values by +/-5 to 6% in benefits per hectare) and are more appropriate to policy decisions than the average values here, which themselves are more appropriate to describe a national picture of how the value from ecosystems is changing over time. The NEA team suggests these values underestimate the true value of rivers and streams as they are linear features. For our purposes, such underestimation is okay, as it reflects the conservative position of the R-ISEW.

The values implicitly include the quality of the water. The higher the water quality, the higher these values are expected to be. However, given the likely insensitivity of these values to marginal changes in water quality, the double counting brought about by including WFD economic values, sometime in the future, would be minimal. To avoid these better, however, the Brander *et al*.[12] value function, upon which the NEA values are based, could be adjusted to minimise the effects of double counting (by turning off water quality-sensitive variables, though possibly at the expense of other important services)..Those variables that do not relate much to water quality could be kept in, and water quality could then be put in separately. However, the fact that this might require switching off certain variables that are important but are affected by water quality is a problem. That said, a far larger barrier to including water quality is the lack of economic figures that can be applied in a meaningful way to the CS. The NERA report[13] failed to produce per unit values (they were only relative improvements of 95% compared to the present baseline scenario). We therefore suggest the ecosystem approach for the near future until WFD-related figures are eventually produced, which will probably not be for some years.

Future development

Developing a WFD approach

At the time of writing, the Environment Agency had not provided us with the data required to perform any analysis. Instead, we valued wetlands in Section 1 by valuing the ecosystem services of the wetlands, which includes rivers and streams. While these may be more accurate of water's value, particularly over the GQA, by looking at the entire ecosystem's value, it fails to capture the quality of the water, and does not conform to the WFD. There is, therefore, a good case for complementing the ecosystem approach used here with the WFD, though as explained above, this has not been possible in this study. While previously the Environment Agency had advised us that the WFD reporting cycle was only every seven years, it has only recently come to light that WFD data is obtainable for 2007, 2008, 2009, and 2010. For future work, or with an extended project, we might have more luck getting hold of this data.

The next challenge is to obtain estimates derived from the NERA WTP study for water quality improvement, but instead of per household we need average water body values (~7000 in the UK), and we need the values to be for incremental changes in water quality. For example, how much the average WTP would be to improve 1 km^2 of water from moderate to good status (under the WFD). This would incorporate actual water quality into the ISEW (not included in Section 1), but it does have its problems. For example, a WTP per area estimate, if we managed to get it, would not work well with linear features such as rivers, but would be more appropriate for lakes. Further adjustments may therefore be necessary. Finally, actually obtaining the proxies would be very difficult, as suggested by Joe Morris.

GQA

With the Environment Agency intending to halt GQA assessments, and no known better economic values for this classification, we recommend not continuing with the GQA for future ISEW reporting. Moreover, the Environment Agency has ‘back-cast’ some GQA results (around 1995), revising previous trends and making them inconsistent with ISEW findings made before such a revision. The question arises as to how to convert previous information on water quality under GQA to any newer assessments, if we cannot back-cast using a new adopted methodology (for instance, WFD data was only being gathered from 2006/2007, making any historical comparisons impossible). This is a research project in itself: there are some possibilities, such as mapping trends in GQA and WFD to estimate how water quality under WFD may have looked pre-2007.

3. Costs of long-term environmental damage

The costs of long-term environmental damage are the single largest negative component of the R-ISEW, accounting for one-fifth of the social, economic, and environmental costs subtracted from the total for England. As such they warrant particular attention. In this development work, we have explored three ways the component could be modified:

1. Updating unit costs of carbon;
2. Using different models to distribute costs over time; and
3. Using new data to distribute costs between regions

In this section of the report we will consider each of these modifications in turn, with the greatest focus given to updating unit costs. We will then show how the proposed changes alter the results for this component compared to the latest update carried out using the old methodology (in 2010). We will also present results using new unit costs, but maintaining the old model for distributing costs over time to explore the resulting differences.

Updating the unit cost of carbon

The current ISEW calculations make use of an estimate of the social cost of carbon from 2002, setting the cost of a carbon-equivalent tonne at £70. Moreover, the research that the estimate is based on doesn't specify how that damage is distributed over time. The current calculations make the simplifying assumption that all the damage will be incurred in a single point of time in 2050.

Since 2002, climate science and the economics of climate change have progressed rapidly. For instance, the *Stern Review* presented estimates that assigned a higher cost to greenhouse gas emissions than those currently used in the calculations, and claimed that a large part of the damage would materialise only after the current century. Incorporating this new knowledge will make the R-ISEW more robust and make sure that long-term environmental damage is properly reflected in its results.

Features of models of climate damage

There are numerous models available that estimate the size of the damage caused by greenhouse gas emissions. A recent review article by Richard Tol listed 47 different articles, giving 211 estimates of the social cost of carbon.[14] Many of the models are so-called Integrated Assessment Models (IAMs) that combine information from natural science and socio-economic analysis of climate change. The IAMs bring together many different dimensions from the costs of abatement and adaptation to estimates of the damage caused by changing the climate. They typically answer broader questions on what the optimal climate policy is and what level of abatement should be undertaken in different time periods.

This section will explain the most important features of such models for the purpose of estimating the marginal damage of greenhouse gas emissions. Having explained these different features of the models, we will be able to make an informed choice on which model to draw on for estimates in the R-ISEW calculations. The most significant features are the following seven:

1. Model structure
2. Climate sensitivity
3. Damage function and risk of catastrophe
4. Equity adjustments
5. Adaptation
6. Range of damages considered
7. Sensitivity analysis

Choice of model structure

Climate-economics models have different frameworks. Stanton distinguishes five different model structures.[15] We will here describe only the structures that are used in the most recent models that we review below: the welfare optimising and simulation models.

Welfare optimising models consist of separate climate and economic sub-models that are interlinked. Production in the economic sub-model results in both emissions and consumption. Emissions in turn affect the climate, causing damages that reduce the amount of production. The model determines the optimal climate policy by maximising the discounted net present value of welfare (which is determined based on consumption, with a diminishing marginal utility). Some of the most widely used climate-economic models, such as DICE and FUND (Framework for Uncertainty, Negotiation and Distribution), are based on a welfare-maximising structure.[16] [17]

Simulation models are based on exogenous predictions about emissions and climate conditions in the future. The outcomes to the climate are hence not affected by the economic model. Some predetermined amount of emissions is available for each period, and the model estimates the corresponding cost of abatement and damage resulting from changes in the climate for each of them. The simulation models don't attempt to answer the question of what level of mitigation would maximise social welfare, rather they estimate the costs associated with various chosen future emission paths. Simulation models are widely used. Most notably, the *Stern Review* was based on the simulation model PAGE2002.[18]

All model structures have some benefits and weaknesses. Simulation models are simpler, but lack information on the feedback between the economy and the climate and their interaction. They also depend on the user of the model selecting the scenario that is most relevant for their current analysis.

Climate sensitivity

Climate sensitivity refers to how much temperatures rise as a consequence of an increase in greenhouse gas concentrations. The standard way of expressing the sensitivity is the amount of increase in temperature that would result from a doubling of the concentration.

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment report, published in 2006, concluded that the most appropriate estimate for climate sensitivity is 3°C. The IPCC results are seen as overly conservative by some climate scientists in light of recent results. The most pessimistic estimates are those of NASA scientist James Hansen, who, drawing on evidence from the paleoclimatic record, concludes that a climate sensitivity of 6°C is the best estimate.

Climate models often have a range of different scenarios and alter the climate sensitivity parameters. For instance the *Stern Review* used a range between 1.5 and 4.5.

Damage function and the risk of catastrophe

Climate models typically have some form of damage function, which translates the predicted increases in temperature (sometimes also rises in sea level) into economic impacts. In most cases the relationship between temperature and economic damage is expressed as in Equation 2, with an equation that assumes damages to increase proportionally to a power of the change in temperature:

$$D = aT^{b} \qquad (2)$$

where D stands for the value of the damage, expressed in either monetary terms or as a share of total economic output and T is the rise in temperature over some baseline period. The exponent b determines the shape of the damage curve, or how quickly damages rise as a consequence of increases in temperature. Because of the potential of exponential growth, the choice of b determines the results of the model to a large extent.

The damage function is typically calibrated by estimates of damage at 2.5°C or 3°C warming. For example, the DICE-2007 model was calibrated to have 1.8% loss of world economic output as a consequence of 2.5°C warming. Given this calibration, the damages created by gradual changes in temperature are estimated by selecting the correct functional form. Because few extensive estimates of overall damages are available, the choice of function is difficult to verify empirically.

In a large number of climate models, the exponent of the damage function is assumed to be 2. This means that the damage function is quadratic. For example, given the damage estimate of DICE-2007 at 2.5°C, a quadratic function would imply that a 6°C increase in temperature would lead to a 10.2% reduction in world output. The functional form chosen can be evaluated by testing whether such conclusions match other predictions made by climate science and economics. Many commentators have stated that they believe quadratic functions underestimate the damage caused by higher temperatures.[19] This is clear in the case of DICE-2007: Many predictions of the consequences of a temperature rise of 6°C include disastrous consequences for ecosystems and human life that would be likely to go beyond a 10.2% reduction in economic activity.[20]

Uncertainty about the damage function can be mitigated in two ways. First, many models include the damage exponent as an uncertain parameter in different scenarios or sensitivity analyses. This makes clear that it cannot be chosen without uncertainty and shows the impact that the choice of the exponent has on the results.

Secondly, many models have separate means to account for discontinuous effects or catastrophic damage at high temperatures. Functions such as Equation 2 assume that damage increases in a continuous fashion across the entire range of temperatures. Changes in the climate might, however, be abrupt and non-linear, instead of being gradual and continuous. There is the possibility of feedback processes, created by changes in carbon sinks or the energy reflected by frozen bodies, which are subject to abrupt changes after certain thresholds in temperature have been passed. Some models include an additional possibility of catastrophic damage to take into account such non-linear effects. With such additional modelling, there is less reliance on the regular damage function to account for all the costs that are associated with very high temperatures. For instance the PAGE2002 model for the *Stern Review* was run with 5°C as the threshold temperature for the possibility of catastrophic events. Once this temperature has been passed, a risk for catastrophic events begins to rise as function of temperature, with a 10% probability increase per degree (as the most likely value of the parameter within a range of different scenarios). A catastrophic event is represented by a 5–20% loss of global economic output.

Adjustments for equity

In climate modelling, costs and benefits are often unequally distributed over time or different regions of the world. Also, some regions and periods in time have lower levels of economic income, and are less able to cope with the damage associated with climate change. In these cases decisions need to be made whether such disparate distributions need to be corrected or weighted differently within the logic of the model. When it comes to changes over time, benefits and damages in the future are typically given a smaller weight by applying a discount rate. Even though discounting is important, the choice of discount rate for the R-ISEW calculations will be done independently of the climate model used, so there will be no discussion of equity over time in this section. The focus will instead be on equity over space or the different regions of the world.

Some climate models treat the world as one whole and do not differentiate between different regions. For instance, some IAMs attempt to maximise a single social welfare function which represents the globe as a whole. In these cases, issues of spatial equality do not arise. Most modern models, however, distinguish an impact between different regions. They calculate economic production, the associated levels of utility, and the damage caused by the climate separately for some number of different regions. With the information such models produce, it is possible to estimate whether some groups of people lose more in relation to others. Should the estimate of the size of the damage be changed if it is unequally distributed?

In principle, damage should attract a higher weight if it is inflicted on less wealthy people, as opposed to those who are rich. This can be justified based on the standard economic assumption of diminishing marginal utility – the fact that the benefits that a person derives from income and goods declines as he or she gets access to more of them. A consequence of this principle is that the same amount of damage will cause a greater loss for a person who is poor in comparison to a person who is rich. The traditional techniques of cost-benefit analysis however often produce precisely the opposite emphasis. Typically economic losses are measured based on their exchange value, and non-market damages are based on WTP. Because poorer people have less economic wealth at their disposal and also a tighter income constraint when WTP is measured, the damage that they suffer is valued less in monetary terms. A large number of existing damage estimates don't correct for this bias.[21] In addition to differential impacts on welfare that are related to the original distribution of wealth, there are concerns of justice or fairness that could be taken into account in damage estimates. For instance, people might display an aversion towards inequality, which might increase due to the fact that some groups suffer disproportionately from the consequences of climate change.

In climate economic modelling, the approach taken is to create a social welfare function with distributional weights, and to monetise changes to it. The social welfare function aggregates the utility levels of individuals in some manner. There are several ways to create such functions, which reflect numerous different conceptions of what an equitable distribution of resources is.[22] The most widely used is the utilitarian welfare function, which is simply a sum of utility functions with declining marginal utilities. The changes to social welfare are turned into monetary units by seeing how large an increase in income would have to take place to create a change in welfare that corresponds to the climate damage. With the utilitarian welfare function, the global damages can be broken down into regional damages with distributional weights according to Equation 3:

$$D_{world} = D_{region} \times \frac{Y_{world}}{Y_{region}} \times \varepsilon \qquad (3)$$

where D stands for damage and Y for average incomes in the regions. ε is the elasticity of marginal utility, or how much an increase in income leads to an increase in its utility. In some cases ε can stand for a measure of aversion towards inequality that incorporates concerns other than declining marginal utility. In the literature, ε is typically estimated to be close to 1.[23] Within one year, such a value has been found to increase the size of the damage by about 25% over unweighted figures. With any sufficiently high inequality aversion, equity weighting typically raises the damage estimates. This is because the damage of climate change is disproportionately concentrated in the areas where the poorer population live. When estimating the net present value of damage over several years, equity weighting tends to have the opposite effect in current models. This is because future generations are assumed to have higher incomes than those living today, and the damage incurred by them will consequently have a smaller weight attached to it.[24] Of course, such assumptions may be unrealistic given current concerns regarding the possibility of continuous economic growth,[25]

The *Stern Review* did not use any equity weights. The report did endorse using such a technique, but did not include it in the analysis, stating time constraints as the reason.

Adaptation

Adaptation activities, such as building defences against sea-level rise or changing agricultural practices to adjust to higher temperatures, can prevent some of the damage created by climate change. The potential for adaptive actions is taken into account in most models by making some assumptions about how much of the damage predicted by the model can be cancelled out. Such assumptions often have large effects on the resulting estimates, even though they are difficult to assess empirically.

The *Stern review* assumed that there was quite substantial potential for adaptation. It assumes that in developing countries, 50% of the economic damages can be undone by low-cost adaptation. OECD countries are expected to be able to cope with 100% of the economic damages created by the first 2 degrees of warming and 90% of that above 2 degrees. In contrast, for non-economic and non-catastrophic damages (see above), the rate of adaptation is assumed to be 25% everywhere.

Some critics have found these assumptions to be overly optimistic. Given the experience of the European heatwave in 2003 and the destruction created by Hurricane Katrina in 2006, an assumption of a perfect response to all damage wrought by climate change seems unduly optimistic.[26]

Range of damages

The damages from climate change can include numerous things, from a simple reduction in economic activity to forced migration or a loss of human or natural life. Climate models traditionally focused only on the literally economic impacts, i.e. the impacts that are felt in GDP measures. These are broadly speaking impacts for which a financial value can be deduced easily, either based on prices of things traded on markets or the economic costs associated with responding to the impact. They can include either a loss of economic outputs in a given period, caused for instance by the need to channel part of annual income to investment into adaptation (e.g. building new dams). The economic damage can also include detrimental or positive changes in the productive capacities of economies. For example, climate change can lead to the destruction of coastal properties due to rising sea levels, or can damage productivity of land in agricultural use due to changing rainfall patterns. Changes in capital are different from changes in income in that their consequences span over a longer period of time. A reduction in a capital stock will reduce the options for generating income in future years as well. For simplicity's sake, the impact on capital stocks is often modelled as though it would be equivalent to a change in the output of an economy in a single period.

