Review of the impacts of carbon budget measures on human health and the environment

Final

Report for Committee on Climate Change

Ricardo-AEA/R/ED58612
Issue Number 2
Date 17/07/2013

Customer:	Contact:
Committee on Climate Change	Daniel Forster Ricardo-AEA Ltd Gemini Building, Harwell, Didcot, OX11 0QR t: 0870 190 6474 e: daniel.forster@ricardo-aea.com Ricardo-AEA is certificated to ISO9001 and ISO14001
Customer reference:	
Review of the impacts of carbon budget measures on human health and the environment	
Confidentiality, copyright & reproduction:	
	Author: Ricardo-AEA: Daniel Forster, Outi Korkeala, Jamie Warmington; EMRC: Mike Holland, Alison Smith **Approved By:** Daniel Forster **Date:** 17 July 2013
Ricardo-AEA reference:	
Ref: ED58612- Issue Number 2	

Executive summary

For its 2010 advice on the fourth carbon budget (covering 2023-27), the Committee on Climate Change (CCC) developed a Medium Abatement scenario to 2030, which illustrated one way in which the carbon budgets could be met. The CCC has assessed “resource costs” (i.e. the inputs required for construction, operation and disposal) and greenhouse gas emissions for the measures within this scenario. However, there may be other impacts on the environment and human health (over and above the climate impacts) – such as the air pollution benefits from reducing fossil fuel combustion, or the visual impacts of wind farms - which are not reflected in market prices. These are known as externalities.

This report presents the results of a project commissioned by the CCC to analyse these externalities, and includes both costs and benefits. Detailed results are contained in a set of accompanying spreadsheets, one for each sector analysed (power, heat, road transport, shipping and aviation, residential and non-residential buildings, industry, and agriculture and forestry) and one for the upstream impacts of fuel production.

In this project the focus has been on gathering and synthesising existing externality estimates. In some instances we have further refined and updated the estimates where new data is available, but on the whole the results represent a synthesis of estimates from prior research. Parallel work by Imperial College and Defra has assessed external impacts related to air pollution and noise, and the results of this analysis have been incorporated into this work.

Synthesis of existing external cost estimates

The externalities that are associated with the mitigation scenario are many and varied. Some of the external costs and benefits are well understood, while for others the understanding is more limited. Likewise, certain impacts are more amenable to quantification and monetisation than others.

For those impacts where it has been possible to estimate the value of the externality, it is clear that the scale of these costs and benefits is potentially significant. A summary of the cost estimates is provided in Table A1 and Table A2 that follow, with impacts for the use stage shown separately to impacts for other life cycle stages.

There are a number of significant co-benefits associated with the use stage of the measures. These relate to impacts on congestion, lifestyle, air quality, road accidents, noise, and water abstraction. However, some important costs were also identified in relation to occupational health and accident risks, as well as noise impacts and impacts associated with heavy metals.

A number of important externalities are associated with other stages in the lifecycle. In particular, measures that reduce fuel consumption have the potential to reduce negative externalities associated with the upstream fuel cycle. At the same time changes in the mix of power generating technologies will lead to increases in certain upstream or downstream costs.

It is important to note that the coverage is not complete, even within a given sector, and the table is therefore an imperfect representation of the total costs and benefits. A simple addition of all of the numbers in the tables will not therefore generate a true ‘total’ for the externalities within the scope of this study. In Table A3 a summary is provided of the main impacts which are considered potentially important, but for which a quantitative estimate has not been derived.

Table A1. Main quantified health and environmental externalities of the CCC's Medium Abatement scenario relative to the baseline during the use stage. Values presented as Net Present Value over the period 2008-2030[1] (£$_{2012}$, million), annual cost in 2030 in brackets.

	Power VS BL2	Power VS BL1	Road transport	Industry	Heat	Residential buildings	Non-residential buildings	Agriculture	Comment
Diet								*162,516 (11,258)*	* Reduced fat intake from halving consumption of meat and dairy produce (not part of core scenario)
Lifestyle			26,101 (2,548)						* Increased walking & cycling in place of car journeys * Recreational benefits of new forests
Major accident risk	-56 (-16)	-54 (-13)							* Increase in nuclear power
Occupational health	-208 (-31)	-58 (-16)							* Increase in offshore and onshore wind, and also nuclear power
Road Accidents			1,531 (231)						* Smarter choices & HGV logistics reduce accident rates * Small increase in accidents from more walking & cycling
Air quality (based on PM10)	2275 (466)	93 (64)	600 (106)	869 (134)	1,114 (297)	642 (78)	138 (14)		* Energy saving and shift to renewables and nuclear cut fossil fuel emissions from power generation and buildings *Smarter choices and HGV logistics reduce vehicle km * Electric vehicles, hydrogen buses reduce emissions intensity

[1] Except for power sector where the period is 2012-2030

	Power VS BL2	Power VS BL1	Road transport	Industry	Heat	Residential buildings	Non-residential buildings	Agriculture	Comment
Noise	86 (22)	-34 (-4)	947 (148)			4,905 (383)			* Electric vehicles and smarter choices reduce noise levels from traffic * Glazing measures reduce exposure to noise.
Heavy metals	40 (8)	-9 (-1)	144 (34)						* Smarter choices and HGV logistics reduce vehicle km * Electric vehicles, hydrogen buses reduce emissions intensity
Water abstraction	565 (122)	155 (46)							Certain measure will consume greater levels of abstracted water
Biodiversity and ecosystems			210 (27)						* Smarter choices and HGV logistics reduce vehicle km, and reduce habitat loss and fragmentation
Congestion			48,450 (8,423)						* Smarter choices and HGV logistics reduce vehicle km , and associated congestion
Total for quantified impacts, use phase	**2,702**	**94**	**77,984**	**869**	**1,114**	**5,547**	**138**	***162516***	

Notes: Coverage is not complete, even within sectors

No quantitative estimates have been derived for the aviation and shipping sectors.

Totals should be interpreted with caution because many significant impacts are not quantified.

Air quality estimates are based on analysis carried out by Imperial College and are presented using a damage cost for particulates referenced against PM10, and quantified over the period 2020 to 2030.

+ +	+	+/-	-	- -	
Significant benefit	Benefit	Benefit or cost	Cost	Significant cost	No effect

Table A2. Main quantified health and environmental externalities of the CCC's Medium Abatement scenario relative to the baseline during the other life-cycle stages. Values presented as Net Present Value over the period 2008 to 2030[2] ($£_{2012}$, million)

	Power, BL2	**Power, BL1**	**Road transport**	**Industry**	**Heat**	**Residential buildings**	**Non-residential buildings**	***Agriculture***	**Comment**
Major accident risk	1121 (193)	-152 (-12)	1 (0.1)	21 (3)	31 (4)	7 (1)	2 (0.2)		* Reduction in coal power means lower risk of cost of coal mining accident
Occupational health	47 (11)	-25 (-5)	13 (1)	12 (1)	101 (16)	27 (3)	15 (1)		* Increase in occupational health risk from nuclear, wind and CCS is more than offset by decrease in risk from coal * Switch from fossil fuels in end-sue sectors reduces risk from coal and oil
Road Accidents	-129 (-17)	-25 (-7)							* Increase in wind drives increases in cost, but based on incomplete analysis of risks for other power technologies
Air quality, R-AEA estimates (based on PM2.5)	-1,008 (-148)	-307 (-77)	50 (5)	10 (1)	151 (25)	46 (2)	26 (2)		* Biomass, wind and nuclear all increase the relative air quality emissions associated with the supply chain * Switch from fossil fuels in end-use sectors reduces risk from coal and oil

[2] Except for the power sector where the period is 2012-2030

	Power, BL2	Power, BL1	Road transport	Industry	Heat	Residential buildings	Non-residential buildings	*Agriculture*	Comment
Hazardous waste/nuclear	-14 (-1)	-3 (-1)							* Increase in hazardous waste from nuclear
Noise	30 (5)	-4 (-0.4)		1	1				* Reduction in coal use decreases noise from mining and coal transport
Hazardous waste/other			4 (0.4)	1	13 (2)	2 (0.2)	2 (2)		* Decrease in oil use in end use sectors reduces hazardous waste generation
Heavy metals	-65	-13							* Power - incomplete estimate: includes increase in emissions from supply of wind farm components but not emissions from other sectors, which could not be quantified
Total for quantified impacts, other life cycle phase	-18	-528	69	45	297	81	46		
Total quantified effects for the sector, all stages	2,683	-434	78,052	914	1,411	5,629	184		

Notes: Coverage is not complete, even within sectors

Other lifecycle stages not assessed for agriculture measures. No quantitative estimates have been derived for the aviation and shipping sectors

Totals should be interpreted with caution because many significant impacts are not quantified.

Air quality estimates are based on analysis carried out by the project team and are presented using a damage cost for particulates referenced against PM2.5

+ +	+	+/-	-	- -	
Significant benefit	Benefit	Benefit or cost	Cost	Significant cost	No effect

Table A3. Main health and environmental externalities where quantitative values have not been derived

	Negative impacts (costs)	Positive impacts (benefits)	Mixed or uncertain impacts (costs or benefits)
Power	• Landscape impacts of dispersed renewable technologies • Impacts of additional fuel production, solvent production and waste generation for Carbon Capture and Storage • Risks of nuclear proliferation	• Ecosystem benefits from reduced eutrophication and acidification due to less coal and gas combustion	
Road transport	• Upstream impacts of increased electricity production for electric vehicles	• Road accident and congestion benefits of speed limiting • Air quality and noise benefits of hybrid cars and vans, efficient vehicles, speed limiting and eco-driving • Ecosystem benefits from reduced eutrophication and acidification due to less oil combustion • Benefits from avoided oil production	
Aviation and shipping		• Noise reduction from improved efficiency in aviation • Air quality impacts around airports • Air quality and wildlife benefits of limiting shipping speeds • Benefits from avoided oil production	
Heat	• Upstream impact of increased electricity production for heat pumps	• Benefits of biogas and biomass from waste in avoiding the costs and impacts of waste disposal (land take, odour, emissions etc)	• Biodiversity, landscape and soil fertility impacts of energy crops
Domestic, non-residential and industrial energy use	• Impacts of additional fuel production, solvent production and waste generation for CCS in industry	• Health and social benefits of improved insulation etc in housing • Benefits from avoided fuel production	

	Negative impacts (costs)	Positive impacts (benefits)	Mixed or uncertain impacts (costs or benefits)
Agriculture and forestry		• Land take benefits from dietary change • Water quality and associated biodiversity benefits (e.g. from more efficient fertiliser application and dietary change) • Air pollution benefits (e.g. from anaerobic digestion, dietary change, reduced fertiliser use)	• Biodiversity, land and water impacts of afforestation

Overall conclusions

The key conclusions from the study as a whole are summarised below, followed by the most important issues for each sector.