For some of the impacts of climate change an estimate of their economic value is not directly available. These are, for instance, changes to human health, changes to biodiversity, or a loss of natural habitat. The impact of climate change on these features is quite difficult to estimate as such. Another challenge is to come up with an economic valuation for them, which would allow such damages to be expressed in a way that is commensurate with economic damages. To place a value on things without a market price, studies often use revealed preference techniques. For instance the value of human health can be deduced by looking at how much more in wages individuals ask for in return for working conditions that are detrimental to their health. When looking at revealed preferences is not possible, like in some cases of damage to ecosystems, WTP surveys are an alternative.

As a rule, contemporary IAMs include some modelling of non-economic costs. There are, however, some differences in how extensive the models are in their reach of non-economic impacts. The differences of six models are summarised in Table 3.1.

Scenarios and sensitivity analysis

The results of the climate model typically depend on a range of variables that cannot be precisely estimated. These include the amount of future emissions, the development of technology and the resulting carbon intensity of the economy, and the sensitivity of the climate to greenhouse gas emissions. As these variables have a large impact on the results of the model but cannot be estimated with much certainty, the models are typically run in a number of different scenarios, and their results are reported separately. Most models include scenarios with different assumptions about the trajectories of future emissions. To estimate a value of the damage caused by each additional tonne of emissions, typically business-as-usual scenarios, in which there is no additional abatement of greenhouse gases in the future, are used.

In sensitivity analysis, all the parameters of the model are systematically varied within a range that is judged to reflect possible values (with more extreme values of parameters less likely). The distribution of the results from the number of runs is observed in order to obtain the most likely estimates as well as confidence intervals. In Monte Carlo simulations, the parameters for runs of the model are selected randomly from within the predetermined range. Using statistical techniques, the results are aggregated from all runs of the model. Using these types of sensitivity analyses can significantly alter and improve the results of the modelling work. In one study, damage estimates made by the *Stern Review* were calculated to be 7.6% higher if the Monte Carlo simulation was used in sensitivity analysis, rather than simply choosing parameters.[27]

Review of models

To accommodate the diversity in methods and results from climate modelling, some researchers have carried out meta-analyses of the model results.[28] In such analyses, all the different estimates from the models are combined and statistical methods are used to show, based on the population of studies available, which studies are outliers, what the most likely values are, and what ranges of values are within certain confidence intervals. Some existing ISEW calculations have made use of the results from such meta-analyses.[29]

For the ISEW modelling work it is possible that some information from the models is required that is not typically reported in publications. For instance, to execute the endowment fund model of long-term environmental damage exactly, information on the temporal distribution of damage from climate change is required. Because of this, the aggregation of results from several different studies is not feasible, and we have to focus on working together with the authors of a single model to get the necessary data. We will consider a range of recently developed models, and select the ones that appear to make the most realistic estimates of future damage, given all the criteria outlined above.

To make this choice, we reviewed the features of a number of the most recent climate models. To identify the most promising models, we went through reviews of climate-related IAMs.[30] [31] [32] We also contacted a number of the leading climate economists to ask for their recommendations for which models to consider, and went through the homepages of several institutions that are working on the topic.[33] Moreover, we did a brief search on databases of academic articles to locate any publications on the topic that had been published after 2006. We selected 6 different climate damage models (Table 3.1).

The different models considered are:

1. PAGE2002 model used in the *Stern Review*
2. PAGE2002 model rerun by Ackerman *et al.* (2008)
3. PAGE09 by Hope (2010)
4. CRED by Ackerman *et al.* (2010)
5. FUND by Anthoff and Tol (2009)
6. DICE 2007 by Nordhaus (2008)

Table 3.1 Features of 6 recent climate models (continued on next page)

Model	Identified problems	Climate sensitivity	Damage function	Adaptation
PAGE2002 model used in the *Stern Review*	Damage function exponent too optimistic; too optimistic about adaptation; no equity modelling; very high threshold before catastrophic risk sets in.	In basic scenario, used a range of 1.5–4.5 °C. Separate high climate sensitivity scenario used range 2.4–5.4 °C.	Damage exponent with range 1–3, with 1.3 as most likely value.	In developing countries, 50% of economic damages eliminated by low-cost adaptation. In OECD countries, 100% of economic damages below 2 degrees eliminated by adaptation, and 90% above 2 degrees. For non-economic impacts, non-catastrophic damages, 25% of impact assumed to be removed through adaptation.
PAGE2002 model rerun by Ackerman *et al.* (2008)	No equity weights; only very optimistic and pessimistic scenarios about adaptation available.	Range of 1.5–4.5°C.	Damage exponent with range 1.5–3, with 2.25 as most likely value.	One scenario with no adaptation, and one with adaptation along Stern's assumptions.
PAGE09 by Hope (2010)	Unclear about how economic and non-economic damage functions were calibrated.	Range 1.38–7.88°C, with 3.17°C as most likely value.	Four different sectors for which impact is estimated separately. These are sea-level rise, economic, non-economic, and discontinuity impacts. Each has its own damage function; the exponent for economic and non-economic impacts is a range of 1.5–3, with 2 as the most likely value.	Information about adaptation potential updated. Less optimistic about adaptation potential than the *Stern Review.*
DICE 2007 by Nordhaus (2008)	Damage estimates too optimistic (see Hanemann 2007). They have been revised upwards, but based on survey of evidence about the USA, still 3–4 times too small; no equity modelling.	3 °C	Quadratic polynomial function that is calibrated based on regional estimates of damage, including sectoral details in agriculture, sea-level rise, health, as well as non-market and catastrophic damages. With 2.5 °C rise, damages are estimated at 1.9% of GDP, and 4.8% at 4°C.	Adaptation not directly modelled. Potential for adaptation is included in some of the damage estimates.

CRED by Ackerman*et al.* (2010)	No catastrophic damage; weak sensitivity analysis; pessimistic about climate sensitivity.	4.5 °C	Polynomial damage function, exponent 2.	No direct modelling of adaptation; regional levels of vulnerability based on prevalence of agriculture and tourism.
Model	**Identified problems**	**Climate sensitivity**	**Damage function**	**Adaptation**
FUND by Anthoff and Tol (2009)	Climate sensitivity too low. Too optimistic on damage: assumes a *reduction* in mortality for low levels of warming and gives smaller value to lives of poor people in comparison to the wealthy; no modelling of catastrophic events or discontinuity.	2.5 °C	Separate impact models for damage in agriculture, forestry, water resources, energy consumption, sea level rise, ecosystems, vector-borne diseases and cardio-vascular diseases. Damages determined as a function of both absolute temperature rise and the rate of temperature rise.	Damages determined by rate of temperature rise slowly fade, reflecting adaptation to damages.

Table 3.1. Features of 6 recent climate models (continued from previous page)

Model	Sensitivity analysis	Modelling of equity	Catastrophic events	Non-economic impacts considered
PAGE2002 model used in the *Stern Review*	Monte Carlo analysis with 31 parameters and 1000 runs.	No equity weights, citing lack of time as reason.	Beyond temperature rise of 5°C, risk of catastrophic event starts to rise by 10% for every °C. A catastrophic event is a loss of GDP in the range of 5–20%.	Separate category of damages for non-economic consequences, such as damage to health and wildlife, is included.
PAGE2002 model rerun by Ackerman *et al.* (2008)	Monte Carlo analysis with 5000 runs; different percentiles reported.	No equity weights.	Threshold temperature with range of 2–4°C, with 3°C as most likely value. Increases in likelihood per °C within range 10–30%, with 20% as most likely value. A catastrophic event is a loss of GDP in the range of 5–20%.	Separate category of damages for non-economic consequences, such as damage to health and wildlife, is included.
PAGE09 by Hope (2010)	Monte Carlo with 112 parameters and 14,000 runs.	Models costs in terms of changes in expected utility, which weights the costs to those with lower wealth higher. The marginal elasticity of utility is one of the uncertain variables, with a range 0.5–1.2.	The modelling of discontinuities and feedback effects has been updated since the *Stern Review*. The likelihood for discontinuities also starts increasing at a lower temperature level.	Includes non-economic damage function that represents damage to human health and ecosystems.
DICE 2007 by Nordhaus (2008)	15 different scenarios with different temperature constraints, climate policies and assumptions about technological change.	No equity weights.	Estimate based on willingness-to-pay measures for avoiding the risk of catastrophic events. Damage caused by risk of catastrophe estimated to be 0.45–1.9% of GDP at 2.5 °C and 2.5–10.8% of GDP at 6°C.	Includes non-market impacts such as increased possibilities for leisure use of nature, health status and environmental services.

Model	Sensitivity analysis	Modelling of equity	Catastrophic events	Non-economic impacts considered
CRED by Ackerman *et al.* (2010)	Five different scenarios, based on varying discount rates and limits on investing outside of regions.	Utility function with higher marginal utility for people with lower income, assuming that 1% increase in consumption yields same increase in utility for all.	No catastrophic events included.	Builds on recent updates on damages estimates used in the DICE model, which take into account the leisure use of nature, health status and environmental services.
FUND by Anthoff and Tol (2009)	Five different scenarios, 4 based on IPCC work and one developed by Richard Tol.	Utilitarian social welfare function with equity weights. 3 scenarios with different levels of inequality aversion.	None	Impact on health and morbidity, forced migration, losses of drylands and wetlands and other impacts on ecosystems.

Choice of model

We recommend the results from the PAGE09 model to be used in R-ISEW modelling, because it offers the best balance between the features listed in our review. The model takes into account the most recent scientific knowledge, especially about climate sensitivity. It also includes a separate model of the impact of sea level that incorporates recent empirical results. It is one of the few models that apply equity weights on the damage results, making sure that the damages caused to people with less income don't appear inconsequential. Also potential for adaptation appears to be modelled more realistically than in other available work.

The 1% discount rate used in the PAGE09 model is close to the Stern Review's chosen discount rate of just above 1%, and therefore preferable to the 3% discount rate used in previous R-ISEWs. It also better reflects the context of intra-generational trade-offs with high stakes (the 3% rate is more appropriate when considering less risky assessments taking place within a single generation's lifetime).

Impact on costs

Until now, the ISEW modelling work has used an estimate of the social cost of carbon (SCCO2) produced by the Treasury and Defra in 2002.[34] They chose an estimate of the net present cost of £70 per tonne of carbon emitted. This cost increases in real terms by £1 per tonne each year. The cost is expressed in year 2000 prices, and would need to be increased to take into account the rise in the marginal damage of emissions, but also inflation in prices. The study emphasises that the chosen value is a 'defensible illustrative value'. The full range of damage estimates that they found from their review was $5 to $125 per tonne of carbon. They chose the £70 recommendation because it matched the result of a single model that was found to be the most sophisticated – because it included features such as equity weighting and a wide range of impacts considered. They also note that this cost appears to match the level of carbon tax that would be required for Britain to meet its international commitments for greenhouse gas emission reductions.

The estimates of the net present SCCO2 presented by the PAGE09 model are considerably higher. The model reports an estimate for the social cost of carbon to be $95 per tonne of carbon dioxide, in 2005 prices. This converts to £166 per tonne of carbon in 2009 prices.[35] However, the principal reason for the higher cost appears to be the discount rate used. Whilst the Defra study used a discount rate of 3%, the PAGE09 model uses a rate of 1%. If we were to assume that both models are discounting back from damage incurred in 2050, as we have done in previous R-ISEWs, then these net present values and discount rates would imply undiscounted damage in that year of £381 per tonne using the Defra model, and £246 per tonne using the PAGE09 model. As we shall see, however, our understanding of the PAGE09 model is that damages are modelled to be occurring much later. As a result, the net present value of £166 per capita represents a larger amount of damage at a later date.

This is all particularly relevant for the endowment fund model, as we shall see, as this model relies on undiscounted costs to calculate the required endowment fund payments.

In sensitivity analysis, Hope *et al.* find that 90% of runs of the model fall between \$10 and \$230. The authors of the model have, in personal communication, estimated that the annual change in the social cost will be 2–3% per year. This is based on results from the PAGE2002 calculations, and has not been verified for the PAGE09 model.

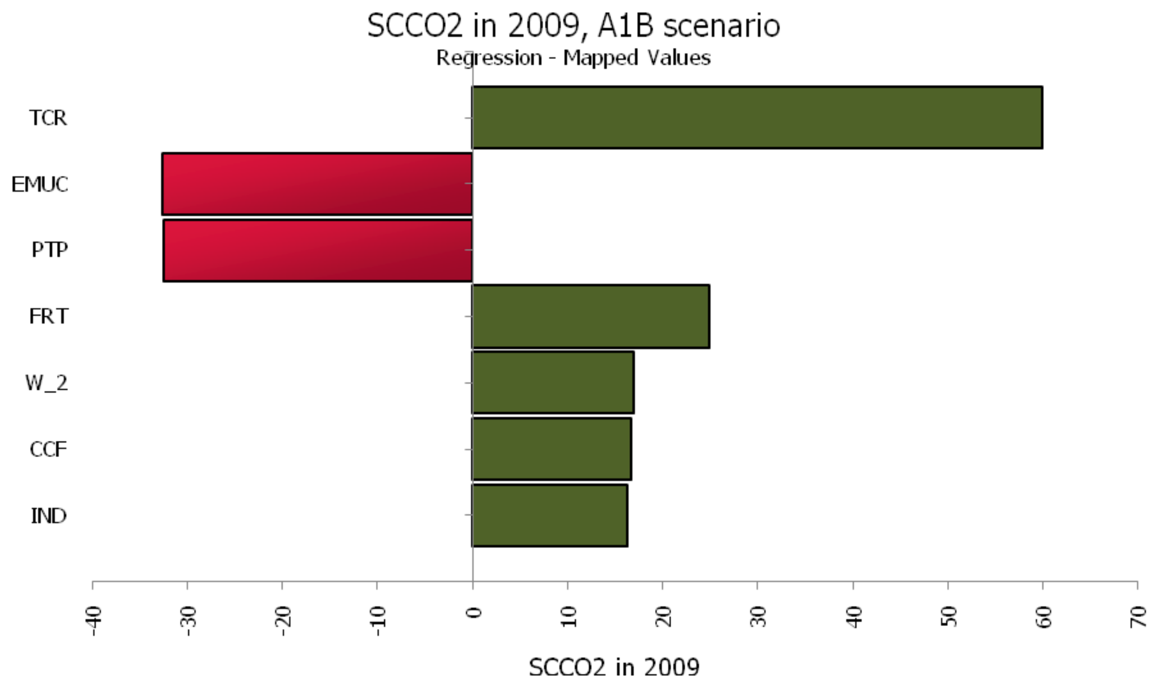

Figure 3.1. Sensitivity analysis: Percentage changes in the social cost of carbon caused by a change of one standard deviation in key variables.

TCR: Transient Climate Response
EMUC: Equity Weights
PTP: Pure Time Preference
FRT: Feedback Response Time
W_2: Weight of non-economic impacts
CCF: Carbon Cycle Feedback
IND: Indirect cooling effect of sulphates

Some features of the PAGE09 model and its results can be understood from the sensitivity analysis shown in Figure 3.1. This shows how much the social cost estimate changes in percentages as a result of changing key variables by one standard deviation. The most important variable is the transient climate response (TCR), i.e. climate sensitivity. Increasing it by one standard deviation increases the social cost estimate by about £105. EMUC represents the size of the equity weights. A higher equity weight actually reduces the cost estimates, because of the fact that future generations, who will incur most of the damage caused by climate change, will have higher income than the present generation. Some variables with a more intuitive impact are the pure-time preference component of the discount rate (PTP), the feedback response time (FRT) and weight of non-economic impacts (W_2).