- The study has identified a very wide range of impacts, many of which are significant. This highlights the importance of taking an integrated view of climate policy, and not basing policy on climate impacts alone.
- For those impacts that have been quantified in monetary terms, the net benefits out weight the net costs by a significant amount (over £85bn). Whilst the totals presented exclude important unquantified costs and benefits, such as certain impacts on landscape and ecosystem services, the inclusion of these impacts is not expected to change the overall conclusion. Therefore, including these impacts in the cost-benefit analysis of climate policy would strengthen the case for setting ambitious climate targets.
- The benefits (e.g. air quality improvements) are often immediate and local, whereas climate benefits may occur on a longer timescale and mainly in a distant region, as well as being harder to demonstrate. Dissemination of the benefits could therefore strengthen public support for climate policy.
- Where there are negative impacts, these can often be reduced by appropriate mitigation actions.
- Most heat and power generation technologies have some kind of negative impact, and climate measures often involve trade-offs between different impacts. For this reason, measures that reduce overall consumption of heat and/or power tend to have a wider range of benefits than those that switch between different technologies.

Power sector

- The main benefits of the abatement scenario are related to air quality impacts arising from the switch from coal and gas fired generation to nuclear and renewables.
- Set against this is an increase in the risk of nuclear accidents and the impacts of nuclear fuel production and waste disposal. In theory, this could be partly mitigated by investment in fourth generation nuclear power plant with advanced passive safety features, though it is uncertain whether this could be deployed on the timescale required and with reasonable costs.
- There is also a landscape impact from increased deployment of onshore wind power. This could be partly mitigated by sensitive siting of wind farms, and full consultation with local communities. Attitudes to wind turbines improve if local communities are given a stake in the benefits of power production.
- The air quality impacts of carbon capture and storage are currently uncertain. Some emissions (NO_x, NH_3) are likely to increase. There will also be an increase in upstream impacts associated with increased fuel production to power the carbon capture process, and additional impacts associated with solvent manufacture and waste solvent disposal.

Road transport

- Substantial benefits arise from reduced congestion and noise as a result of avoided journeys through ‘smarter choices’ (active travel, a shift to public transport and demand reduction) and improved HGV logistics. The benefits of reduced congestion are estimated as £8.4 billion per year in 2030, with a net present value of £48 billion from 2008 to 2030. Noise reduction benefits are £150 million in 2030, with a net present value of £950 million. Further noise reduction arises from electric vehicle use.
- Perhaps surprisingly, one of the main impacts in the road transport sector is a very large health benefit as a result of increased exercise from walking and cycling instead of driving. This is estimated to provide benefits worth over £2.5 billion per year in 2030, with a net present value of £26 billion from 2008 to 2030 (for a shift of just 1.7% of car km to active travel).

- Smarter choices and improved HGV logistics also give a net reduction in accidents worth £230 million in 2030 with a net present value of £1,500 million from 2008 to 2030. However, this figure includes an increase in accidents as a result of a shift to walking and cycling, as cyclists suffer higher accident rates than drivers. It is important to note that this impact can be very significantly reduced, or even turned into a benefit, by investment in safety measures to protect active travellers, especially the provision of safe cycle routes as well as encouraging greater driver awareness.
- Further health and environmental benefits accrue from reduced air pollution as a result of avoided car and HGV use, a shift to electric and hybrid vehicles and improved fuel efficiency. The health benefits are estimated to have a net present value of £600 or 100 million in 2030 million. The air quality benefits are offset to some extent by additional emissions from power generation, but these tend to take place away from centres of population. The benefits can be enhanced by a switch to cleaner power generation technologies, such as renewables.
- The noise and air quality benefits of a switch to public transport are offset by emissions from public transport vehicles (trains, buses and coaches). The benefits can therefore be enhanced by investing in cleaner and quieter vehicles for public transport.

Aviation and shipping

- Substantial co-benefits arise from the air quality impacts of avoided fuel combustion. The benefits are large for shipping because of the high sulphur content of marine fuels. Significant benefits could also arise around UK airports, especially at Heathrow where air quality limits for NOx are regularly exceeded.
- Reduced aircraft movements could also have significant noise reduction co-benefits. If there was a sufficient reduction in flights, the need for expansion of UK airport capacity would be avoided, which would have significant benefits in terms of land take. There could also be landscape and biodiversity benefits if the avoided expansion was the proposed site in the Thames estuary, which is an important feeding and breeding ground for birds.
- Benefits of slow steaming could include reduced collisions with marine mammals. Ship collisions are the main cause of mortality for the last few hundred North Atlantic right whales, for example, but the risk of a collision proving fatal is greatly reduced at slower speeds. There could also be benefits from reduced noise, which has damaging impacts for marine life. Slow steaming greatly reduces fuel consumption and associated polluting emissions as well as providing significant economic benefits from reduced fuel costs.
- Based on the results of previous studies, an enforced reduction in flight capacity was found to have the greatest co-benefits. This is a significant finding in light of current proposals to increase runway capacity, which would have the opposite effect.

Industry and buildings

- The energy saving measures deployed in the CCC scenario have significant benefits for air quality and also through avoided upstream impacts of fuel production (coal mining accidents, oil spills etc).
- Many of these measures have other benefits: building insulation and draughtproofing provides benefits for health and comfort, and industrial process improvements can lead to better working conditions (by reducing noise, heat and vibration) as well as resource efficiency and reduced waste.
- Largest quantified benefit is the noise benefit from double glazing in residential buildings: the benefits have a net present value of 4.9 billion, estimated as £ 400 million in 2030.
- For options involving a switch to bioenergy, benefits are offset against the impacts of producing and burning the biofuel. Biofuels from waste tend to have greater lifecycle benefits than those from crops, due to the avoided impacts of waste disposal. For

biofuels from crops, the impacts can be positive or negative depending on the type of crop, cultivation method and previous use of the land. For the combustion stage, emissions can be broadly similar to those from the equivalent solid, liquid or gaseous fossil fuels except that there are generally lower heavy metal emissions. Combustion impacts can be mitigated by using best available combustion technology, or by encouraging the use of combined heat and power to minimise emissions per unit of delivered energy.
- For solar thermal heating, there are large air quality benefits.
- For heat pumps, the benefits of avoided fuel combustion must be offset against the need for additional power generation. These impacts can be mitigated by a switch to clean, sustainable power sources.
- As for the power sector, the impacts of CCS are not yet clear. There may be some benefit for air quality due to the need to minimise SO_2 emissions, but this could be offset by higher NOx emissions, and the increased energy requirement of the whole process, as well as by the impacts of solvent production and waste solvent disposal.

Agriculture and forestry

- Significant health and ecosystem benefits for air and water quality arise from measures to reduce excess application of fertilisers.
- Anaerobic digestion of farm waste and manure leads to a wide range of benefits including improved air and water quality, reduced odour, displaced fossil fuels (and so avoided impacts of fuel production) and generation of a useful product (soil improver) as well as an on-farm energy source.
- Although not part of the core CCC scenario, an additional scenario in which consumption of animal products was halved resulted in very large health benefits (from reduced intake of saturated fat) with a net present value of over £100 billion from 2008 to 2030. There would be associated benefits for land take, water consumption, air and water quality (from avoided fertiliser use and manure production) and biodiversity.
- Afforestation can also lead to benefits for biodiversity, landscape, recreation and air, soil and water quality (through trees absorbing pollution, and tree roots stabilising soil and filtering out pollution). However, these benefits depend on the choice of species to plant, the cultivation method and the previous use and biodiversity value of the land. Benefits can often be maximised by choosing mixed native species rather than monocultures of non-native species, by avoiding sites with high existing biodiversity or landscape value, and by using sustainable cultivation methods (minimising the need for agrochemicals or irrigation).

The status of this research

It must be recognised that this research has been performed on a short time scale. It has therefore been based for the most part on a review and evaluation of existing literature. In some areas a large amount of information has been identified, in others very little. We acknowledge that some of the sources used are now dated and others may be of questionable relevance to the UK. However, we believe that the research has succeeded in providing a benchmark for consideration of the externalities of climate mitigation activities as well as providing good guidance on which externalities are likely to be most significant

There are though a number of uncertainties in the results presented. This includes uncertainties associated with the values published in the literature, reflecting both uncertainties in the environmental and health impacts, and also uncertainties in monetisation of these impacts. In addition, the application of these values to the CCC's mitigation scenarios introduces further uncertainties. For example, there are uncertainties associated with how the impacts of smarter choices are allocated between active travel, public transport and avoided journeys. Finally, there are uncertainties associated with data gaps in the analysis, including where it has not been possible to quantify important impacts.

Table of contents

1 Introduction

Ricardo-AEA, in collaboration with EMRC, has been commissioned by the Committee on Climate Change to carry out a review of the impacts of carbon budget measures on human health and the environment.

This is the final report from the study, which presents an overview of the objectives of the study, the methodology that has been employed in delivering these objectives, and the overall study findings. Accompanying this report are a series of data capture templates, which provide more detailed analysis of the impacts in accordance with a standardised accounting framework.

1.1 Background

The advice that the Committee on Climate Change (CCC) provides on carbon budgets is based on detailed modelling of a range of technologies and behaviours that could be deployed across the economy. For its 2010 advice on the fourth carbon budget (covering 2023-27), the CCC developed a Medium Abatement scenario to 2030, which illustrated one way in which the carbon budgets could be met.

In assessing the costs and benefits of measures, the CCC has focused on "resource costs" (i.e. the inputs required for construction, operation and disposal) and direct emissions (i.e. emissions produced during the "use" phase). These costs and emissions reductions were reflected in Marginal Abatement Cost (MAC) curves, which allowed the ranking of abatement measures in terms of their cost-effectiveness in delivering emissions reductions in each of the carbon budgets.

1.1.1 Allowing for externalities

The MAC curves provide a powerful tool for understanding the most important measures for delivering emissions reductions at least cost, and the comparison of measures on an equal basis. However, this approach does have certain limitations. In particular, most MAC curves exclude certain impacts on the environment and human health (over and above the climate impacts) which may have an economic value, but this value may not be reflected in market prices. These are known as externalities.

The implication of failing to take into account external costs or benefits within the analysis is that the ranking of mitigation options does not take into account the full costs and benefits to society of the measures. Assessing, quantifying and valuing these external costs therefore allow decision makers to prioritise measures from a socially optimal perspective.

1.1.2 Using externalities in policy analysis

An understanding of the externalities associated with specific technologies or activities is an important input to policy making. However, it is necessary to not only understand the total extent of the potential external costs or benefits, but also the extent of any internalisation. More specifically, it is important to understand whether existing policies may have already internalised some of these costs, for example by generating an implicit cost for these impacts which is already taken into account within decisions. The most obvious examples are taxes and trading schemes, which impose a cost which is borne by the polluter for the damage which they cause. Therefore, the extent to which the external costs are truly 'external' may differ from one measure to the next[3].

[3] In practice, this issue can partly be addressed in constructing the MAC curve by excluding policy costs (e.g. price of allowances) from the analysis. However, this is not always clear cut for all policy costs.

It is therefore important to understand the extent to which external costs have been limited or internalised, and the extent to which additional interventions are required to limit these costs further.

1.2 Aims and objectives of the study

The overall aim of the study is to provide the CCC with an improved understanding of the total external costs associated with its mitigation scenario.

The specific objectives are as follows:

- systematically review the externalities to health and the environment for measures in the CCC's Medium Abatement scenario, quantifying them where possible;
- identify the potential mitigation options that can be used to limit negative externalities.

Further information on the scope of the analysis is provided below.

1.3 Scope of the study

The scope of the study is extremely broad. It covers each of the individual measures within the CCC's mitigation scenario, across a range of sectors. For each measure, the impacts have been assessed from a life-cycle perspective, across a range of environmental and human health end points.

1.3.1 Sectoral coverage

The analysis has considered almost all of the sectors contributing towards the CCC's mitigation scenario. These are:

- Electricity production
- Heat production
- Energy use in industry
- Energy use in buildings (residential and non-residential)
- Energy use in surface transport
- Energy use in aviation
- Energy use in maritime shipping
- Agriculture and forestry

For certain sectors there are important interactions when considering impacts from a life-cycle perspective. For example, external costs associated with electric vehicles will include impacts associated with the electricity production. These interactions have been included where possible.

1.3.2 Measures

The CCC's Medium Abatement scenario to 2030 includes a large number of mitigation measures (grouped into around 90 in total for this project). The analysis has aimed to capture the diversity of measures within the scenario.

However, to allow the analysis to be more manageable certain measures have been grouped where the external costs are considered to be similar in nature. In particular, the following simplifications have been made:

- Insulation measures for residential buildings have been partially grouped.
- Heating and product efficiency measures for non-residential buildings have been partially grouped.
- Process improvements for the different industry sectors have been combined into a single generic "process improvement" measure.
- A single option has been selected to represent the energy efficiency improvement in international shipping.

In addition, to fully understand the external costs of the CCC's mitigation scenario it was necessary to consider not only the mitigation measures, but also the counter-factual technologies that would have been implemented otherwise. For example, in relation to renewable heat measures, the net effect compared to the CCC's mitigation scenario would be the external costs and benefits of the renewable heat measures minus the external costs and benefits foregone from not requiring the counterfactual (e.g. oil heating) measures.

Therefore, in assessing the external costs a distinction has been made between two measures types:

- **Substitution measures** – these measures represent the substitution of a current technology or activity, with a low carbon alternative. This would include, for example, the substitution of electricity produced by a gas CCGT power plant with electricity from renewable sources. It would also capture fuel switching, for example from diesel to biodiesel.
- **Efficiency measures** – these measures are associated with improvements in the efficiency of technology or activity. These measures do not generally represent the substitution of one technology for another, but instead reflect a more efficient version of the measure. The impacts of the measures are therefore likely to be more marginal, than for measures associated with the substitution of different technologies.

In practice, the distinction between the two categories is not always clear cut, since the efficiency measures may also be associated with some substitution of technologies, or components of technologies. However, this distinction is workable in most cases, and is useful for interpreting the different measures within the CCC's scenario. It can also be used to describe the basis upon which the external costs have been assessed, as well as how the impacts are aggregated to assess the total scenario impacts.

In the case of substitution measures it is useful to understand the *absolute* external costs of the low carbon measures in the CCC mitigation scenario, but also the external costs of the technologies they are substituting. In this way the net external costs associated with the shift in technology can be derived. The analysis also provides an understanding of the trade-offs in external costs between one technology and the next. It also means that the external costs are frequently assessed as negative (in absolute terms), even though when compared to the counterfactual technology the net impact may be positive.

However, for efficiency measures it is not as important to define a counterfactual measure, as in most cases the measures are not radically different, but represent marginal changes to existing measures. Therefore, for these measures it makes more sense to assess the *relative* external costs of the measures. This means the impacts of these measures are generally positive, relative to a situation without the measure in place.

Whilst this distinction is useful for interpreting the different measures, it does however mean that those measures assessed in absolute terms (i.e. substitutes) cannot be directly compared with those measures assessed in relative terms (i.e. efficiency measures). This distinction is made clear in the analysis.

1.3.3 System boundary

System boundary is a term used by practitioners of life-cycle assessment to describe the scope of the assessment, and the extent to which up-stream or down-stream process are included or excluded. Since a number of important environmental and health externalities may be associated with the wider life-cycle of the measures, the analysis distinguishes between:

- **Use stage** – these impacts relate to the measures in use. For power generation technologies this relates, for example, to the operation of the power plant, and for surface transport the operation of the vehicles. In the buildings sector, this relates to impact associated with changes in direct fuel combustion (but not impacts associated with the production of the fuels).

- **Life-cycle stage –** these impacts are related to up-stream or down-stream processes. For energy efficiency measures, this includes for example the impacts associated with avoided fuel or electricity production, and the impacts of insulation manufacture. Downstream processes include disposal of wastes.

1.3.4 Impact categories

The HM Treasury Green Book supplementary guidance for appraising policy impacts on human health and the environment was used as the starting point when defining the impact categories to consider. This identifies the following externality types:

- **For health:** diet, lifestyle (e.g. exercise), psycho-social environment (e.g. stress, crime), housing conditions (e.g. cold, damp, indoor air quality), accidents & safety, chemical exposure, infection, geophysical factors (e.g. uv light, radon), economic factors (e.g. poverty, employment).
- **For environment:** vulnerability to climate change, waste, air quality, landscape, water (pollution, abstraction, flooding), biodiversity & ecosystems, noise.

This list of impacts was used in the analysis with some modifications.

- For certain impact categories, the list was expanded or modified, for example, accidents and safety was disaggregated into major accidents, occupational risks and transport-related accidents.
- Economic factors (e.g. fuel poverty, employment) were excluded from the analysis as they have been considered in previous CCC research. The same applies to vulnerability to climate change.
- Direct impacts of the measures on greenhouse gas emissions were excluded as this is already accounted for in the mitigation scenario.
- Direct impacts on air quality and noise were analysed separately by Imperial College and Defra, and the results are summarised in Appendix 1 and 2.

1.3.5 Definition of external cost

The project has taken a broad interpretation of where external costs may arise. The analysis has been framed around each of the impact categories described above. For some impacts, the costs are more obviously missing from current markets e.g. landscape. However, other impacts (e.g. resource use) are more clearly covered by existing markets, but market imperfections may mean the values do not reflect the full social cost. Take three examples:

- Occupational health impacts: Workers in risky occupations (e.g. coal mining) may have the added risk that they face internalised through higher wage rates and insurance. However, for effects to be fully internalised requires (amongst other things) that workers have perfect knowledge of the risks faced, and are mobile within the jobs market (i.e. they have transferable skills, alternative employment is available, and there are no barriers to movement).
- Major accidents in the oil and gas industry: In some parts of the world damage may be partly or completely internalised through insurance, compensation and fines. This may be the case with Deepwater Horizon, for example, but may not be the case were such an accident to occur in some other parts of the world.
- Water abstraction: Abstracting at volumes that reduce water flows, levels and qualities to the point where ecosystems are damaged generates economic losses associated with loss of biodiversity and final goods such as informal and formal recreation, amenity and property values. Current prices charged for abstraction reflect the cost of managing the licensing system as opposed to the environmental impacts of abstraction.

The approach taken has therefore been to quantify such effects, but leave open the question of the extent to which they are internalised, given the lack of definitive guidance in the literature and recognising the constraints on the present study. In some cases reference has been made to the existing policy framework, but it has not been possible to evaluate in any detail the extent to which current policies internalise the external costs. This should be the subject of further analysis.

1.4 Interpretation of the results

There is a temptation in any economic analysis to focus on the final aggregated result of the cost or benefit across all effects observed. However, because many important effects cannot be quantified, it is not always possible to provide meaningful totals for particular measures. Likewise, it is not always possible to compare the impacts and external costs of different measures on a consistent basis. Nevertheless, important conclusions can be drawn regarding:

- The linkage of activity to a wide range of impacts
- Information on the relative importance of different effects
- Identification of likely trade-offs, and suggestions for addressing them
- Understanding of where in the life-cycle the impacts arise.

The results of the study should be viewed with these issues in mind.

2 Methodology

This chapter describes the approach that has been followed in meeting the study objectives. In particular, it describes the accounting framework that has been developed to capture and synthesise the external cost literature.

2.1 Development of the accounting framework

The Accounting Framework is designed to collate information on the externalities of impacts of a large number of climate control options in the following sectors; power generation, surface transport, shipping and aviation, energy use in heating, in industry and in residential and non-residential buildings, and agriculture and forestry. By doing so it is necessary that the Framework facilitates consistent treatment of effects both within and between sectors.