The temporal distribution of damage

The endowment fund model for calculating long-term environmental damage requires an estimate for when the climate damage takes place in the future – the temporal distribution of damage. As we have mentioned, all damages were assumed to fall in the year 2050. An examination of the information in the *Stern Review*, however, shows that this was unduly pessimistic. According to Stern, most of the harm will in fact be incurred in the next century. Information about the temporal distribution of the PAGE09 model is not available to date, and our budget prevented us from commissioning work by Hope to elaborate on it. However, given the model is based on that used in the *Stern Review*, we were able to assume that the temporal distribution of damage is similar. For the updated run of the endowment fund model, we set the year when the damage materialises to 2150. Doing so implies that the final undiscounted damages, calculated from the net present value, are assumed to be larger – £665 per tonne as opposed to £246 per tonne. However, it also means that the endowment fund has a longer time to accrue, meaning that the amounts of money that we need to be putting aside at the moment are less than if the damage were to come sooner. The combined impact of these two effects is to reduce the annual cost of servicing the endowment fund by about 20%.

Figure 3.2 shows how the estimated annual cost in 2008 varies according to the year damages are assumed to incur costs, from 2050 to 2200. As can be seen, the variation is not too dramatic, and the two effects mentioned in the paragraph above counteract each other to some extent. The lowest annual cost is estimated if one assumes damages will take place at around 2100 – at this point the total final damages estimated based on the 1% discount rate are still not that great and the model assumes 90 years to accrue funds to cover it. Beyond that point, however, the estimated final damages grow steadily and the extra time provided to accrue funds to cover them does not compensate.

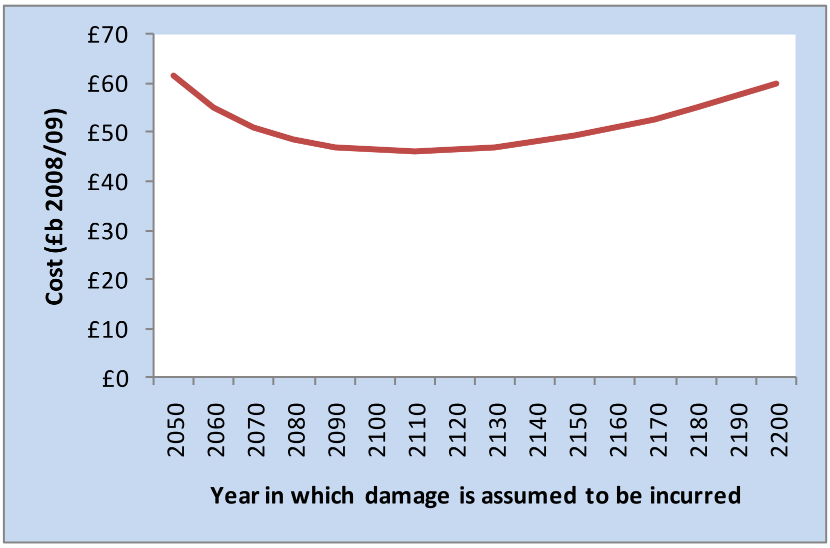

Figure 3.2. Estimated cost in the UK in 2008, based on different assumptions of year damage is incurred.

Different cost models over time

Calculating the total costs of climate change and an SCCO2 is difficult enough, as has been seen in the previous section. Also daunting is the task of determining how to assign those costs in an indicator such as the R-ISEW: which regions are responsible for the costs and in which year. Temporally, costs are accumulated over time, including far back into the past, and will be felt in the future. Spatially, emissions produced in one region may have been associated with production in another, and consumption in a third. And the costs themselves will be felt globally, not specific to any of the regions involved in their production, nor indeed the UK as a whole. In this section we will present two approaches to calculating the temporal pattern for results. The first, the endowment fund, we have used in all previous calculations of the R-ISEW. The second, the ecological debt model, was developed during the scoping work in 2009 and is implemented for the first time in this report. Which model is used depends to an extent on the purpose of the R-ISEW or ISEW being calculated.

Revisiting the endowment fund model

To date, the R-ISEW has used a unique and innovative approach to modelling the costs of long-term environmental damage over time. The costs of greenhouse gases emitted in previous years are included in the calculations for each year, on a cumulative basis. This is justified from the perspective of sustainability: The damage from the present and past emissions will predominately take place in the future. In order to maintain levels of economic welfare, the economy will have to be prepared for this damage, including the harm caused by emissions from past years. The Index, it is argued, must therefore be adjusted corresponding to the increasing cost of dealing with the future problems of climate change caused by emissions present *and* past.

The easiest way to do this would be to simply add all cumulative emissions together and calculate a cost each year by multiplying the sum with the SCCO2 in that year. However, as noted by the critic Eric Neumayer, this would lead to astronomical costs that would overwhelm the rest of the ISEW.[36] For example, in 2008, the total cost for England would be £8.3 trillion – almost thirteen times the final ISEW using current calculations. To respond to this criticism, **nef** and Tim Jackson developed an approach based on a model of a hypothetical endowment fund. A given year's R-ISEW value is adjusted by the amount that would need to be set aside each year from that year onwards so that the endowment fund reaches the required size by the point at which damages will be incurred (2050 in the previous model).

This approach is consistent with an interpretation of the ISEW as the level of service flow that can be enjoyed indefinitely. It simply subtracts from the current consumption levels an amount which we should be setting aside to prepare for climate change – it is implied that future years will also see the same annual payment into the fund. Without such preparation, the level of service flow enjoyed in a given year cannot be sustained when the damages associated with climate change materialise. Whether or not we are producing any emissions in a given year is not necessarily relevant. Even if we stop emitting today, we will still face substantial environmental damage in the future and the fact that we are not dealing with it implies that our current level of income is not sustainable.

As we noted in the scoping work, however, the endowment fund has difficulty fitting the S + ΔK accounting framework. The framework restricts the ISEW to consideration only of productive activity within the given time period – to do otherwise risks leaving the ISEW unbounded, and also risks mixing stocks and flows. The endowment fund is a clever way of getting around the latter of these two problems (by converting the stock of environmental damage accumulated over the years into a regular annual payment), but it very clearly does not get around the former problem. Ultimately, the bulk of the endowment fund payment required for any given year is the result of productive activity in previous years. As well as infringing the time frame, this also means that the endowment fund methodology is very insensitive to changes in annual emissions, be that an increase or a decrease.

On further inspection, it is also clear that this methodology is not actually consistent with an interpretation of the ISEW as the level of service flow that can be enjoyed indefinitely. In determining the amount of money that needs to be set aside for the endowment fund, only current and past emissions are considered. Future emissions are not considered. Of course, it is inevitable that there will be future emissions, and that these will contribute to long-term environmental damage. This increase in the cost means that annual payments to the endowment fund, if they are to be constant over time, would need to be much higher than currently calculated.

Ecological debt method

In the scoping project, we developed a similar approach based on the metaphor of ecological debt that incorporates past and present emissions, though to differing degrees. This approach still relies on the assumption that we should be saving to deal with damages that will be incurred at a future date; the fact that we are not doing so means that we are incurring a hypothetical ecological debt. This debt increases every year by an amount proportional to emissions in that year, and calculated based on the net present value of the marginal cost of these emissions. However it also increases because the debt from previous years has not been dealt with and that pre-existing debt’s net present value grows as we move closer to the point at which those damages will occur. The approach proposed is to include both the cost of new emissions and the increase in the net present value of past emissions in the cost for a given year. This avoids any risk of double counting and restricts the impact of past emissions on the R-ISEW in any given year.

In this report we present results using this new method for the first time. Calculations were only made using this method with the new SCCO2 from PAGE09, not with the old SCCO2 from the Defra study. It is worth noting that the large discount rate (3%) used in the Defra study would actually mean that costs using this method would be quite high as change year-on-year would be larger.

Distributing costs between regions

In past R-ISEWs, CO_2 emissions were costed to regions based on air emissions maps produced from the NAEI (National Air Emissions Inventory). In other words, the highest costs were attributed to regions which directly produced the most CO_2. These typically were regions with histories of energy production – Yorkshire and the Humber, the East Midlands, and the North East.

The scoping project highlighted the distinction between such an approach and one which attributes costs at the point of consumption. For example, whilst much of the electricity in this country has been produced in power plants in the three regions mentioned above, of course they do not consume any more than other regions. Furthermore, in the case of energy consumption for the manufacture of goods, the goods themselves may not be consumed within the region they are produced. In other words, up to three regions can be implicated in the production of gases leading to climate change – and that's ignoring any further complications in terms of lengthy production chains or disconnects between where a company may be based and where it carries out its activities.

Our scoping report came to the conclusion that, where possible, the R-ISEW should seek to cost as close to the final consumer as possible. In the case of CO_2 emissions, this implies costing emissions where energy is consumed in the case of domestic use and personal transport, and where goods are purchased in terms of emissions involved in manufacture. However, this was not identified as a priority for this development project.

Nevertheless, new data identified during the course of the 2010 R-ISEW update made it possible to explore a small step in this direction. The Department of Energy and Climate Change (DECC) now produces estimates of CO_2 emissions per region, based on the point of *energy* consumption. Of course, this is not the same as final consumption for all types of energy consumption, but it is a step in the right direction. Furthermore, it might help to tackle the sharp differences in the costs of long-term environmental damage previously seen between energy-producing regions such as Yorkshire and the Humber, and other regions.

Table 3.2 shows the proportions of CO_2 emissions attributed to each region in 2005 based on both the NAEI emission data and the DECC data.

Table 3.2: Proportions of CO_2 emissions attributed to each region based on different data sources, 2005.

	North East	North West	Yorkshire &Humber	East Midlands	West Midlands	Eastern	London	South East	South West	England
NAEI	4.8%	10.2%	17.0%	10.7%	6.7%	7.7%	5.9%	12.7%	4.9%	80.5%
DECC	6.4%	11.3%	10.0%	7.7%	8.5%	8.7%	8.7%	12.7%	8.0%	81.9%

As can be seen, using the DECC figures dramatically decreases the proportion of CO_2 emissions attributed to Yorkshire and the Humber from 17.0% to 10.0% and also decreases those attributable to the East Midlands from 10.7% to 7.7%. Meanwhile the proportion for the North East actually increases to 6.4% – a large proportion considering its population. Most other regions also see an increase, particularly London and the South West.

Effect of changes

In this section, we present the impact of these changes on the component calculated between 1994 and 2008 for all regions. We also present the impact on the total cost of this component for the UK as a whole, back to 1930.

New social costs

Figure 3.3 shows how per capita costs come down considerably using the new SCCO2 figures from PAGE09 in the endowment fund model. The decrease is by just over a factor of 3, with little variation between regions and no change in their rank order.

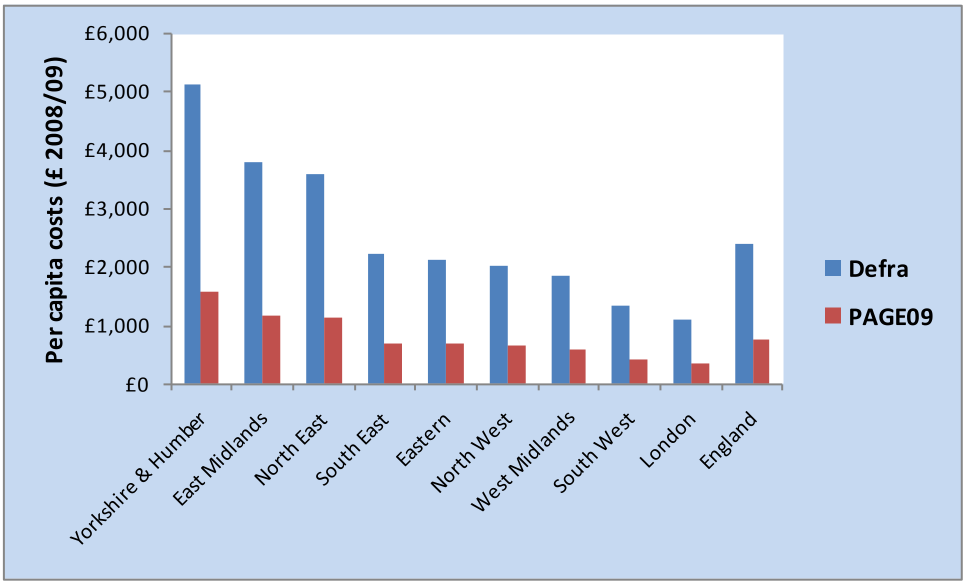

Figure 3.3. Impact of PAGE09 SCCO2, region by region, 2008.

Ecological debt model

Figure 3.4 contrasts the results of the ecological debt model with those from the endowment fund model, for the UK overall back to 1930 (using the new SCCO2 estimates). It also presents the actual emissions in each year, and the marginal cost associated with them.

As one can see, annual emissions rose until the 1970s, before a generally declining trend began. Costs associated with these emissions (the orange line), on the other hand have generally tended to increase because of the increasing cost of emissions year on year (as every further tonne accumulates the unit cost is assumed to increase) from £34 per tonne in 1930 to £164 per tonne in 2009.

Adding the change in the net present value of past emissions to calculate the total change in ecological debt produces the red line. It starts at the same value as the orange line (£4.7 billion in 1930). However, it slowly moves away from it such that, by 2008, the marginal damage from that year came to £28.8 billion whereas the increase in ecological debt was £45.3 billion – almost 60% higher.

The costs calculated using the old endowment fund methodology are also shown for comparison. As it happens, the figures are not that different for the period in which the R-ISEW is calculated (1994–2008), with costs in 1994 slightly lower than according to the ecological debt methodology (£34.0 *vs* £35.2 billion) but higher in 2008 (£48.9 *vs* £45.3 billion). The important difference, however, is the sensitivity of the new methodology to annual fluctuations in CO_2 emissions. The peaks and troughs of annual emission figures can be traced in the annual figures for change in ecological debt, albeit distorted by a steady increase resulting from the growing past debt, and the increasing SCCO2 year-on-year. In contrast, the line for the endowment fund is very smooth, looking almost like a theoretical mathematical function than the product of calculations from real world data. Whereas the ecological debt methodology allows for decreases in the annual figures to be seen in some cases (the last time being in 1999 when the figure dropped slightly as a result of a 4% decrease in emissions from 1998), costs calculated according to the endowment fund rise relentlessly, regardless of declines in emissions

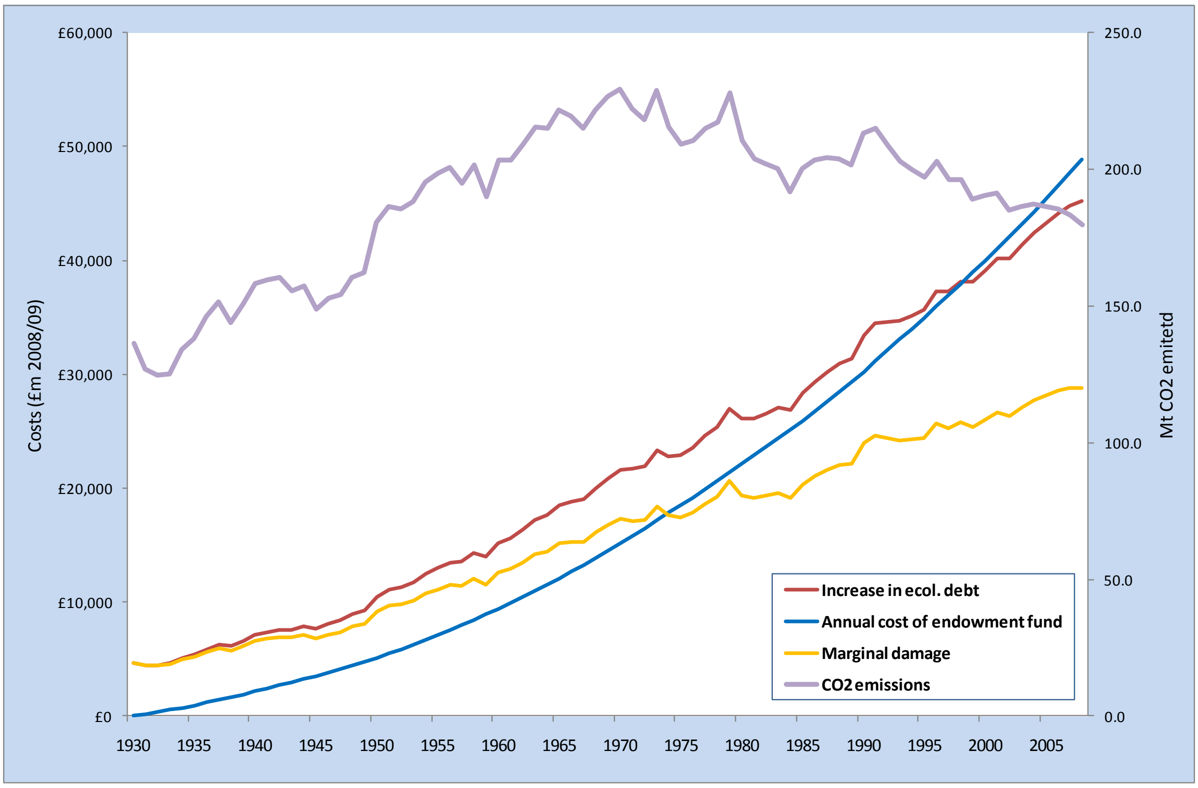

Figure 3.4. Ecological debt and endowment fund model annual costs of long-term environmental damage.