The list of impacts against which effects are assessed is based on UK government guidance, for example from the Department for Health (2004)[4] and Defra (Dunn, 2012)[5]. This was supplemented by knowledge of the literature on externalities and on impacts. On this basis the following listing was developed:

Table 1. Impacts selected for assessment

Health impacts	Ecological impacts
Diet	Hazardous waste generation
Lifestyle	Solid waste generation (non-hazardous)
Psycho-social environment (e.g. stress, crime)	Air quality
Housing Conditions (e.g. cold, damp, indoor air quality)	Heavy metals and other trace pollutants
Major accident risk	Materials damage from air pollution
Occupational health	Landscape
Water pollution - health	Land take
Air quality	Water abstraction
Air quality: effects outside UK	Water pollution
Hazardous waste generation	Biodiversity and ecosystems
Geophysical factors (e.g. uv light, radiation)	Subsidence
Noise	Soil erosion/fertility
Infection	Resource use (metals/minerals)
Road traffic impacts (accidents)	Road traffic impacts (congestion)
	Greenhouse gas emissions (up- and down-stream of the controlled activity)[6]

The Accounting Framework is simply a grid with climate control measures laid out horizontally and impacts on the vertical axis. There are five levels to the Framework, which has been developed in Excel:

1. Qualitative assessment of the presence or absence of impacts across all measures deployed in the sector.
2. Data sheets for each measure, providing the underpinning detail for the assessment
3. A summary sheet to collate the unit impact scorings for each sector

[4] Department of Health (2004) Policy Appraisal and Health. http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_4095414.pdf.
[5] Dunn, H. (2012) Accounting for Environmental Impacts: Supplementary Green Book Guidance. http://www.hm-treasury.gov.uk/d/accounting_environmental_impacts.pdf.
[6] The CCC has also carried out its own assessment of lifecycle GHG emissions (http://www.theccc.org.uk/wp-content/uploads/2013/04/Reducing-carbon-footprint-report.pdf) which should be referred to for the CCC's conclusions on this topic.

4. Analysis sheet to provide quantification at scenario level
5. Supplementary information (references, definition of impacts)

2.1.1 Qualitative assessment of the presence or absence of impacts

Each cell of the initial qualitative assessment states whether an impact exists in each of the categories listed above, whether it will be positive or negative and then whether it is likely to be significant or less significant in the opinion of those entering data. The assessment was split in two, the first half dealing with impacts directly arising from the use stage (power generation, heating, driving, etc.) and the second dealing with wider life-cycle impacts.

Figure 1. Qualitative assessment

Qualitative scoring of impacts		+ +	+	+/-	-	- -	
		Significant benefit	Benefit	Benefit or cost	Cost	Significant cost	No effect
Click on abatement options to move to worksheets containing full details	Timing of fertiliser application	Avoiding excess fertiliser	Livestock breeding	Feed modification	Anaerobic digestion	Species introduction	Cover tanks
Diet							
Lifestyle							
Psycho-Social environment (e.g. stress, crime)							
Housing Conditions (e.g. cold, damp, indoor air quality)							
Major accident risk							
Occupational health					+		+
Road accidents							
Water pollution - health	++	++	+			+	
Air quality	+	+	+	+	++	+	+
Air quality outside UK	+	+	+	+	+	+	+
Hazardous waste							
Noise							
Infection					+		
Geophysical factors (UV, radon)	+	+	+		+	+	+

In this example, there is expected to be no effect of the first five impact categories (blank cells). The next row (occupational health) contains positive effects (i.e. benefits). For water pollution, the measures related to fertiliser application are associated with significant positive effects.

2.1.2 Data sheets for each technology or control option

Supplementary sheets for each technology or control option were designed to assess quantitatively where possible, otherwise qualitatively, the magnitude of impacts, where present. Justification of the scoring was provided, especially where quantification was not possible and only qualitative scores could be generated. The robustness of reported data was also assessed. Consideration was given to how positive externalities could be enhanced and negative externalities controlled.

Figure 2. Extract from technology data sheets (effects on congestion linked to traffic reduction)

Congestion	
Magnitude (qualitative, absolute)	++
Magnitude (quantitative, absolute)	-12.37 pence per vkm avoided in 2012
Justification of magnitude	Reduced car km leads to direct congestion reduction. Figures are from DfT
Robustness	Moderate. Note that DfT figures are much higher than CE Delft figures for Europe.
Increasing co-benefits, reducing trade-offs	Co-benefits could be enhanced through targeting measure at areas where congestion is a major problem, e.g. cities
Reference	DfT 2012b

2.1.3 Summary of unit input data

These sheets collate information from the detailed datasheets. Where values are available they are reported against a functional unit, varying by sector as appropriate (e.g. pence per kWh or pence per 1000 vehicle.km). Where values are not available the qualitative scores are presented.

Where values have been quantified the results are presented in the template. The values have been reported as single estimates, as the breadth of impact categories and measures did not allow the results to be reported easily as ranges within the template. Therefore, while the quantitative results are reported as precise single point values, there are uncertainties associated with the estimates. In some cases these uncertainties are significant.

Figure 3. Extract from the summary sheet showing unit impact scores for the power sector

	Click on abatement options to move to worksheets containing full details	Nuclear	Coal	Natural gas CCGT	Natural gas OCGT	Coal with CCS	CCGT with CCS	Biomass
	Discount rate / Base case power plant efficiency	3% discount rate	37.50%	51.60%	51.60%	37.50%	51.60%	30.50%
Generation stage: Human health	Diet							
	Lifestyle							
	Psycho-Social environment (e.g. stress, crime)							
	Housing Conditions (e.g. cold, damp, indoor air quality)							
	Major accident risk	0.009	-	-	-	-	-	-
	Occupational health	0.0044	0.0013	0.0009	0.0009	0.0013	0.0009	0.00072
	Water pollution - health	note 1	-	-	-	-	-	-
	Air quality	0.00011	- -	- -	- -	- -	- -	- -
	Air quality: effects outside UK	note 1	- -	- -	- -	- -	- -	- -
	Hazardous waste generation	1.10E-06	-	-	-	-	-	-
	Geophysical factors (e.g. uv light, radiation)							
	Noise	-	0.016	-	-	0.016	-	0.019
	Infection	-	-	-	-	-	-	-

2.1.4 Scenario analysis

These sheets take the unit impact data from the summary of input data and multiply by the change in functional unit in the CCC's medium abatement scenario to generate a cost or benefit for each year. The results are expressed as the net present value of the stream of costs or benefits over the scenario period, using a discount rate of 3.5%[7]. For effects that have been scored qualitatively, consideration is given as to whether the change in activity within the scenario is sufficient for an impact to be considered 'significant' or not. A common format has been adopted wherever appropriate across the different worksheets.

For certain sectors, scenario analysis has not been performed due to the lack of quantitative data on the external costs.

[7] For nuclear waste a discount rate of 3% and 0% has been applied, as this reflects the rate used in the primary literature

Figure 4. Extract from the scenario sheet showing monetised impact values for the transport sector[8]

Click on abatement options to move to worksheets containing full details	Conventional ICE vehicles	Electric cars and vans	Plug in hybrid cars and vans	Hydrogen buses	Biofuels	Improved vehicle efficiency	Walking/cycling
Total vehicle km 2012-2030, baseline (billi	10195	0	0	0			
Total vehicle km 2012-2030, mitigation (bi	9419	307	551	1			-118
Difference (billion vkm)	-775	307	551	1			-118
Diet							
Lifestyle							23,728
Psycho-Social environment (e.g. stress, crime)							+
Housing Conditions (e.g. cold, damp, indoor air quality)							
Major accident risk							
Occupational health							
Road accidents							-1,591
Water pollution							
Air quality		124	+	13		+	136
Air quality - outside UK		+	+	+		+	+ +
Hazardous waste							
Noise		341	+	+		+	209

However, even for those sectors where certain quantitative estimates have been derived, there remain a number of effects that could only be assessed in qualitative terms. This pattern is observed across all sectors, reflecting limitations on data availability. Any totals for quantified values should therefore be used with caution, as in most cases they are likely to omit certain important impacts where quantitative data is unavailable.

2.1.5 Supplementary information

Final sheets provide a description of impacts, in order that these may be considered consistently, and a listing of the references used in development of the spreadsheet for each sector. In some cases a calculation sheet has also been added to describe any calculations made.

2.2 Analysis of the impacts

To a very large degree the assessment of impacts was based on literature review rather than original analysis. Preference was given to estimates derived using impact pathway / DPSIR approaches (see figure) rather than cruder top-down approaches. The key to this approach is the presence of clear links between the imposition of a burden of some kind, quantification of associated impacts and subsequent valuation.

[8] The air quality impacts have been assessed separately, by Imperial College and valued by the project team (see Appendix 1).

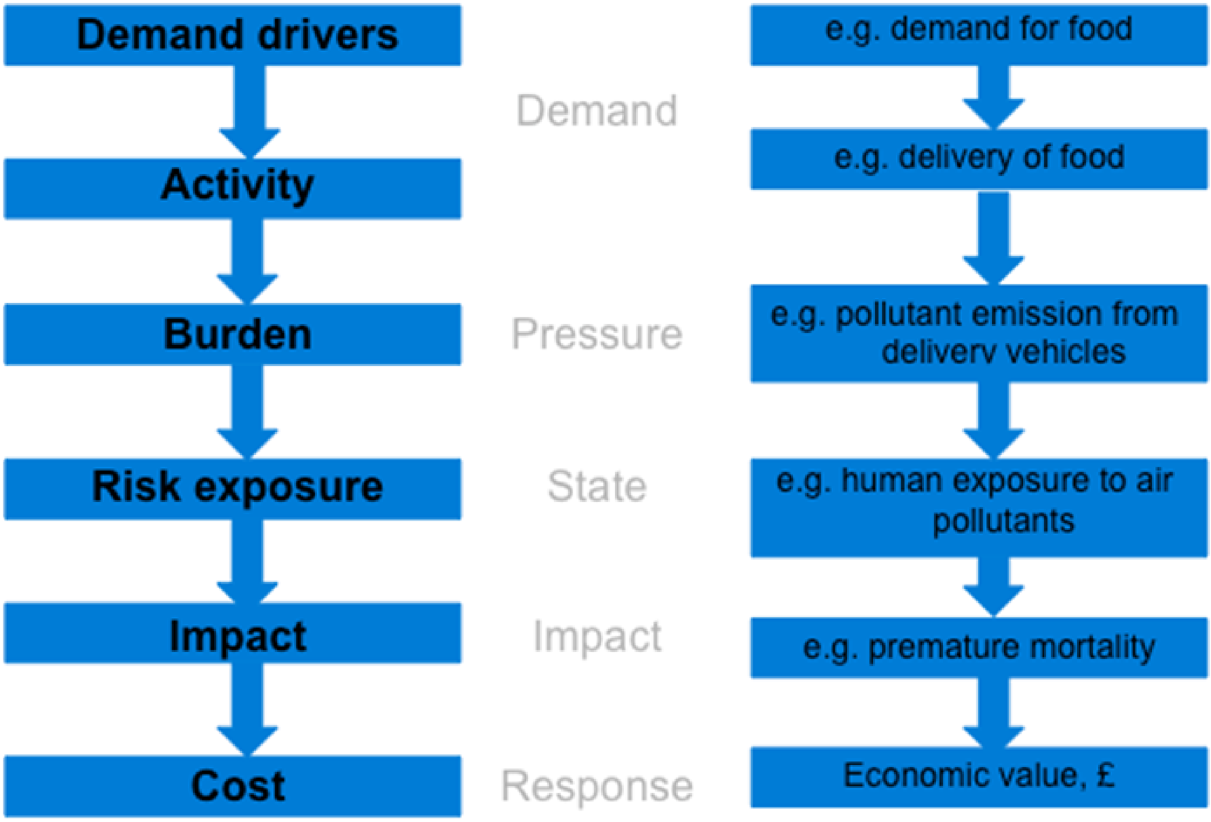


Figure 5. Illustration of the impact pathway or DPSIR approach

Consideration was given as to whether results were still relevant. Updating of results, where applied, considered a number of issues, for example:

- Currency and price year, ensuring that all are reported in 2012£.
- UK government guidance, where it took a different approach to that used in the studies used. An example concerns the assessment and valuation of life-cycle air quality impacts from European work. Using the EMRC database of Power generation externalities, information on emissions of air pollutants was taken and multiplied by damage factors reported for UK government by IGCB[9], rather than using the original results which are based on different assumptions. This conversion was not possible in many cases, but was performed as far as data permitted.[10]
- Trends since original reports were released. For the energy and transport sectors there is a substantial literature dating from the early 1990s to the mid-2000s that covers impacts since ignored, for example on major and occupational accident rates. Consideration was given as to whether the rates used remained applicable, and if not adjustments were made. One notable example concerned major accidents at oil rigs, which in the original analysis were dominated by the disasters at the Piper Alpha and Alexander Kielland rigs. As accidents on this scale (at least so far as human casualties are concerned) have not happened in the last 25 years in the industry, these two accidents were removed from the analysis. It is noted that it is possible for potential impacts to have increased over time also, for example where fuel extraction moves to more hostile environments or to less regulated parts of the world.

[9] IGCB (2007) Economic analysis to inform the air quality strategy. http://www.defra.gov.uk/environment/quality/air/airquality/publications/stratreview-analysis/index.htm. The latest estimates of damage costs for NOx, PM and SO_2 are given in: http://www.defra.gov.uk/environment/quality/air/airquality/publications/stratreview-analysis/annexes-icgb.pdf. A general description of the methods used is provided by Watkiss et al (2006) http://www.defra.gov.uk/environment/quality/air/airquality/panels/igcb/documents/dcs-report2006.pdf

[10] Changes in air pollutant emissions linked directly to the emission control options considered are being assessed separately by Imperial College. However, this does not extend to life-cycle emissions to the extent that they, too, are affected.

In some cases, estimates of externalities were obtained that covered several of the impacts listed in the tables within a single number. In these and other cases, care was taken to avoid double counting of impacts.

The qualitative scoring is clearly subjective. A simple 5 point scale was adopted. Each effect was therefore scored as likely to be significant (++ or - -, depending on the direction of impact) or less significant (+ or -). Where no effect was expected, or the scale of the effects was very small, then the impact was scored as having "no effect". The scoring took various factors into account, including:

- Knowledge of the general scale of an impact, whether quantitative or qualitative
- Information on legislation in place to control impacts
- Consideration as to what extent emission control options might influence the effect in question.

However, the qualitative scores are subjective, reflecting the experience and biases of the analyst responsible for them. Given the large number of impact/option combinations assessed it is inevitable that some, and perhaps not a small number, will attract different views. It is to be hoped that where disagreement arises we have provided sufficient information to initiate further informed debate.

The fact that an impact has been ascribed a monetary value should not be taken to imply that it is necessarily 'significant'. Given the scope of the study, values were adopted according to availability rather than as a result of a prioritisation process.

When ascribing a 'less significant' score to a large number of effects the question naturally arises as to the significance of all such effects taken as one. It may be the case that the cumulative effect becomes significant. Further work to quantify the impacts would be required to discern the likely combined effect.

2.3 Caveats and uncertainties

The preceding text highlights the uncertainties present in the analysis. Even with this uncertainty the study has generated a number of useful outputs (see below). Those using the results provided by the Accounting Framework should recognise the study for what it is, a wide ranging exercise seeking to provide a first overview of the co-benefits and trade-offs implicit in the CCC's medium scenario.

For some sectors very major issues exist, and results need to be heavily caveated. This is probably none more so than for deployment of nuclear power technologies. Estimates of the externalities of nuclear have typically generated very low numbers, comparable to most renewable technologies.

However, major nuclear accidents will cause damage running into billions, with the industry incapable of gaining full insurance cover. The estimated probability of such accidents is very low, and putting the two (magnitude and probability) together typically generates a rather modest externality per unit of power generation. However, as events at Fukushima have demonstrated, a low probability of an accident is not a guarantee of safe operation. The regulatory environment has a role in managing this risk. In relation to this, the Interim Report from HM Chief Inspector of Nuclear Installations on the implication of the Japanese earthquake and tsunami for the UK Nuclear Industry[11] did not revealed any gaps in scope or depth of the Safety Assessment Principles for nuclear facilities in the UK, or any significant weaknesses in the UK nuclear licensing regime. However, it was recognised that with more information there is likely to be considerable scope for lessons to be learnt about human behaviour in severe accident conditions that will be useful in enhancing contingency arrangements and training in the UK for such events.

[11] Japanese earthquake and tsunami: Implications for the UK Nuclear Industry. Interim Report. HM Chief Inspector of Nuclear Installations 18 May 2011

There is a further issue with the external cost estimates from nuclear power with respect to long-term storage of high level radioactive wastes. On the basis that these wastes will remain extremely hazardous for a very long time (around 100,000 years, so many times longer than recorded human history), is it logical to consider some guarantee of safe storage?

Questions also arise in relation to internalisation of impacts. To illustrate, the Deepwater Horizon disaster in the Gulf of Mexico was a major event in several ways, for its effects on workers, residents and businesses along the Gulf and ecosystems. However, BP has spent billions of dollars on clean-up, compensation and on fines and is set to pay more. To what extent should the accident be considered an externality, when much of the damage appears to have been internalised?

The integration of impacts on ecosystems and ecosystem services still presents problems for the analysis. Whilst this field of work is growing rapidly, analysis in many areas remains elusive. One particularly problematic issue here concerns the impacts of wind farms on landscape: assessment of impacts at an individual site may be possible, but an aggregate assessment of damage for a major programme of wind farm development poses major challenges.

It is rather easy to provide an overview of effects that assumes continuation of long-established supply chains bringing in goods and materials from other countries with advanced regulatory systems. This is not necessarily the case, and the origin of some goods like oil that are traded on open world markets cannot always be guaranteed. Associated impacts may be considerably higher than anticipated.

Finally, there are issues around new technologies, with hydraulic fracturing of shale gas plays providing a good example. The debate is split between those who say that it can be done with no problems at all (which may be the case in some locations) and those who argue for a complete moratorium (there have certainly been some problems at some sites). Perhaps the main conclusion that can be drawn is that confidence in the assessment of effects of hydraulic fracturing and other controversial new technologies cannot be considered particularly robust.

3 Impacts associated with individual measures

This section summarises the results of the analysis for individual abatement measures. It provides a high level summary of the main external cost estimates for each measure, in pounds per functional unit (e.g. vehicle km or kWh). Section 4 then describes how these cost estimates are used to give an estimate of the co-benefits or trade-offs associated with the CCC abatement scenario.

The overall external costs associated with each of the measures are documented in the accounting templates. A selection of results are summarised below, at a sector level.

Firstly, results are presented for power production and primary fuel production. These sectors are important sources of emissions in their own right, but also represent important “upstream” sources of external costs. Results are then presented for the road transport sector. This sector represents an important energy end-use sector, as well as having important non-energy related external costs.

For measures relevant to the other sectors (residential and non-residential buildings, heat, shipping and aviation, agriculture, industry) detailed results are not repeated below, but can be found in the accompanying spreadsheets. Instead, a high level summary of the main impacts and conclusions at a sector level is provided below.

3.1 Presentation of results

For each sector, a consistent approach has been used to present the results. This includes:

- A summary table showing for each measure the existence of an impact, the direction of the impact and its potential significance
- A summary table showing the value of any external costs, where quantitative estimates have been identified.

Where values have been quantified the results are presented in most cases as single estimates, as the breadth of impact categories and measures did not allow the results to be reported easily as ranges. Therefore, while the quantitative results are reported as precise single point values, there are uncertainties associated with the estimates - in some cases very large uncertainties.

The inclusion of upstream and downstream impacts presents an additional challenge when presenting results, since external costs may be associated with a number of different parts of the lifecycle. For transparency, a distinction is therefore made between the external costs associated with the “use stage” of the measure, and those impacts associated with “other lifecycle stages”.

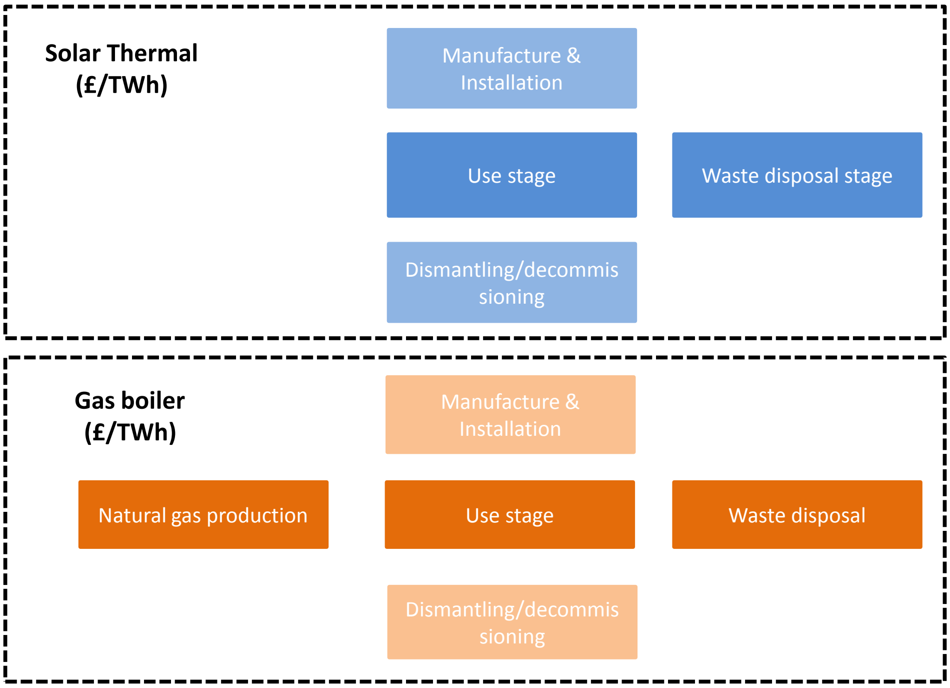
Furthermore, to provide clarity on the stages in the lifecycle which contribute the external costs a distinction is made between the lifecycle impacts associated with:

- Manufacture, installation and decommissioning on the measures (e.g. wind turbine, heat pump, insulation material);
- Fuel production for primary fuels (oil, gas, coal, biomass);
- Electricity production;
- Waste disposal (solid waste disposal to landfill).