Future scenarios

Figures 3.5 and 3.6 show two possible scenarios for the future (from 1990 to 2050) and how the two models would represent them. In Figure 3.5, total annual emissions fall to 80% of 1990 levels by 2050, at a steady rate of 3.4% per year from 2009 onwards. This is in line with the 2008 Climate Act target, though it should be noted that whilst that target excludes international aviation and shipping emissions, our calculations *include* them. In this scenario, we make no assumptions about any investments for adaptation. However, we do assume that the rate of increase of SCCO2 over time is lower (1.5% per year instead of 2% per year) as a result of a worldwide slow-down in air emissions.

As can be seen, despite emissions falling rapidly, neither model predicts a decrease in annual net costs. The endowment fund model continues to generate ever-increasing costs, rising to almost £100 billion in 2050. The ecological debt model, on the other hand, does appear to be affected by declines in emissions – one can see that the rate at which the annual net cost increases is much lower once emissions begin falling – the cost only coming to £48.7 billion in 2050 – only 7.5% higher than in 2008. However, with the past debt still growing, and the unit cost continuing to rise, albeit more slowly, it fails to decrease, despite the marginal costs of each year's emissions declining (as shown in the orange line).

In the second scenario (Figure 3.6), emissions are assumed to fall at the same rate, but now we also assume that some money is invested into adaptation from 2011 onwards: 0.1% of the UK's GDP is invested in 2011, rising linearly to 1.0% by 2020 and continuing then at 1.0% till 2050.

Looking at the ecological debt model, this investment is rewarded with substantial decreases in the size of this cost – down to £11.4 billion in 2050. However, it should be remembered that the component never reaches below £0, which would indicate a full move to sustainability. Calculations like this would demonstrate that such levels of investment of adaptation and mitigation, whilst making the UK *more* sustainable, would not make it fully sustainable. To achieve this by 2050, according to the model, investment would need to increase to 1.4% of GDP a year. In this way the 'cost' would fall below £0 by 2048 – i.e. we would finally begin to start paying back our ecological debt.

Note that, using the endowment fund model produces a very different picture. Whilst the increased monies going into adaptation lead to a slight decrease in annual net costs until 2020, once the adaptation rate reaches 1.0%, the component continues to increase as before – reaching £68.9 billion a year in 2050. Even if this rate increased to 1.4% a year (as in the previous paragraph), the annual net cost would still rise to almost £60 billion a year.

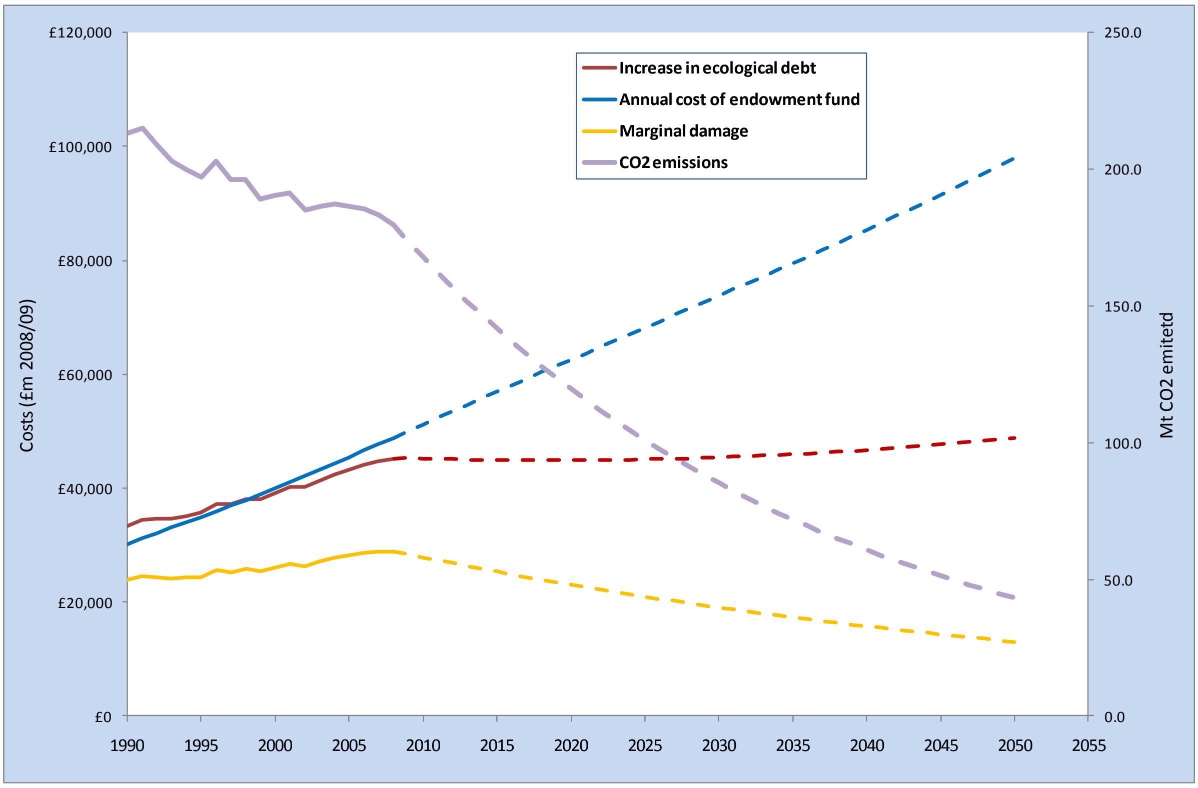

Figure 3.5. Future scenario with 80% reduction in emissions by 2050, but no adaptation.

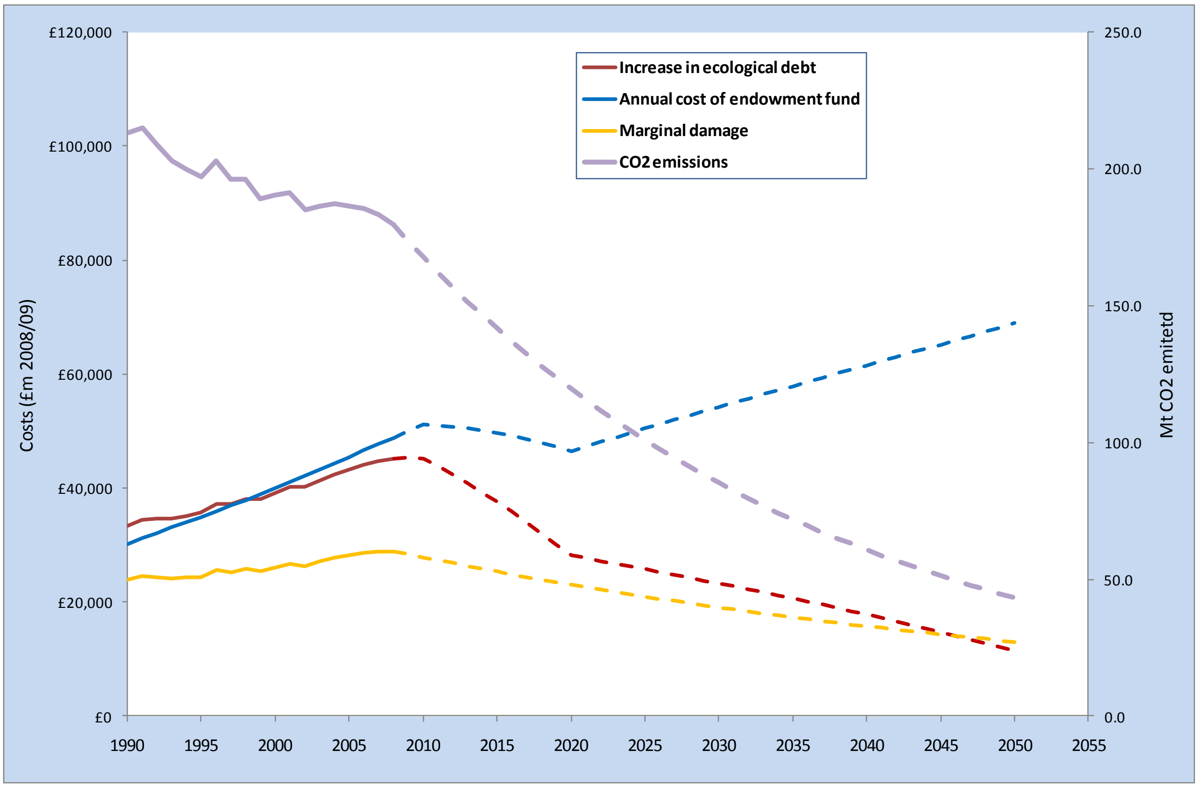

Figure 3.6. Future scenario with 80% reduction in emissions by 2050 and adaptation expenditure rising to 1.0% per year.

Regional patterns

Figure 3.7 shows how the two models differ in terms of the pattern for regions in 2008. There is no difference in rank order, but the ecological debt model serves to narrow the gap between regions, with Yorkshire and the Humber's per capita costs coming down from £1,597 to £1,094, whilst London's costs increase from £360 to £482 per capita. Figure 3.8 also shows how the ecological debt methodology reveals differences in trends from one region to another. Actual regional emissions data is only available from 2003 onwards. From that point, one can see differences in the patterns of costs from region to region. Yorkshire and the Humber's ecological debt costs fall dramatically from 2005 to 2006, the result of CO_2 emissions dropping from 24,577Mt to 16,036Mt, according to the NAEI. The East Midlands also sees a fall in costs in that year, whilst London and other regions see rises. Further work would be required to better understand why there is such a sharp discontinuity in the emissions data between 2005 and 2006 – it may be to do with a change in the methodology in the NAEI.

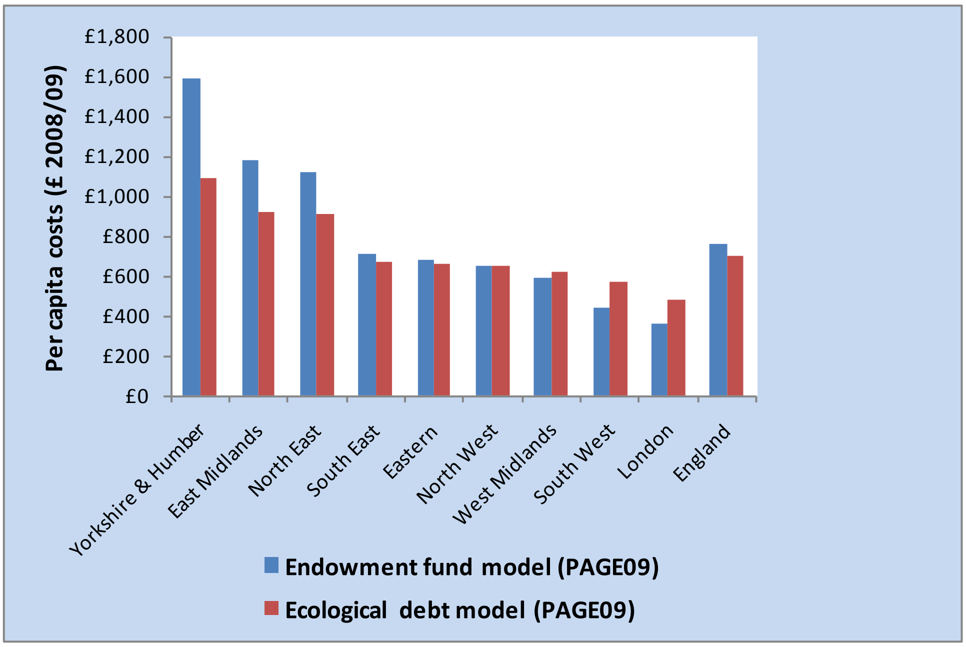

Figure 3.7. Ecological debt vs. endowment fund model – regional comparison, 2008.

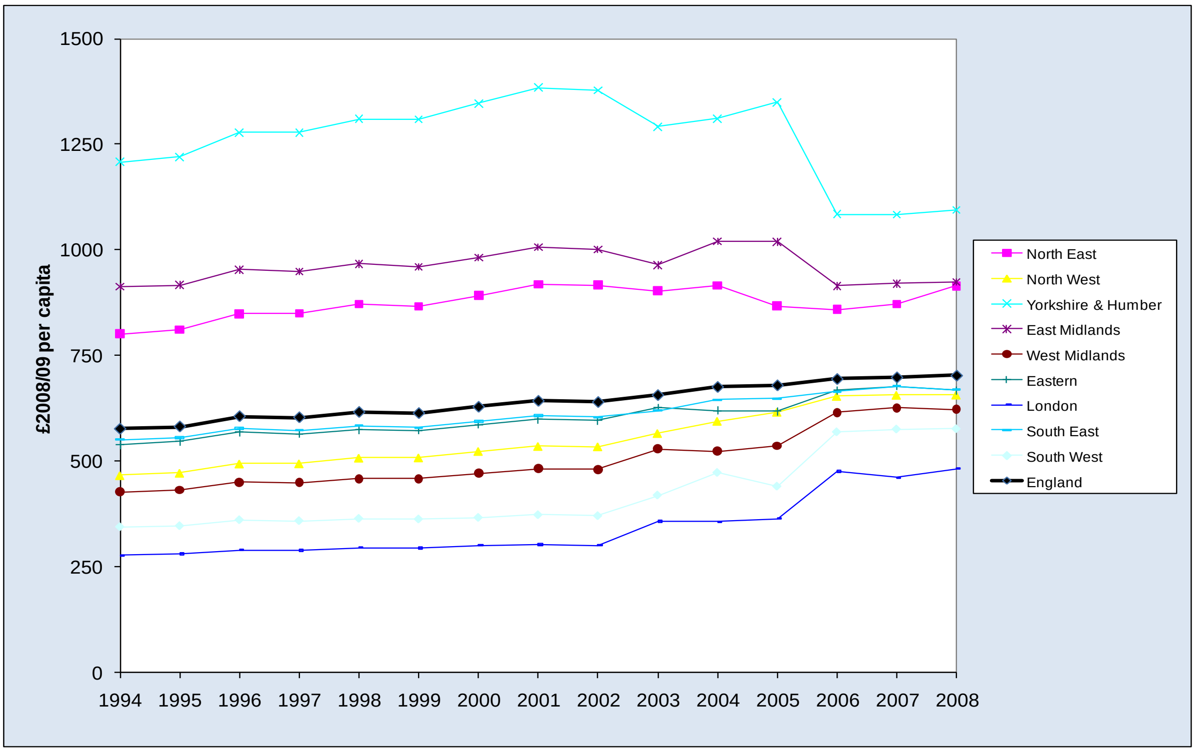

Figure 3.8. Ecological debt methodology with PAGE09 figures, and NAEI regional emissions data.

New data for regional distribution

Introducing the new DECC data on emissions by region of consumption makes no change to the overall figures for the UK, of course, but it does dramatically change the regional rankings, as is shown in Figure 3.9.

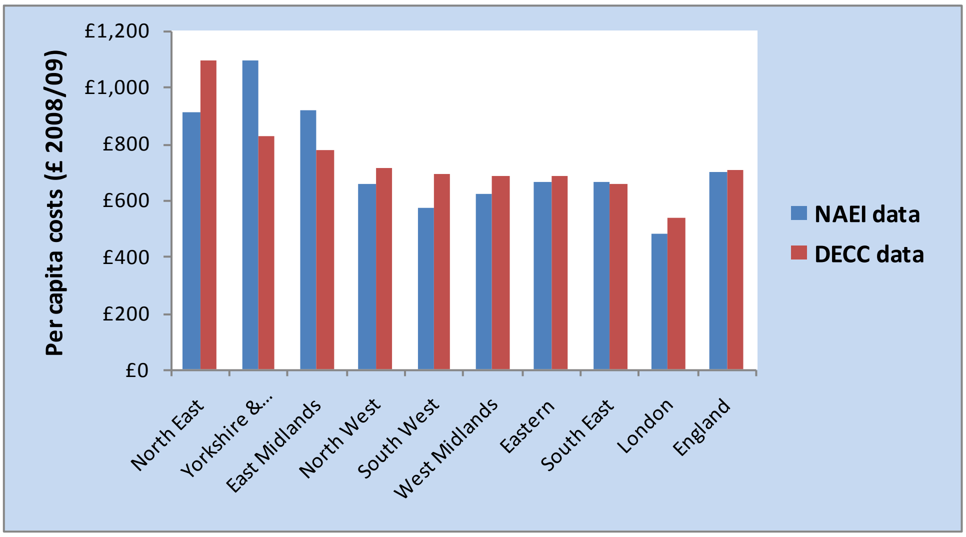

Figure 3.9. NAEI data vs. DECC data – regional comparison, 2008, using ecological debt model.

It is now the North East which has the largest per capita costs of any region, with Yorkshire and the Humber second. Meanwhile, the South West's costs rise to overtake those of other southerly regions, including the South East and the West Midlands. The discontinuity in 2005 is now no longer present in the data.

4. Public expenditure

The theoretical framework we are using is premised on the idea that defensive expenditure, in reaction to negative impacts of current economic activity, should be subtracted from the total R-ISEW. This definition prompted an analysis of what the R-ISEW currently does with public expenditure. The only public expenditure which was included was health and education expenditure, when there are many other aspects of public spending which may not be defensive, or at least not defensive in response to current economic activity.

Analysis of state expenditure categories

We took as a starting point the categories used in the Public Expenditure Statistical Analysis (PESA) tables. These tables cover all government expenditure, including that which passes through local authorities. For each category we considered whether it could be considered a defensive cost or not.

Expenditure is considered defensive if it does not directly contribute to welfare, but rather protects welfare from the negative externalities of current social and economic structures. For example, expenditure on police is assumed to be defensive because it is not a contribution to welfare, but rather a protection against potential negative impacts on welfare as a result of crime.

This is not a simple matter, partly due to the breadth of each category. For instance, public order and safety spending includes prisons, the judiciary system, and the police, but also fire-protection services and matters of dealing with immigration and citizenship. It is debatable how much of the need for law enforcement can be attributed to the economy and its side-effects. Arguably conflict in some shape or other would exist in even the most socially just societies. It would be possible to choose some percentage as an estimate of the share of public order and safety spending that is non-defensive, but this choice would be highly arbitrary.

Some other categories of public spending are even harder to judge. For example, it is debatable whether expenditure on military really adds to a nation's economic welfare. Some ISEW calculations do in fact judge it to be partly or fully defensive.[37] But it is hard to see how it fulfills the criteria of being a response to some harmful side-effects of current economic activities. Another factor to consider are the potential indirect benefits of spending such as military expenditure. For example, research undertaken for military purposes has often lead to technologies that later contribute to welfare for the general public.

The large and growing share of public spending that goes to servicing public sector debt interest is a similar case. Public sector debt is a consequence of a very complex process. Historically, a large part of the government budget deficits were created in periods of economic downturn, when governments responded to the shortfall in aggregate demand by increasing public consumption. That is naturally not the only reason for public sector debt, nor does it sufficiently take into account what the public resources were used for. There is therefore no simple way of judging whether the debt interest payments are defensive or not.

Nevertheless some categories which we had previously ignored (and thereby implied to be defensive) seemed to be clear candidates for inclusion as positive factors in the new R-ISEW. First, for public spending on transportation, we used the calculations that are being used for private expenditure to determine the degree to which the spending is non-defensive. According to those calculations, between about 13% and 20% of all trips made in different regions are commuting, and consequently considered to be defensive. When considering public expenditure on transportation, the remainder of this expenditure (so between 80% and 87%) will be added to the R-ISEW.

Secondly, we identified expenditure on science and technology and expenditure on recreation, culture and religion, as non-defensive (Table 4.1). These areas are either investments in future well-being (in the case of science and technology) or directly have a positive impact on current well-being (in the case of recreation, culture and religion).

Table 4.1. Simplified categories of public expenditure in PESA divided to non-defensive and partly or fully defensive, and whether they are included in the R-ISEW calculations.

Area of public spending		
Health	Non-defensive	Already Included
Education	Non-defensive	Already Included
Economic affairs: Science and technology	Non-defensive	Included
Recreation, culture and religion	Mostly non-defensive	Included
Transport	Partly defensive	Included (in part)
General public services: Public and common services	Partly or fully defensive	Excluded
General public services: Public sector debt interest	Partly or fully defensive	Excluded
Defence	Partly or fully defensive	Excluded
Public order and safety	Partly or fully defensive	Excluded
Environment protection	Partly or fully defensive	Excluded
Housing and community amenities	Partly or fully defensive	Excluded
Social protection	Partly or fully defensive	Excluded

As a result we added to the component expenditure on recreation, culture, religion, science, technology, and a percentage of transport not relating to commuting. We considered including data on local authority expenditure, but the PESA tables should include at least most of this, and doing so would risk double-counting.

Results

The extra spending categories add around a further 14% to public expenditure for England as a whole. We were only able to source data back to 2002 for this extra spending so earlier figures had to be estimated, but it is clear that there was a trend for this proportion to decrease over the time series indicating that spending on these areas increased at a slower rate than that for health and education.

Comparing regions, the extra components add the most for London (up to an extra 25% in 2003), with other regions typically having figures between 11% and 15%.This is mostly due to particularly high transport expenditure in the capital. However, Figures 4.1 and 4.2, presenting public expenditure with and without the extra components, show they do not make too much difference to the overall pattern. London’s lead over other regions is extended, whilst the South East does marginally better out of the changes than neighbouring regions such as the South West.

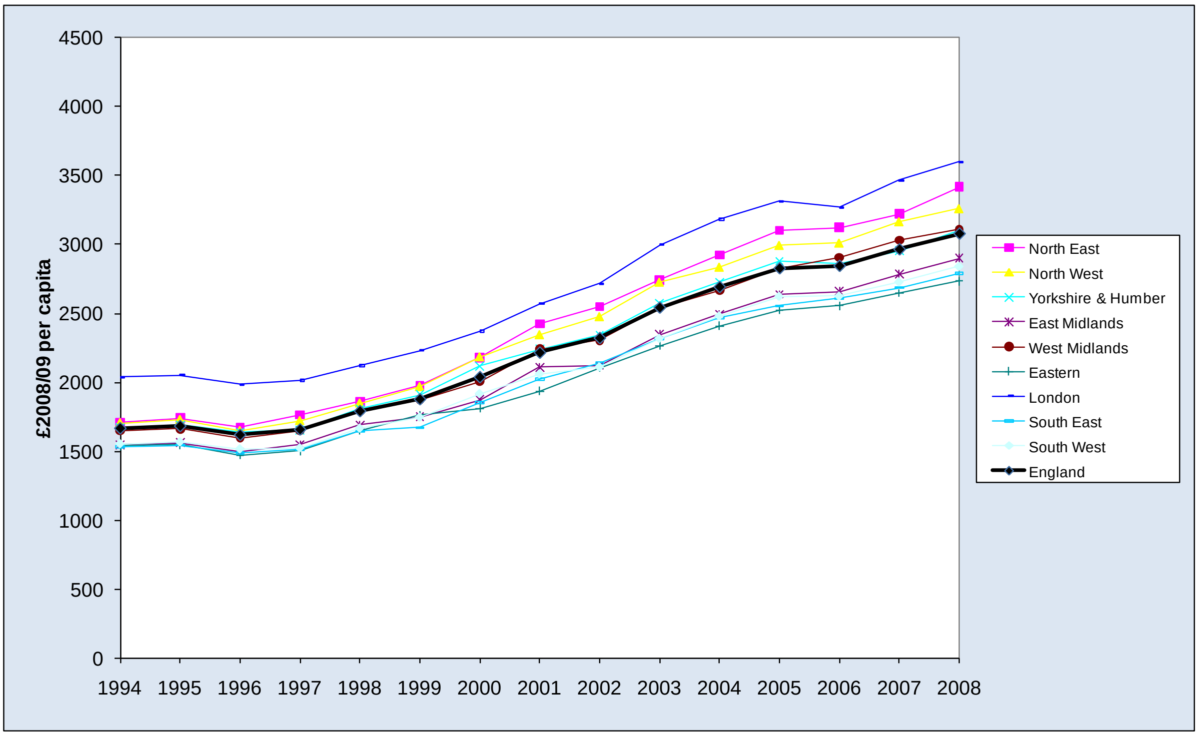

Figure 4.1. Public expenditure, old methodology

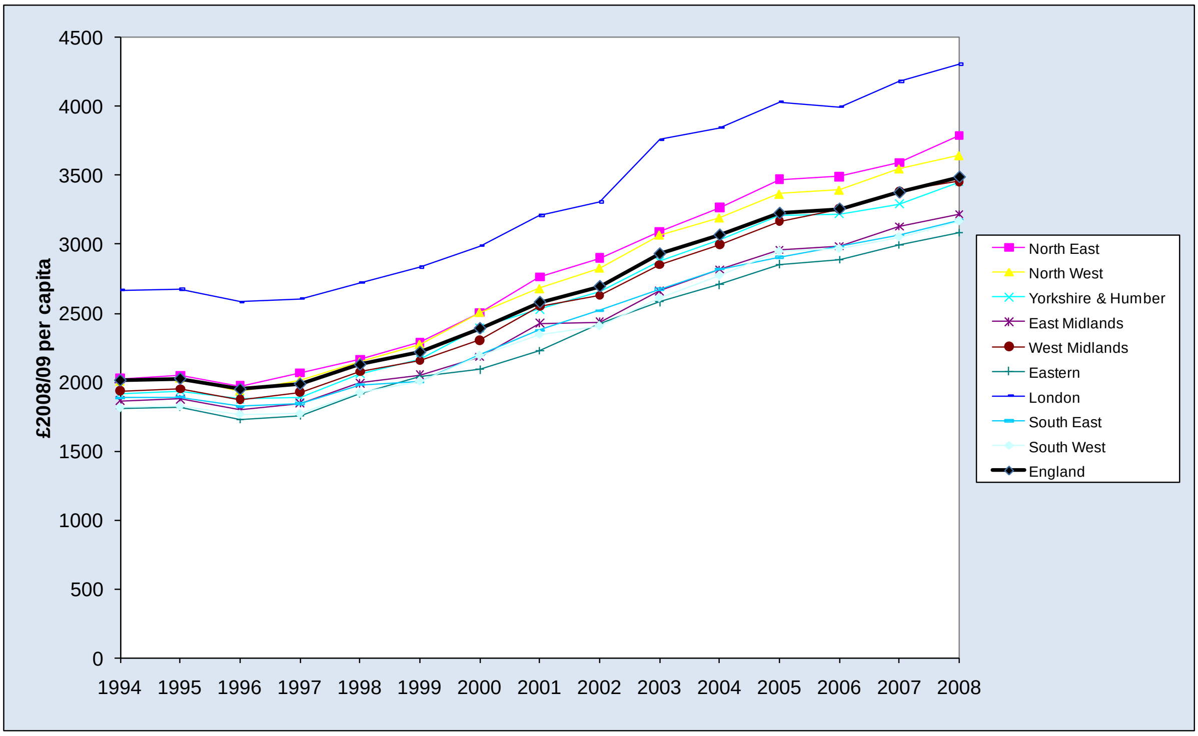

Figure 4.2. Public expenditure, new methodology

5. Other components

Net capital growth

As has been highlighted in update reports, the net capital growth component has been one of the key drivers of variability between regions and over time for the R-ISEW. For example, London's rapid rise in the R-ISEW in recent years appears to be due to increasing capital growth, while declining figures for Yorkshire and the Humber appear to be related to a reduction in this component. Whilst this variability may be valid, its significance in the calculations motivated us to take a closer look and ensure we were using the best approach. A further motivation is that the rolling averages used to calculate this component have led to estimates being revised dramatically from year to year. For example, in last year's update we estimated the net capital growth component to be responsible for a £704 million reduction in the R-ISEW for the North East in 2007. In the latest update, because of the way later data is rolled into the rolling average, this figure, for the same year, now stands at only £41 million – a huge reduction. These revisions are responsible for some major changes in the estimates for the overall R-ISEW and leave the R-ISEW vulnerable to the critique that it is not robust enough to be used for policy.

Our development work identified several ways in which the component can be improved:

1. Using mid-year population estimates to calculate populations of working age.
2. Changing the way we use net capital expenditure figures by region to estimate the changes in stock.
3. Ensuring total stocks for all regions and countries add up to the figures for the UK.

New methodology

The approach now taken is as follows (see methodology paper to find out about old methodology). As in the past, three main datasets are used for the calculations: capital stocks for the UK overall,[38] net capital expenditure by region from the Annual Business Inquiry (ABI) from 1998 onwards[39] and estimates for the population of working age, by region. The population estimates now all come from the ONS mid-year population estimates datasets, which go back to 1981.[40]

Net capital stock change is dependent on three factors: capital expenditure, depreciation of capital stock, and population increase. The first factor of course leads to increased growth, whilst the other two serve to dampen capital growth. The challenge for this component is to estimate stock depreciation. To do this we compare total UK capital expenditure from the ABI with the increase in capital stocks. The difference, which ranges between £40 and £90 billion each year, is assumed to result from stock depreciation. This allows us to calculate a depreciation factor (typically around 4%) for each year which is assumed in later calculations to be the same for all regions.

These calculations are only possible from 1998 onwards, when ABI data is available. To estimate depreciation factors for earlier years, we assume a linear relationship between the national depreciation factor and the percentage change in stock nationally and use the latter to estimate the former.

With an estimated depreciation rate and regional values for capital expenditure (estimates for earlier years can be calculated using a linear trend),we have most of what we need to estimate capital stock change from one year to another for each region. What we lack is a starting point – what were capital stocks in 1993? We have a figure for the UK as a whole, but not for the regions. We estimate these using two sources: first we use the regional distribution of capital expenditure for the years 1994 to 1998 to estimate the distribution of stocks in 1993 – the assumption being that regions which spend a lot on capital already have a lot. Secondly we use regional GVA figures for the years 1989 to 1993 – on the assumption that regions with the greatest value added have the greatest capital. These two distributions are averaged.

Ultimately, the distribution of capital stock at the start of the time series is of secondary importance as we only intend to use the change over time, as can be demonstrated using sensitivity analysis comparing our chosen approach with other possible methodologies. Table 5.1 shows the number of regional rank changes of different sizes that would result from each alternative methodology. For each of the alternative methodologies, for each year, we count how many regions change their regional rank in that year by different amounts, in comparison with the chosen methodology. We do this for all 15 years, from 1994 to 2008.