This distinction is also useful for providing an assessment of the relative burdens associated with the different primary fuels and electricity generation sources. This is important when considering the relative benefits of energy efficiency and fuel switching measures. The modular approach also allows other assumptions to be easily tested e.g. change in power generation mix, as well as the net effect of the CCC's abatement scenario to be explored.

An illustration of how the modular approach can be applied in the case of switching from gas heating to solar thermal is shown in the figure below. Information is required on both the external costs associated with the mitigation option (solar thermal), and also the external costs associated with the counter-factual technology (gas boiler). In both cases, external costs will be associated with the use stage, but also the upstream production of fuel (for the gas boiler) as well as the manufacture, installation, dismantling and decommissioning of the measures. Waste disposal impacts are likely to be small for both measures, in this example.

Figure 6. Illustration of the system boundary and different stages in the lifecycle



3.2 Electricity production

The results from the assessment of the main electricity production technologies are shown below.

3.2.1 Presence or absence of an external cost

Figure 7 provides a high level assessment, for each measure and impact category, of the presence or absence of an impact during the use phase. This is followed in Figure 8 with an assessment of the impacts associated with the other life cycle stages.

3.2.2 Valuation of the external costs

In Figure 9, external cost estimates are presented for each of the measures. The values are expressed in terms of the relevant functional unit, which for electricity production measures is p/kWh of electricity produced.

Valuation estimates are reported where they have been identified in the literature. However, for a large number of impacts a valuation is lacking. Quantification of externalities for nuclear power generation is subject to a number of issues relating to long term risks, discounting, etc. These are discussed in more depth in Section 4.1.2.

Figure 7: Electricity production: Presence or absence of a cost associated with the use stage of measures

	Click on abatement options to move to worksheets containing full details	Nuclear	Coal	Natural gas CCGT	Natural gas OCGT	Coal with CCS	CCGT with CCS	Biomass	Onshore wind	Offshore wind	Marine	Other renewables
Other life-cycle stages: Health	Diet											
	Lifestyle			-	-		-					
	Psycho-Social environment (e.g. stress, crime)			-	-		-					
	Housing Conditions (e.g. cold, damp, indoor air quality)											
	Major accident risk	-	- -	- -	- -	- -	- -					
	Occupational health	-	-	-	-	-	-	-	-	-	-	-
	Road accidents	-	-	-	-	-	-	-	-	-	-	-
	Water pollution	-	-	-	-	-	-	-	-	-	-	-
	Air quality	-	-	-	-	-	-	-	-	-	-	-
	Hazardous waste generation	- -	- -	-	-	- -	-	-				-
	Geophysical factors (e.g. uv light, radon)											
	Noise	-	-	-	-	-	-	-	-	-	-	-
	Infection											
Other life-cycle stages: Environment	Hazardous waste generation	- -	- -	-	-	- -	-	-	-	-	-	-
	Solid waste generation (non-hazardous)	-	- -	-	-	- -	-	-	-	-	-	-
	Greenhouse gases	- -	- -	- -	- -	- -	-	-	-	-	-	-
	Air quality	- -	-	-	-	-	-	-	-	-	-	-
	Heavy metals and other trace pollutants	- -	-	-	-	-	-	-	-	-	-	-
	Materials damage from air pollution	-	-	-	-	-	-	-	-	-	-	-
	Landscape	-	-	-	-	-	-	+ / -	- -	- -	- -	-
	Land take	-	-	-	-	-	-	- -	- -	-	-	
	Water abstraction	-	-	-	-	-	-	+ / -	-	-	-	-
	Water pollution	-	-	-	-	-	-	-	-	-	-	-
	Bioversity and ecosystems											
	Subsidence	-	-	-	-	-	-					
	Congestion	-	-	-	-	-	-	-	-	-	-	-
	Soil erosion/fertility							+ / -	-			
	Resource use (metals/minerals)	-	-	-	-	-	-	-	-	-	-	-

Notes: The presence or absence of impacts linked to the further deployment of each technology, and whether they may be positive or negative. Effects considered significant are given a rating of - - or ++, less significant effects are rated - or +.

Figure 8: Electricity production: Presence or absence of a cost associated with other lifecycle stages of measures

	Click on abatement options to move to worksheets containing full details	Nuclear	Coal	Natural gas CCGT	Natural gas OCGT	Coal with CCS	CCGT with CCS	Biomass	Onshore wind	Offshore wind	Marine	Other renewables
	Discount rate / Base case power plant efficiency	3% discount rate	37.50%	51.60%	51.60%	37.50%	51.60%	30.50%				
Generation stage: Human health	Diet											
	Lifestyle											
	Psycho-Social environment (e.g. stress, crime)								-			
	Housing Conditions (e.g. cold, damp, indoor air quality)											
	Major accident risk	0.009	-	-	-	-	-	-		-	-	
	Occupational health	0.0044	0.0013	0.0009	0.0009	0.0013	0.0009	0.00072	0.02	0.02	0.02	0.0013
	Water pollution - health	note 1	-	-	-	-	-	-		-	-	
	Air quality	0.00011	- -	- -	- -	- -	- -	- -				
	Air quality: effects outside UK	note 1	- -	- -	- -	- -	- -	- -				
	Hazardous waste generation	1.10E-06	-	-	-	-	-	-				
	Geophysical factors (e.g. uv light, radiation)											
	Noise	-	0.016	-	-	0.016	-	0.019	0.01			
	Infection	-	-	-	-	-	-	-				
Generation stage: Environment	Hazardous waste generation	-	-	-	-	-	-	-				
	Solid waste generation (non-hazardous)	-	-	-	-	-	-	-	-	-	-	-
	Air quality	-	- -	- -	- -	- -	- -	- -				
	Heavy metals and other trace pollutants	-	0.0049	-	-	0.0049	-	0.0049				
	Materials damage from air pollution		-	-	-	-	-	-				
	Landscape											
	Land take											
	Water abstraction		0.05	0.026	0.026	0.05	0.026	0.05				
	Water pollution	-	-	-	-	-	-	-		-	-	
	Bioversity and ecosystems	-							-	-	-	
	Subsidence											
	Soil erosion/fertility											
	Resource use (metals/minerals)	see datasheet	see datasheet	see datasheet	see datasheet	see datasheet	see datasheet	see datasheet				

Notes: The presence or absence of impacts linked to the further deployment of each technology, and whether they may be positive or negative. Effects considered significant are given a rating of - - or ++, less significant effects are rated - or +.

Figure 9: Electricity production: Valuation of external costs for the use phase (Units: Pence per kWh. Currency: £, 2012)

	Click on abatement options to move to worksheets containing full details	Nuclear	Coal	Natural gas CCGT	Natural gas OCGT	Coal with CCS	CCGT with CCS	Biomass	Onshore wind	Offshore wind	Marine	Other renewables
	Discount rate / Base case power plant efficiency	3% discount rate	37.50%	51.60%	51.60%	37.50%	51.60%	30.50%				
Other life-cycle stages: Health	Diet											
	Lifestyle			-	-		-					
	Psycho-Social environment (e.g. stress, crime)			-	-		-					
	Housing Conditions (e.g. cold, damp, indoor air quality)											
	Major accident risk	-	0.1000	0.0015	0.0015	0.1000	0.0015			-	-	
	Occupational health	0.0089	0.015	0.0076	0.0076	0.015	0.0076	0.00037	0.01	0.01	0.01	0.016
	Road accidents	-	-	-	-	-	-	-	0.013	0.013	0.013	-
	Water pollution	-?	-	-	-	-	-	-	-	-	-	-
	Air quality	0.03	-	-	-	-	-	0.1000	0.043	0.056	0.056	0.069
	Hazardous waste generation	0.0004	-	-	-	-	-	-	-	-	-	0.02
	Geophysical factors (e.g. uv light, radon)											
	Noise	-	0.0027	-	-	0.0027	-	-	-	-	-	-
	Infection											
Other life-cycle stages: Environment	Hazardous waste generation	-	-	-	-	-	-	-	-	-	-	-
	Solid waste generation (non-hazardous)	-	-	-	-	-	-	-	-	-	-	-
	Greenhouse gases	0.022	0.25	0.027	0.027	0.25	0.027	0.17	0.03	0.035	0.035	0.3
	Air quality	-	-	-	-	-	-	-	-	-	-	-
	Heavy metals and other trace pollutants	note 1	-	-	-	-	-	-	0.0065	0.0067	0.0067	
	Materials damage from air pollution	-	-	-	-	-	-	-	-	-	-	-
	Landscape	-	-	-	-	-	-	+/-	- -	- -	- -	-
	Land take	-	-	-	-	-	-	- -	- -?	- ?	-	
	Water abstraction	-	-	-	-	-	-	+/-	-	-	- -?	-
	Water pollution	note 1	-	-	-	-	-	-	-	-	-	-
	Bioversity and ecosystems	-	-	-	-	-	-	-	-	-	- -?	-
	Subsidence	-	-	-	-	-	-					
	Congestion	-	-	-	-	-	-	-	-			
	Soil erosion/fertility	-						-	-			
	Resource use (metals/minerals)	-	-	-	-	-	-	-	-	-	-	- -?

Notes: The values are expressed per functional unit – in this case pence per kWh of electricity generated. In generating the estimates certain assumption are embedded in the analysis, including for example the efficiency of electricity generation, the supply chain for the power stations and their overall operating performance.

3.3 Primary fuel production

The results from the assessment of the main fuels that are consumed in the end-use sectors are shown below. For biomass a range of supply sources have been explored, but these are not exhaustive.