As can be seen, generally, most rankings do not change (93 out of 135 cases if the selected approach is replaced by only using GVA). Importantly, few changes result in the latest years, and none of the suggested methodologies change the rank order of regions in the last year of the data set, 2008. This is because the different assumptions only affect the starting conditions so, as one moves on to later years, they will have less and less effect.

Having estimated the starting capital stocks for each region, the process of estimating future years is straightforward. To calculate net growth, the change for any given year (compared to the previous one) is compared with the increase in population of working age. So, for example, if capital stocks grow in a region by 3%, but so does the working age population, then net capital growth will be 0%. In this way a figure can be calculated for capital growth above that required for a growing population.

Table 5.1. Changes in rank, compared with chosen methodology, caused by different assumptions of starting points for capital stocks

Change in rank	Only GVA	Only expenditure	Combined, but using capital expenditure for all years
0	93	90	120
1	35	25	14
2	6	12	1
3	1	4	0
4	0	3	0
5	0	1	0
Rank swaps, 2008	0	0	0
Rank swaps, 2004-2007	3	1	0

In the previous methodology, this led to some quite erratic figures, which we needed to smooth by taking rolling averages at three points in the calculations. In this methodology, values appear less erratic, and the variability that does exist over time – with sharp dips in 1996 and 2002 – is entirely consistent with the ONS time series on capital stocks, which we assume to be a robust data source. Indeed, the only data source we need to be wary about is the ABI – documentation accompanying the data warns us not to be to confident about the figures. As such, we have chosen to take a rolling average only at the end of the calculation process, and restrict it to a 3-year rolling average weighted at the centre, rather than a 5-year rolling average.[41]

Sensitivity to rolling averages

The benefits of such an approach can be seen in Figure 5.1. The biggest problem with the old methodology was how much the figures for the last two years in the time series would be altered by new data affecting rolling averages (as mentioned at the beginning of this section. Figure 5.1 shows that this rolling means that estimates for the penultimate year of one update were on average £770 million off the estimates for that year in the previous update, and that estimates for the antepenultimate year were also £734 million off on average.[42] The new approach leads to average changes of £304 million for the penultimate year, and only £18 million for the anti-penultimate year. The changes in the anti-penultimate year stem not from rolling averages, but from re-estimating back casts, and only appear when comparing results with data up to 2006 with results with data up to 2005 – in other words it will no longer play any role in future updates.

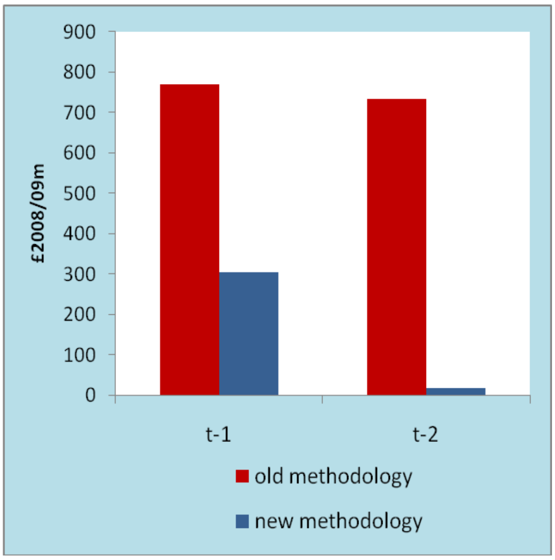

Figure 5.1. Average change in component value from one calculation to the next across regions using old and new methodology

As such, this new methodology would mean that future updates will only deviate from one another by a small amount and only in the penultimate year of calculations.

Results

Figures 5.2 and 5.3 compare the results for data from 1994 to 2008 using the new methodology with that using the old methodology. As one can see, the difference is substantial. In the past, rolling averages had led to English figures not varying much over time, but with some quite substantial long-term changes for regions. It appeared that regions took turns to see capital growth – first the East Midlands, then Yorkshire and the Humber, then the East Midlands again, then London. These patterns emerged with little immediate connection to the source data.

The new methodology leads to much greater variability over time for England as a whole – variability which, as we have said, is consistent with the data on capital stocks. But, the differences between regions are less substantial; regions tend to maintain the same relative positions to one another. So, whereas London goes from second lowest to second highest in the space of two years (2004 to 2006) in the old methodology, it now remains in the highest position for most of the time series, with just one dip to the English average in 2002. Meanwhile, the drop in Yorkshire and the Humber's position from top in 2004 to second bottom in 2008 in the old methodology is now only seen as a slight fall in relative position, from fourth to sixth. This dampening of cross-regional variation seems appropriate given the only regional data we have is the ABI and there is little substantial change to be seen there.

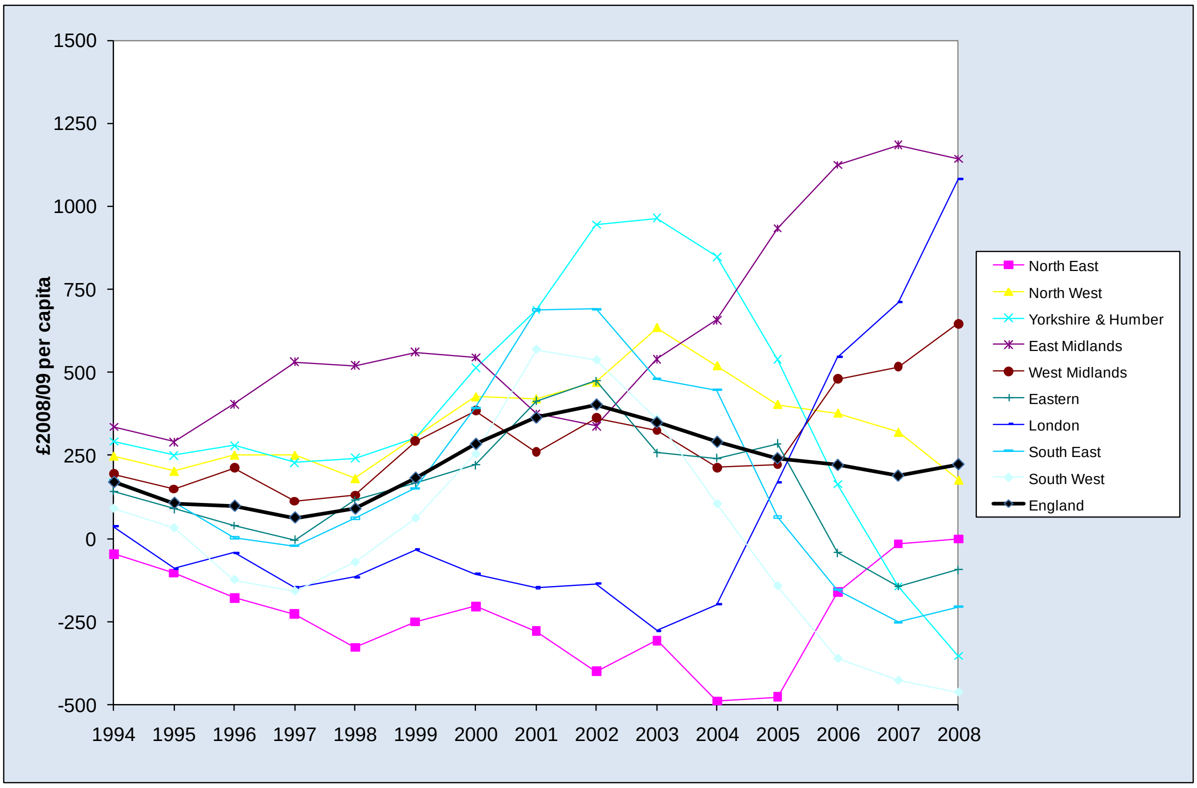

Figure 5.2. Net capital growth component, old methodology.

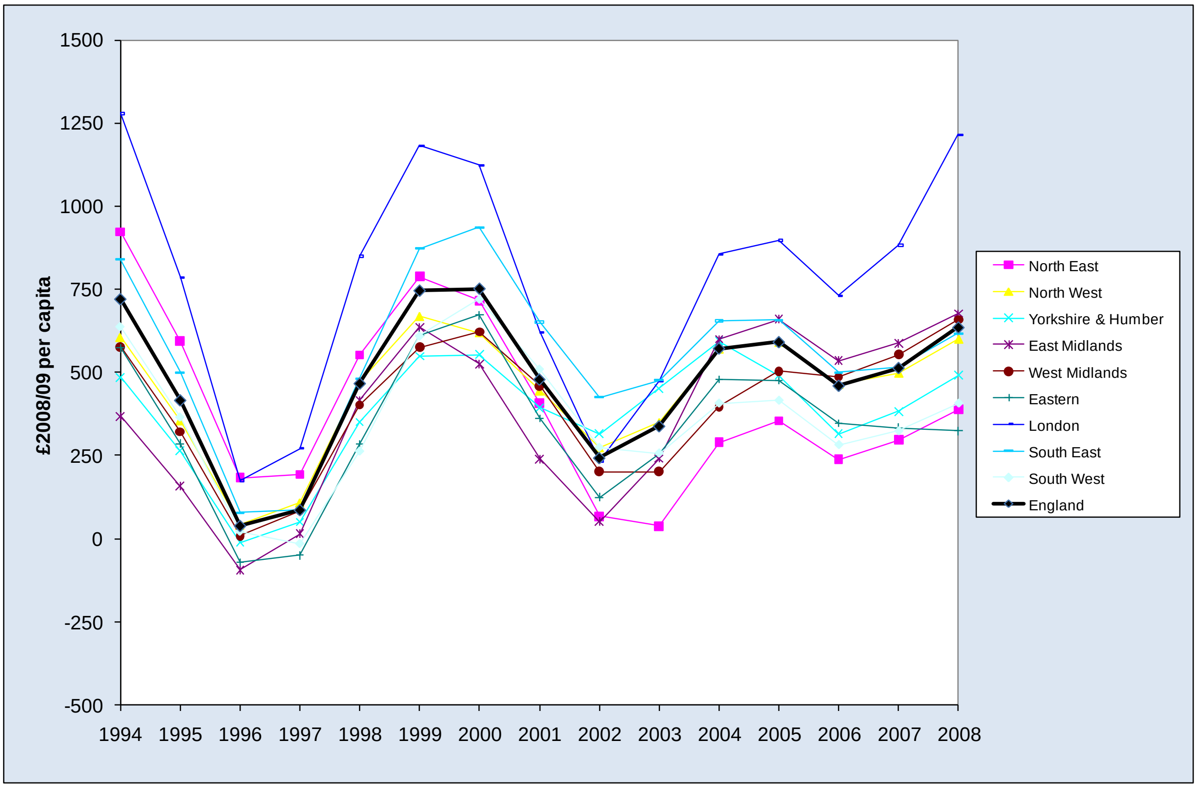

Figure 5.3. Net capital growth component, new methodology.

Net international position

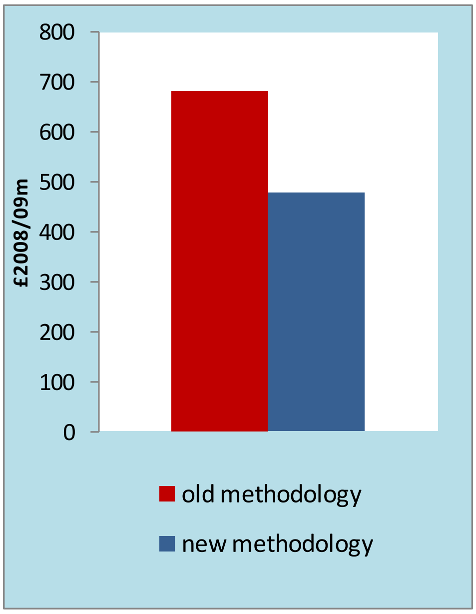

Figure 5.4. Average change in component value from one calculation to the next across regions using old and new methodology.

This is another component that plays an important role in the final R-ISEW values. Its calculation is particularly difficult at the regional level given the lack of trade data, and the component underwent substantial innovation in creating the R-ISEW. Reviewing the approach taken, the only suggested change is to revise the rolling average methodology that was introduced to cope with fluctuating results. Again, this should reduce the liability for the penultimate year in the time series for any particular update to differ from that in the previous update. We propose taking a three-year centre-weighted rolling average, again putting more weight on data from the year in question than the two adjacent years. The result is not a substantial change (Figures 5.5 and 5.6).

In Figure 5.4 (as in Figure 5.1), we show how the change leads to different average changes to the values calculated for t-1.[43] Of course, we are still taking rolling averages, so there is still some change resulting when new data is added. Inevitably there will be a trade-off between the quality of having figures that only change minimally from year to year and having smoother trajectories on this component, which are likely to better reflect the reality. Figure 5.7 shows the values with no rolling averages taken.

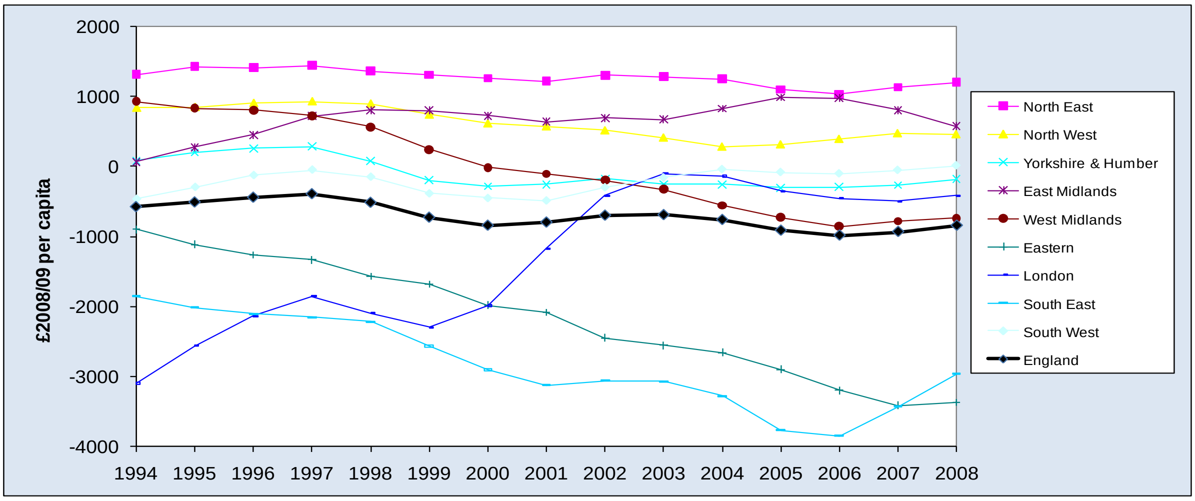

Figure 5.5. Net international position component, old methodology.

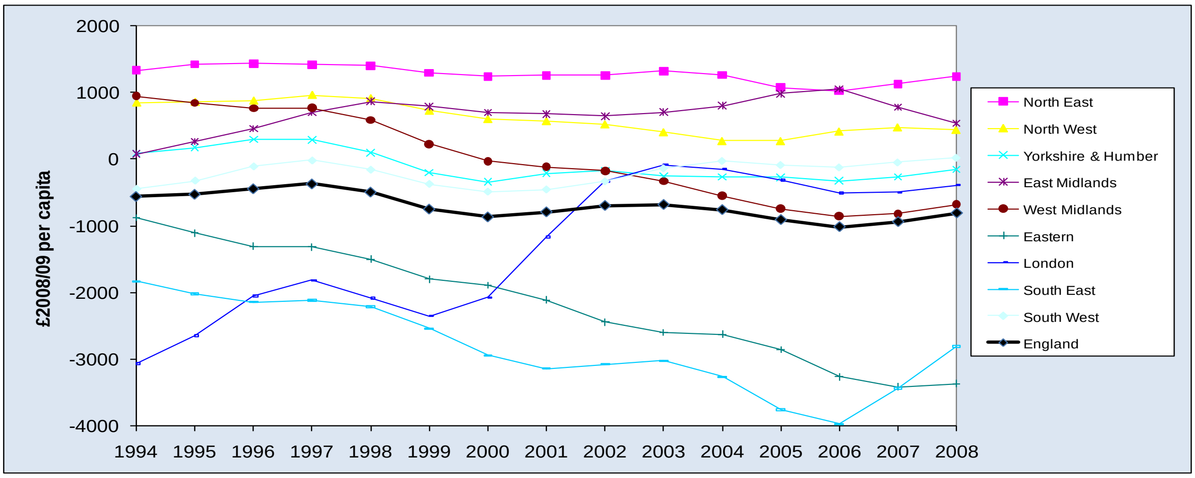

Figure 5.6. Net international position component, new methodology.

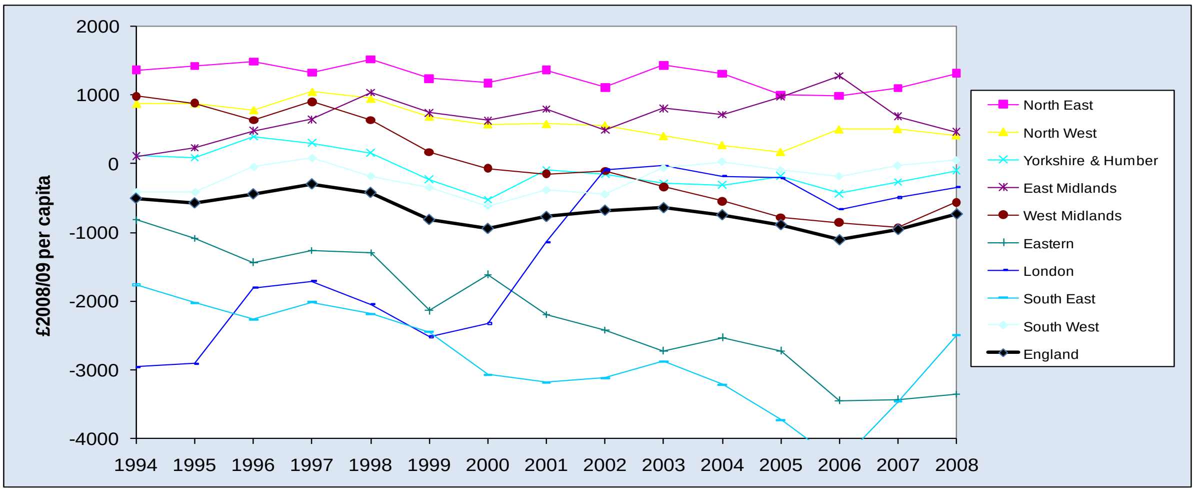

Figure 5.7. Net international position component, without rolling averages.

Commuting

The commuting component is based on two parts – the value of the time spent commuting and the actual expenditure on commuting. The challenge for the second of these is to calculate the percentage of transport expenditure, available from the Expenditure and Food Survey, that is attributable to commuting. New data in the 2008 National Transport Survey have allowed us to simplify this. Table 4.8 of the survey (not shown here) provides a breakdown of distance travelled and purpose of journey by mode of transport for Great Britain as a whole for 2008. This allows us to estimate the percentage of expenditure in this year for Great Britain that can be attributed to commuting. For example, for car drivers, the figure is 25.4%, which works out at £13 per household per week for Great Britain for 2008.

To estimate regional figures and figures for previous years, we use data from the Regional Transport Survey on the number of trips that are commuting trips which is available for most years back to 1999 for all modes combined. We assume the pattern for each mode of transport is the same as the pattern for all modes combined (remember this is not the pattern for actual number of commuting trips, but percentage of all trips that are commuting trips – if there is a significant modal shift or reduction in travel in general, then this should be apparent in the regional expenditure data).

The results for 1994 to 2008 for all regions are shown in Figures 5.8 and 5.9 (note this only includes expenditure, not the value of the time spent commuting, which accounts for about half this component).

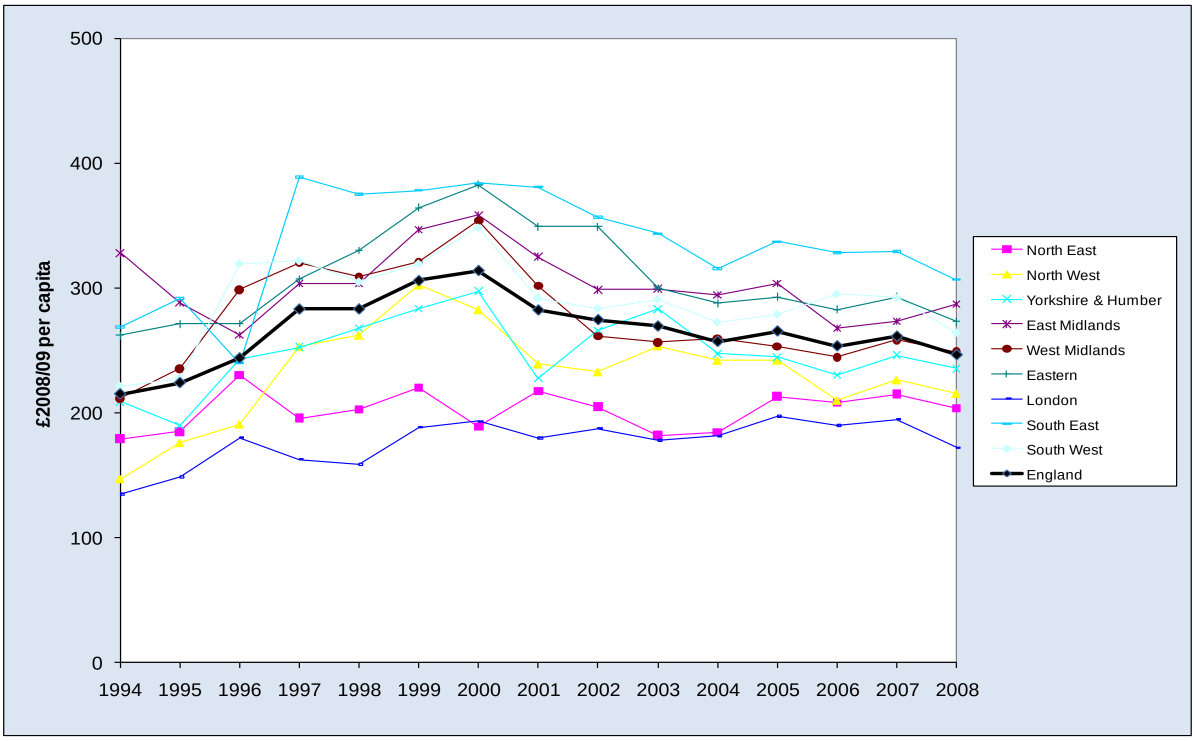

Figure 5.8. Commuting expenditure, old methodology.

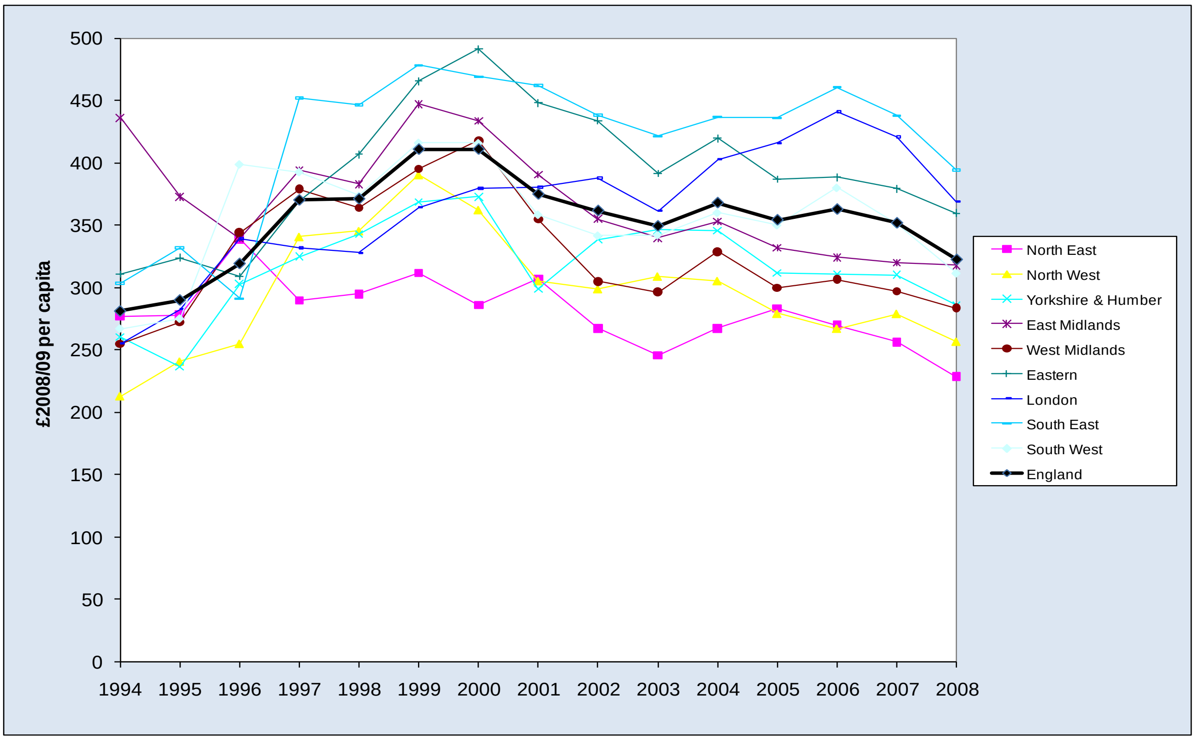

Figure 5.9. Commuting expenditure, new methodology.

The first difference to note, is that figures across England are now higher - £322 per capita in 2008 versus £246 per capita using the old methodology. This can be seen across the time series, though the new methodology does appear to also accentuate differences – with costs increasing by 46% between 1994 and 1999 versus only 42% in the old methodology. Secondly, there are some quite big changes to the regional pattern. Most notably, London's costs now increase, to be the second highest per capita for the last four years of the time series, when they were the lowest for most of the time series using the old methodology. Conversely, the East Midlands now falls from second highest costs (in the old methodology), to fourth highest and below the English mean.

Consumer durables

The scoping report recommended removing this component as not being consistent with the theoretical framework. The results presented here take this step.

6. Revised calculations

The combined effect of all these changes on the R-ISEW for 1994 to 2008 can be seen by looking at Figures 6.1 to 6.4. Overall (Figure 6.1), the changes tend to increase the R-ISEW for England by about 20% over the time period, mostly due to the decreased costs of long-term environmental damage from the new SCCO2 values. Over time, the rate of increase has been roughly equivalent – 2.3% instead of 2.4% using the old methodologies. However, even using the new methodology, the R-ISEW still highlights how GVA overestimates economic well-being in the English regions.

As figures 6.3 and 6.4 show, the difference on the impact on regions is more substantial. All regions see their R-ISEW increase, but some more than others. London's only increases by 10% (for 2008), whilst Yorkshire and the Humber's increases by 70% (Figure 6.2). Whilst London retains its top place in 2008, it only does so by a marginal amount, and the South West's value is higher for the five preceding years. Meanwhile, Yorkshire and the Humber is lifted from bottom place to seventh, with the East of England now firmly in bottom place.

Retaining the endowment fund model has a tiny impact on the overall scores (in the graph we produced to look at this difference the lines for the two methodologies could hardly be distinguished). However, the different methodologies do imply different orders for the regions (Figure 6.5). Using the endowment fund takes Yorkshire and the Humber down to eighth place again, and the South West into top place.

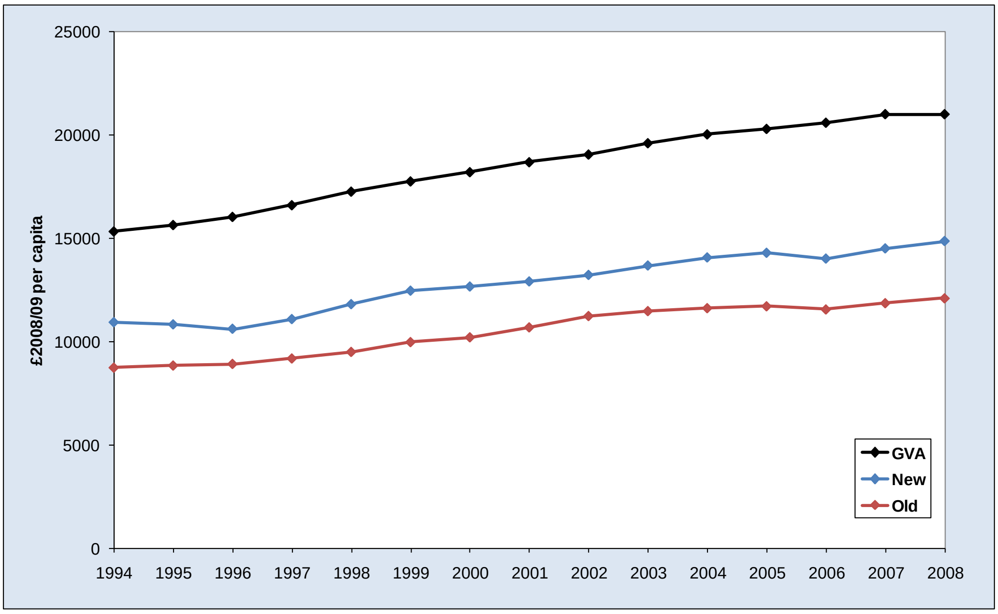

Figure 6.1. R-ISEW per capita for England, old and new methodologies.

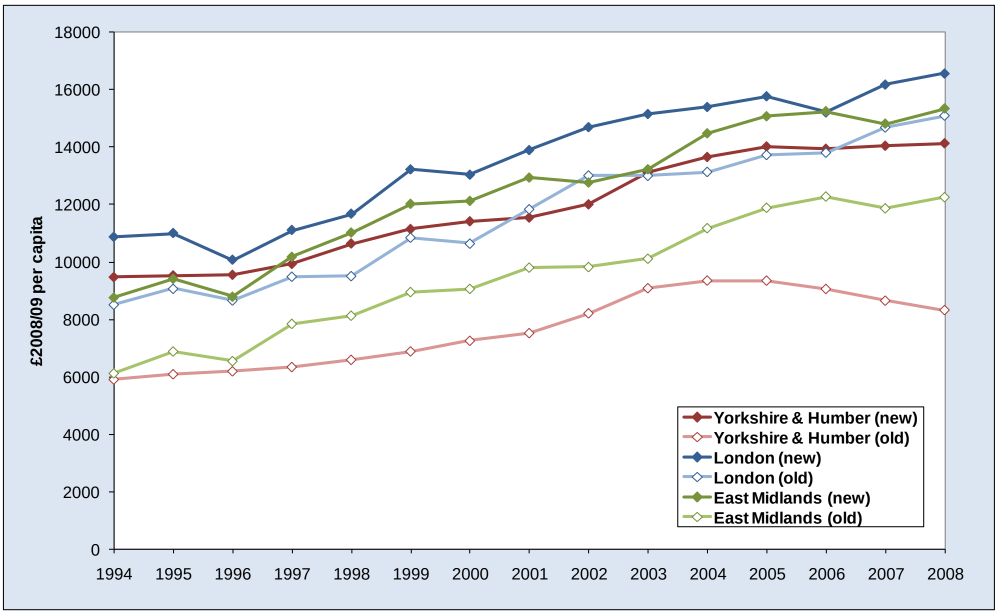

Figure 6.2. R-ISEW per capita for selected regions, old and new methodologies.