3.3.1 Presence or absence of an external cost

Figure 10 provides a high level assessment, for each measure and impact category, of the presence or absence of an impact during the other lifecycle phase. Impacts associated with the “use phase” i.e. combustion, are captured in the analysis in the respective end-use sector where the fuel is consumed, and are not repeated below

3.3.2 Valuation of the external costs

In Figure 11, external cost estimates are presented for each of the measures. The values are expressed in terms of the relevant functional unit, which for primary fuel production is p/kWh of energy content.

Valuation estimates are reported where they have been identified in the literature. However, as shown in the figure for a large number of impacts a valuation is lacking. The quantitative estimates therefore represent only a limited proportion of the total externalities.

Figure 10: Primary fuel production: Presence or absence of a cost associated with the other lifecycle stage of measures

		Oil	Natural gas	Coal	Biogas	Biomass_energycrops	Biomass_waste	Biofuels_waste	Biofuels_energycrops	Biofuels_foodcrops
Other life-cycle stages: Health	Diet	-								
	Lifestyle	-	-							
	Psycho-Social environment (e.g. stress, crime)	-	-							
	Housing Conditions (e.g. cold, damp, indoor air quality									
	Major accident risk	- -	- -	- -	-	-	-	-	-	-
	Occupational health	- -	- -	- -	-	-	-	-	-	-
	Road accidents	-	-	-						
	Water pollution	-	-	-		-		+/-	-	-
	Air quality	- -	-	-	+	-			-	-
	Air quality outside UK	- -	-	-		-			-	-
	Hazardous waste generation	-	-	-						
	Noise	-	-	-		-	-	-	-	-
	Infection									
	Geophysical factors (e.g. uv light, radon)	+	+	+						
Other life-cycle stages: Environment	Hazardous waste generation	- -	-	-						
	Solid waste generation (non-hazardous)	-	-	-	+	-	+ +	+ +	-	-
	Greenhouse gases	- -	- -	- -	+	-	+ +	+ +	-	-
	Regional air pollutants (NH_3, NO_X, PM, SO_2, VOCs)	- -	-	-	+/-	-	+/-	-	-	-
	Heavy metals and other trace pollutants	-	-	-						
	Materials damage from air pollution	-	-	-		-		-	-	-
	Landscape	-	-	-	+	+/-	+	+	+/-	+/-
	Land take	-	-	-	+	-		+	-	- -
	Water abstraction	-	-	-		-			-	-
	Water pollution	-	-	-		-		-	-	-
	Bioversity and ecosystems	-	-	-		+/-		-	+/-	-
	Subsidence	-	-	-						
	Congestion	-	-	-						
	Soil erosion/fertility	-		-	+	+/-			+/-	-
	Resource use (metals/minerals)									

Notes: The presence or absence of impacts linked to the further deployment of each technology, and whether they may be positive or negative. Effects considered significant are given a rating of - - or ++, less significant effects are rated - or +.

Figure 11: Primary fuel production: Valuation of external costs for the other lifecycle impacts stage (Units: £/tonne for oil/coal, £ per 1000m3 for gas). Currency: £, 2012

		Oil	Natural gas	Coal	Biogas	Biomass_energycrops	Biomass_waste	Biofuels_waste	Biofuels_energycrops	Biofuels_foodcrops
Other life-cycle stages: Health	Diet	-								
	Lifestyle	-	-							
	Psycho-Social environment (e.g. stress, crime)	-	-							
	Housing Conditions (e.g. cold, damp, indoor air quality									
	Major accident risk	0 to 0.33	0 to 0.29	2.3	-	-	-	-	-	-
	Occupational health	1.46	0.37	0.34	-	-	-	-	-	-
	Road accidents	-	-	-						
	Water pollution	-	-	-		-		+/-	-	-
	Air quality	5.55	-	-	+	-			-	-
	Air quality outside UK	- -	-	-		-			-	-
	Hazardous waste generation	-	-	-						
	Noise	-	-	0.08		-	-	-	-	-
	Infection									
	Geophysical factors (e.g. uv light, radon)	+	+	+						
Other life-cycle stages: Environment	Hazardous waste generation	0 to 0.94		-						
	Solid waste generation (non-hazardous)	-	-	-	+	-	+ +	+ +	-	-
	Greenhouse gases	7.2	1.43 to 8.0	5.68	+	-	+ +	+ +	-	-
	Regional air pollutants (NH3, NOX, PM, SO2, VOCs)	- -	-	-	+/-	-	+/-	-	-	-
	Heavy metals and other trace pollutants	-	-	-						
	Materials damage from air pollution	-	-	-		-		-	-	-
	Landscape	-	-	-	+	-	+	+	+/-	+/-
	Land take	-	-	-	+	-		+	-	- -
	Water abstraction	-	-	-		-		-	-	-
	Water pollution	-	-	-		-		-	-	-
	Bioversity and ecosystems	-	-	-		+/-		-	+/-	-
	Subsidence	-	-	-						
	Congestion	-	-	-						
	Soil erosion/fertility	-		-	+	+/-			+/-	-
	Resource use (metals/minerals)									

Notes: The presence or absence of impacts linked to the further deployment of each technology, and whether they may be positive or negative. Effects considered significant are given a rating of - - or ++, less significant effects are rated - or +.

3.4 Road transport

Road transport includes measures that improve the energy efficiency of current transport activities, measures that shift from fossil fuels to alternative fuels and measures to shift demand to other modes and methods. Therefore the net external costs of this mitigation pathway are represented as the difference between the external costs associated with the modes and method in the baseline scenario, and those in the mitigation scenarios. As described above, the external costs associated with the production of primary fuels are important.

3.4.1 Presence or absence of an external cost

The results for the assessment of the road transport measures are shown below. In Figure 12, an assessment is made of the presence or absence of an impact associated with the use phase, and Figure 13 shows the impacts associated with primary fuel production, making reference to the external cost values described above, as well as any impacts arising from production, installation and decommissioning of the technologies.

3.4.2 Valuation of the external costs

In Figure 14, external cost estimates are presented for each of the measures during the use phase. The values are expressed in terms of the relevant functional unit, which for road transport is p/vkm.

Valuation estimates are reported where they have been identified in the literature. However, for a large number of impacts a valuation is lacking. Encouragingly, for several of the most significant impacts a value is available in the literature to indicate the scale of the cost/benefit.

Figure 12: Road transport: Presence or absence of a cost associated with the use stage of measures

	Click on abatement options to move to worksheets containing full details	Conventional vehicles	Electric cars and vans	Plug in hybrid cars and vans	Hydrogen buses	Biofuels_foodcrops	Biofuels_waste	Biofuels_energy crops	Improved vehicle efficiency	Smarter choices: reduction in car vkm Walking/cycling	Smarter choices: reduction in car vkm Demand reduction	Smarter choices: reduction in car vkm Public transport	HGV logistics savings	Eco driving all vehicles	Speed limiting cars and vans
Driving: Health	Diet														
	Lifestyle									++	+	+			
	Psycho-Social environment (e.g. stress, crime)	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	++	+	+/-	+	+?	+?
	Housing Conditions (e.g. cold, damp, indoor air quality														
	Major accident risk														
	Occupational health														
	Road accidents	- -	- -	- -	- -	- -	- -	- -	- -	-	++	++	++	?	++
	Water pollution - health														
	Air quality - UK	- -		-		- -	- -	- -	-	++	++	+	++	+	+
	Air quality - Outside UK	-		-		- -		- -	-	++	++	+	++	+	+
	Hazardous waste														
	Noise	- -	-	-	-	- -	- -	- -	-	+	+	+	++	+?	+
	Infection														
	Geophysical factors (e.g. uv light, radon)														
Driving: Environment	Hazardous waste generation														
	Solid waste generation (non-hazardous)														
	Greenhouse Gases	Being assessed elsewhere: outside project scope													
	Regional air pollutants (NH_3, NO_X, PM, SO_2, VOCs)	- -		-		- -	- -	- -	-	++	++	+	++	+	+
	Heavy metals and other trace pollutants	-		-					-	++	+	-	++	+	+
	Materials damage from air pollution	-		-		-	-	-	-	+	+	+	+	+	+
	Landscape														
	Land take														
	Water abstraction														
	Water pollution	-		-		-	-	-	-	+	+	-	+	+	+
	Bioversity and ecosystems	-	-	-	-	-	-	-	-	+	+	+	+	+	+
	Subsidence														
	Congestion	- -	- -	- -	- -	- -	- -	- -	-	++	++	++	++	+	+
	Soil erosion/fertility														
	Resource use (metals/minerals)														

Notes: The presence or absence of impacts linked to the further deployment of each technology, and whether they may be positive or negative. Effects considered significant are given a rating of - - or ++, less significant effects are rated - or +.

Figure 13: Road transport: Presence or absence of a cost associated with the other lifecycle stages for the measure

	Click on abatement options to move to worksheets containing full details	Conventional vehicles	Electric cars and vans	Plug in hybrid cars and vans	Hydrogen buses	Biofuels_foodcrops	Biofuels_waste	Biofuels_energy crops	Improved vehicle efficiency	Smarter choices: reduction in car vkm – Walking/cycling	Smarter choices: reduction in car vkm – Demand reduction	Smarter choices: reduction in car vkm – Public transport	HGV logistics savings	Eco driving all vehicles	Speed limiting cars and vans
Other life-cycle stages: Health	Diet														
	Lifestyle														
	Psycho-Social environment (e.g. stress, crime)	-													
	Housing Conditions (e.g. cold, damp, indoor air quality														
	Major accident risk	- -	-	-	-	-	-	-	-	+	+	+	+	+	+
	Occupational health	- -	-	-	-	-	-	-	-	+	+	+	+	+	+
	Road accidents														
	Water pollution	-	-	-		-	+/-	-	-						
	Air quality	- -	- -	-	-	-		-	-	+	+	+	+	+	+
	Hazardous waste generation		-	-											
	Noise														
	Infection														
	Geophysical factors (e.g. uv light, radon)														
Other life-cycle stages: Environment	Hazardous waste generation	- -	-	-					-	+	+	+	+	+	+
	Solid waste generation (non-hazardous)		-	-		-	+ +	-							
	Greenhouse gases	Being assessed elsewhere: outside project scope													
	Regional air pollutants (NH_3, NO_X, PM, SO_2, VOCs)	- -	- -	-	-	-	-	-	-	+	+	?	+	+	+
	Heavy metals and other trace pollutants	-		-					-	+	+	?	+	+	+
	Materials damage from air pollution	-	-	-				-	-	+	+	?	+	+	+
	Landscape	-	-	-	-	+/-	+	+/-	-	+	+	?	+	+	+
	Land take	-	-	-	-	- -	+	-	-	+	+	+	+		
	Water abstraction	-	-	-	-	-	-	-		+	+	+	+	+	+
	Water pollution	-	-	-		-	-	-	-	+	+	+	+	+	+
	Bioversity and ecosystems	-	-	-	-	-	-	+/-	-	+	+	+	+	+	+
	Subsidence		-	-											
	Congestion														
	Soil erosion/fertility					-		+/-							
	Resource use (metals/minerals)	-	-	-	-	-	-	-	-						

Notes: The presence or absence of impacts linked to the further deployment of each technology, and whether they may be positive or negative. Effects considered significant are given a rating of - - or ++, less significant effects are rated - or +.