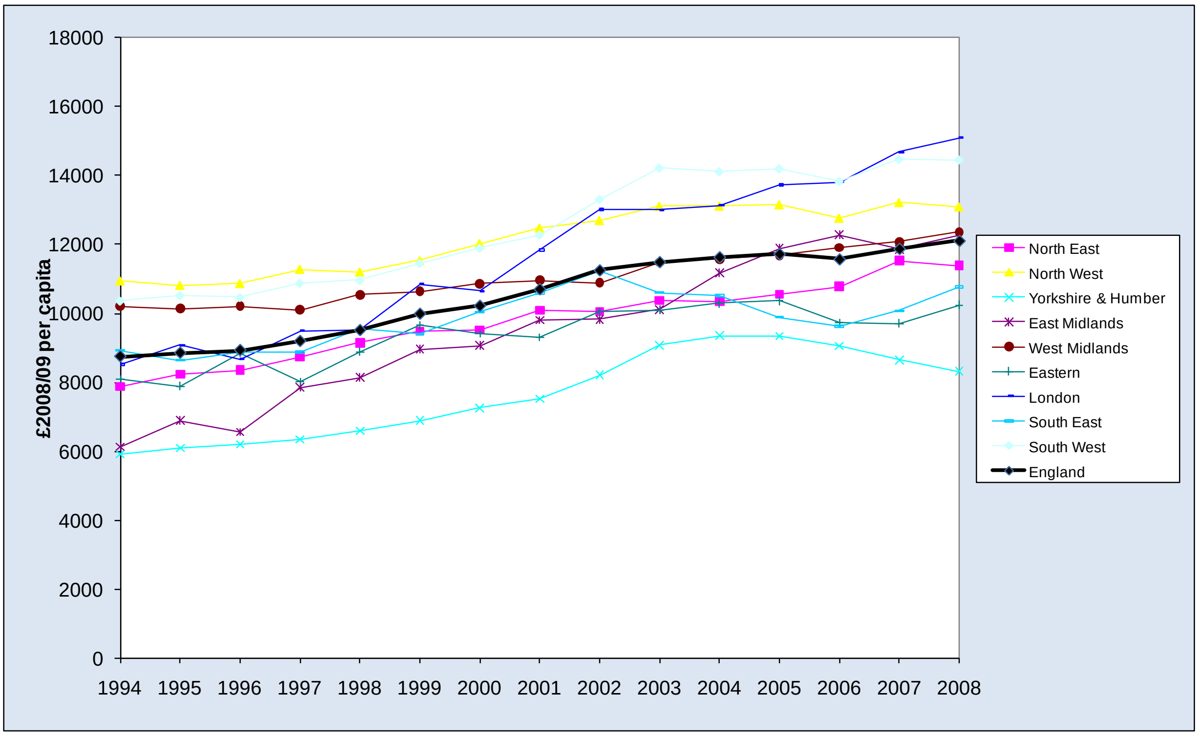

Figure 6.3. R-ISEW per capita all regions, old methodology.

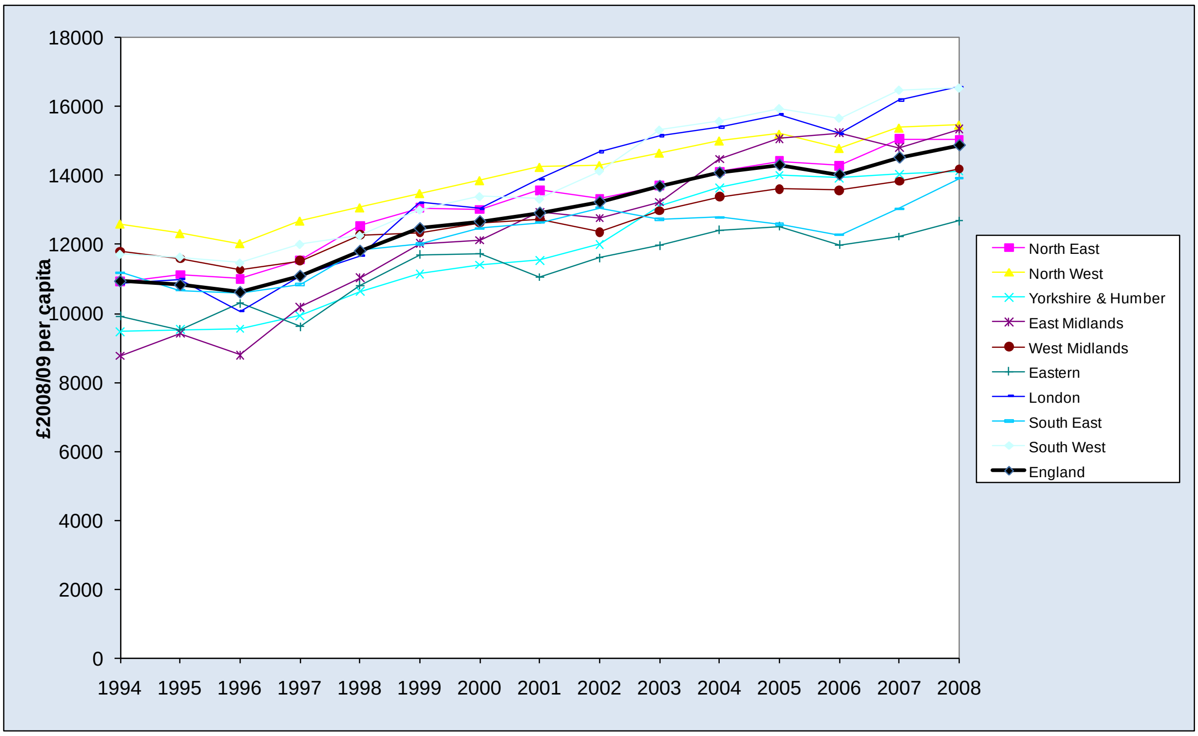

Figure 6.4. R-ISEW per capita all regions, new methodology.

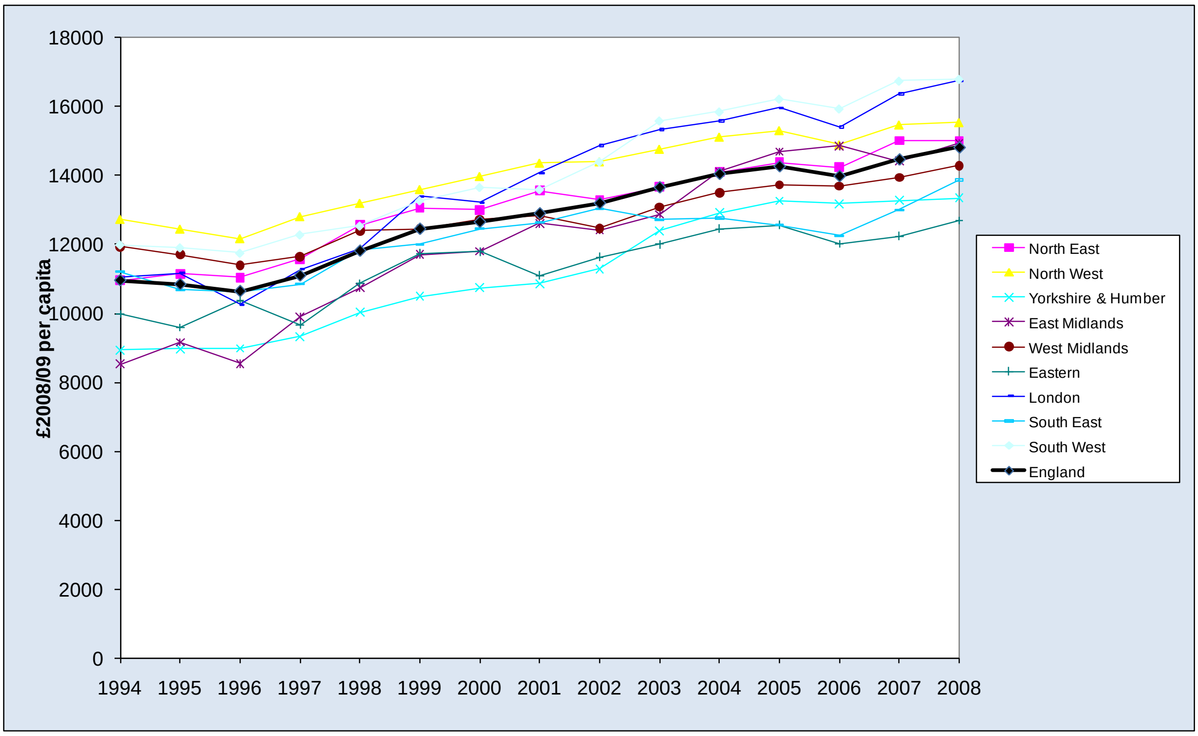

Figure 6.5. R-ISEW per capita all regions, new methodologies but retaining endowment fund model.

7. Conclusions

This development project faced several challenges and setbacks, most notably in terms of the announced abolition of the Regional Development Agencies, and the delays in reporting by the National Ecosystem Assessment. Nevertheless it has provided a rare opportunity to improve the R-ISEW and explore the impacts of changes to it. In some cases, the changes proposed must be considered place holders until better data is generated, particularly in terms of natural habitats and water pollution. However, the process of doing this puts us in a good position to be able to incorporate new data as and when it arrives, and to do so in a coherent fashion.

The changes proposed are listed below (with their status in italics):

- Natural habitats: Use raw data from the Countryside Survey to calculate changes in habitat stocks at the regional level. Use new unit values per hectare of a range of habitats by discounting annual flow values from the National Ecosystem Assessment. *Status: Data has been extracted from the Countryside Surveys for 2000 and 2007, but could benefit with some corroboration from staff at the Survey, and from other data sources. With regards to unit values, a first attempt has been made, but unit values might change, and new unit values might become available when the Assessment is completed mid 2011. Also, discounting model could be discussed with clients.*

- Water pollution: Check for publications of river quality status data by the Environment Agency using the new Water Framework Directive, as well as new economic valuations of the benefits of changes in water quality as assessed by the Directive, calculated per metre of river (as opposed to per capita). *Status: Data still not available but likely sources have been identified.*

- Long term environmental damage: Replace unit value of carbon equivalent emissions of £70 per tonne, with new higher value from PAGE09 model. Also adjust discount rate and change over time accordingly. We recommend using the new ecological debt model to value this component for each year, and using new Department of Energy and Climate Change data distributing CO_2 emissions to regions according to energy consumption, instead of emission. *Status: Changes are ready to be implemented. Decision required from clients on model to use (ecological debt model or endowment fund model), and on whether costs should be distributed according to point of energy consumption instead of point of emission.*

- Public expenditure: Incorporate expenditure on science and technology, on recreation, culture and religion, and a proportion of that on transport, as positive impacts on R-ISEW. *Status: Ready.*
- Net capital growth: Overhaul component, so as to better reflect national changes in capital expenditure over time, and lead to more stable results yet are more sensitive to changes over time. *Status: Ready.*
- Net international position: Adjust rolling average methodology to lead to more stable results yet are more sensitive to changes over time. *Status: Ready.*
- Commuting: Overhaul component, making use of newly available data from the National Transport Survey. *Status: Ready.*
- Consumer durables: Remove component, until such time as we have new data on lifetimes of consumer durables so as to better estimate true service flow from them. *Status: Ready.*

The results presented here implement all the changes that we propose that are already possible. The clients, or indeed anyone else who wished to calculate the R-ISEW. would of course need to make decisions with regards to each of the changes to decide whether they feel they are appropriate.

We believe they represent a substantial improvement on the R-ISEW as they:

- Bring it closer to a simple and consistent theoretical framework (the sum of net service flows and the net change in capital stocks, resulting from the productive activity in a given period).
- Utilise state of the art science (in the case of natural habitats and long-term environmental damage).
- Utilise new data sets (in the case of commuting and long-term environmental damage).
- Broaden components to include important elements hitherto ignored in our R-ISEW (natural habitats other than wetlands, more areas of public expenditure).
- Involve simpler calculations (in the case of long-term environmental damage, net capital growth and commuting), or remove components that were hard to interpret (in the case of consumer durables).
- Are likely to be more sensitive to real year-on-year changes (in the case of long-term environmental damage, natural habitats, net capital growth and net international position).

The new R-ISEW presented here should be a more useful tool for regional policy makers to help them assess overall progress and make necessary trade-offs.

Appendix 1. Scoping report recommendations

These are the recommendations that came from the scoping report produced in 2009.The recommendations that we are taking forward in this development project are marked with the following symbol: ▸

- Give further thought to a theoretical framework, in consultation with RDAs, and with further literature review.
- Identify unit values for natural habitats other than wetlands. ▸
- Re-evaluate the water pollution component. ▸
- Develop components for the depletion of renewable resources, specifically fisheries, but possibly also forests.
- Decide on LTED costing mode. ▸
- Review updates of the costs of LTED since the *Stern Review*, and implement in our chosen costing model. ▸
- Implement rationalisations to the split of environmental costs between consumers and producers.
- Assess the possibility of adjusting consumer expenditure to account for real discount rates and changes in product durability.
- Assess the possibility of including other elements of public expenditure. ▸
- Assess the possibility of augmenting divorce as a measure of family breakdown.
- Incorporate leisure time.
- Continue to follow the work of the Stiglitz Commission.
- Explore the potential of the scenario-modelling tools with other non-infrastructure projects.
- Develop software to automate scenario modelling.

Appendix 2. Broad habitats in Countryside Survey

#	Broad Habitat	#	Broad Habitat
1	Broadleaved Mixed and Yew Woodland	24[44]	(ph) Lowland Beech and Yew Woodland
2	Coniferous Woodland	25	(ph) Upland Mixed Ashwood
3	Boundary and Linear Features	26	(ph) Wet Woodland
4	Arable and Horticulture	27	(ph) Upland Oakwood
5	Improved Grassland	28	(ph) Lowland Mixed Deciduous
6	Neutral Grassland	29	(ph) Native Pine Woodland
7	Calcareous Grassland	30	(ph) Lowland Hay Meadow
8	Acid Grassland	31	(ph) Upland Hay Meadow
9	Bracken	32	(ph) Lowland Calcareous Grassland
10	Dwarf Shrub Heath	33	(ph) Upland Calcareous Grassland
11	Fen, Marsh, Swamp	34	(ph) Lowland Acid Grassland
12	Bog	35	(ph) Fen
13	Standing Open Waters and Canals	36	(ph) Purple Moor Grass Rush Pasture
14	Rivers and Streams	37	(ph) Reedbed
15	Montane	38	(ph) Blanket Bog
16	Inland Rock	39	(ph) Lowland Raised Bog
17	Urban	40	(ph) Limestone Pavement
18	Supra-littoral Rock	41	(ph) Maritime Cliffs and Slopes
19	Supra-littoral Sediment	42	(ph) Sand Dune
20	Littoral Rock	43	(ph)Strandline/Coastal Vegetated Shingle
21	Littoral Sediment	44	(ph) Coastal Saltmarsh
22	Sea	45	(ph) Northern Birchwood

Endnotes

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[6] Derived using data from the Countryside Survey (2010) which reports data for 2007. The Countryside Survey also reports 95% confidence intervals for these proportion estimates which highlight the uncertainty of the data used. For example the estimate for the proportion of Broadleaved Mixed and Yew Woodland in land class 1 in 2007 ranged from a lower interval of 7.5% to an upper interval of 18.9%. Similarly the change estimated ranged from -1.1% to +0.7%.

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[41] By weighting at the centre, we mean we take an average over three years giving double-weight to the central year of the three as follows (where U = unrolled figure and R = rolled figure): $R_t=(U_{t-1}+2U_t+U_{t+1})/4$.

[42] These figures have been calculated afresh, starting with the data for the latest update, then subtracting the source data year by year and recalculating the component, back until 2005 (i.e. three pairs of iterations). This means that we are ignoring changes in the results that would have been caused by changes in the deflation factors or by updates of source data for existing years.

[43] We again based this on comparing three pairs of iterations, going back to 2005, and starting with all the data available in 2008.

[44] Note there is no BH 23.