Figure 14: Road transport: Valuation of external costs for the use stage (Units: Pence per vehicle km. Currency: £, 2012)

	Click on abatement options to move to worksheets containing full details	Conventional vehicles	Electric cars and vans	Plug in hybrid cars and vans	Hydrogen buses	Biofuels_foodcrops	Biofuels_waste	Biofuels_energy crops	Improved vehicle efficiency	Smarter choices: Walking/cycling	Smarter choices: Demand reduction	Smarter choices: Public transport	HGV logistics savings	Eco driving all vehicles	Speed limiting cars and vans
Driving: Health	Diet														
	Lifestyle									28.68	+	2.87			
	Psycho-Social environment (e.g. stress, crime)							+/-		++	+	+/-	+	+?	+?
	Housing Conditions (e.g. cold, damp, indoor air quality)														
	Major accident risk														
	Occupational health														
	Road accidents	-1.70	-1.70	-1.70	-	-1.70	-1.70	-1.70	-1.70	-1.92	-1.68	1.42	0.75	?	++
	Water pollution - health														
	Air quality	- -		-		- -	- -	- -	+	+	+	+	43.38	+	+
	Air quality outside UK			-		- -		- -							
	Hazardous waste														
	Noise	-0.25	-	-	-	- -	- -	- -	+?	0.25	0.25	0.08	1.69	+?	+
	Infection											-			
	Geophysical factors (UV, radon)														
Driving: Environment	Hazardous waste generation														
	Solid waste generation (non-hazardous)														
	Greenhouse gases	Being assessed elsewhere: outside project scope													
	Regional air pollutants (NH_3, NO_X, PM, SO_2, VOCs)	-0.03		-	-	- -	- -	- -	+	0.03	0.03	0.00	0.32	+	+
	Heavy metals and other trace pollutants	-0.04		-					+	0.04	0.04	-0.05	0.52	+	+
	Materials damage from air pollution	-		-		-	-	-	+	+	+	+	+	+	+
	Landscape														
	Land take														
	Water abstraction														
	Water pollution	-		-		-	-	-	+	+	+	-	+	+	+
	Bioversity and ecosystems	-0.08	-0.08	-0.08	-0.32	-0.08	-0.08	-0.08		0.08	0.08	0.05	0.45		+
	Subsidence														
	Congestion	-12.37	-12.37	-12.37	-31.12	-12.37	-12.37	-12.37	-12.37	12.37	12.37	10.75	-50.28	+	+
	Soil erosion/fertility														
	Resource use (metals/minerals)														

Notes: The values are expressed per functional unit – in this case, pence per vehicle km. In generating the estimates certain assumptions are embedded in the analysis, for example the location of the transport routes and the operating practices. It also notable that quantitative estimates are not available for all fuel sources on a consistent basis.

3.5 Other sectors

As described above, detailed results for the other sectors are summarised in the respective spreadsheets and are not detailed here.

In general, less quantitative data was identified for the other sectors, and where quantitative estimates were calculated they were generally made at the level of the overall scenario rather than for specific measures. The scenario level results are described further in the next chapter.

The absence of quantitative results does not mean that there are not important external costs associated with the measures in these sectors. In fact the diversity of measures in these sectors suggests a greater breadth of impacts may exist. In some sectors, such as heat, the measures are substitutes for conventional fossil fuel or electric systems, and are very different in nature. Therefore, the choice of technology will have a large impact on the net external costs. In other sectors, such as residential and commercial buildings, the measures are largely related to improvements in the efficiency of existing technologies of processes. In these cases, the relative impacts are more likely to be positive overall with the impacts closely related to changes in energy consumption.

Further details on those external costs which are expected to have a significant impact, but for which quantitative estimates were unavailable, are provided in chapter 5.

4 Scenario analysis

This chapter estimates the costs that would result from the changes in deployment of each measure under the CCC's medium abatement scenario, including reduction in baseline technologies (e.g. fossil fuel-based electricity generation, gas boilers). The analysis is purposely illustrative given the large uncertainty in the results presented in the previous chapter, but aims to demonstrate the scale of the external costs associated with the mitigation scenario.

It has not been possible to provide a quantitative estimate of the external costs across all sectors covered by the CCC's mitigation scenario. Instead, the analysis has focussed on selected sectors where the external costs are known to be significant, and where external cost estimates are readily available: the electricity production, primary fuel production and surface transport sectors. For the other sectors, the analysis has focussed on a smaller number of impacts, such as impacts associated with air quality.

The approach that has been adopted has been tailored for each sector to reflect both the availability and resolution of the measures data and the unit of measurement. For some sectors e.g. electricity production, it has been possible to calculate the scenario impacts at the level of individual measures. For other sectors the impacts are calculated for the scenario as a whole i.e. impacts are aggregated across a range of measures.

4.1 Electricity production

4.1.1 Scenario projection

The analysis has considered two alternative scenarios provided by the CCC for the electricity production sector (Baseline 1 and Baseline 2). In each case, the scenario specifies the relative mix of different power generation technologies to 2030. Baseline 1 assumes that existing renewables targets for 2020 will be met, following which there will be a "dash to gas". Baseline 2 assumes no effort is made to encourage renewable or new nuclear development after 2008 (the start of the carbon budgets), with new demand met by a 50:50 mix of coal and gas plant. The medium abatement scenario assumes a large shift from coal and gas to nuclear and renewable capacity, together with deployment of CCS.

The net impacts of the scenario therefore reflect the difference between the total external costs and benefits of the medium abatement scenario, and the total external costs and benefits of the respective Baseline scenarios.

4.1.2 Valuation of external costs

The impact of the CCC's medium abatement scenario for the power sector has been analysed as follows:

- The change in capacity of each of the power generation technologies in each year was defined with respect to each of the baseline scenarios
- The external cost values for the literature were reviewed, updated in some cases, and then normalised per functional unit (kWh output)
- The cost or benefit for each impact in each year was estimated by multiplying the change in capacity by the external cost per kWh.
- The Net Present Value over the period 2012-2030 was calculated from these figures, using a discount rate of 3.5%. Note that this period differs from the other sectors, which assess NPV over 2008-2030, because the CCC scenario data did not extend back to 2008 for the power sector.

The NPV values were copied into the Scenario Impacts sheet. Where no quantitative estimate was possible, a qualitative judgement of the scale of the impact was made, resulting in a score of + (benefit), ++ (significant benefit), +/- (mixed evidence), - (negative externality) or - - (significant negative externality).

The scenario analysis for Baseline 2 (generation stage) is shown in Figure 15 and that for other life cycle stages in Figure 16.

Damage estimates for nuclear power

The nuclear fuel chain provides some burdens that are extremely challenging for analysis;

- The potential for major accidents that combine large consequence with very low probability
- High level wastes that will remain hazardous for more than 100,000 years
- Lower level wastes such as mine tailings that again may pose risk over very extended timescales
- Risks of nuclear proliferation and use of radioactive substances by terrorist organisations (not addressed at all by the study as there is a lack of estimates of externalities)

Therefore, the damage estimates for nuclear should be treated with great caution as they paint an incomplete picture without additional information. The use of probabilised damage estimates for major nuclear accidents is of most use when dealing with a large number of power plants over a long time. Here, we have a relatively small change in nuclear generation assessed over only an 18 year period. The most likely outcome over this period is that there will be no major nuclear accidents involving release of core materials in the UK, under which circumstances actual damage would be zero.

However, there is some likelihood that an accident could occur, with damage extending to many billions of £. This burden would fall on society as the nuclear industry is not able to access insurance on this scale. Hence for nuclear we quantify a result towards the lower end of a plausible range from £0 to many £billions for major accidents. The problems do not stop there.

Whilst the internal costs for nuclear power generation supplied to the CCC include an amount for high-level radioactive waste management, they do not fully internalise the risk. Wastes will remain hazardous for 100,000 years or more, given the long half-lives of certain radionuclides. Very few attempts have been made to model associated externalities, recognising that any forecast of what future society will be like on these timescales is speculative in the extreme. However, this applies as much to the security of long-term storage as it does to the impact assessment. We therefore consider it reasonable to include some estimate, in part to raise recognition of the persistence of risk.

The use of any positive discount rate over such a period will reduce any but the most immediate effects to a tiny fraction of the total (undiscounted) impact (some of our results indicate a difference of 4 orders of magnitude between discounted and undiscounted estimates). Such results are of course not only influenced by discount rate but also by the scenario selected for evolution of the impact: if nuclear waste repositories remain secure from external access and geologic conditions remain as they are today there may be no problem. Equally, if effective cures for cancer are developed (remembering we are talking about a 100,000 year time profile), there is no problem. However, if people do access highly radioactive materials, damage could be very large indeed. What our analysis shows, therefore, is that whilst there is a good chance that the impacts of nuclear power will be low, this cannot be guaranteed.

For this reason, results are reported for both a 0% and 3% discount rate for nuclear alone, to provide transparency regarding actual impact (through use of the 0% rate). Ideally the analysis using 3% would have been recalculated using the Treasury's approach for long term discounting, though this was beyond the scope of the study. Given the timescales involved, associated differences would have little effect on cross-technology comparisons.

From the perspective of any policy targeted at improving sustainability it is clearly important that these issues are understood, and that if expansion of nuclear power is seen as part of the solution to climate change, actions are taken to mitigate them. From a UK angle, the lesson of Fukushima is less to do with the risks of siting nuclear plant in seismologically active regions, than the fact that engineers and technologists are not always good at forecasting risk.

Completeness of quantification

There are a number of gaps in the quantification, including some that are likely to be significant (e.g. non-UK air pollutant impacts on health). For some effects quantification has been undertaken for some technologies but not for others; a perhaps striking example being the assessment of emissions of heavy metals and other trace pollutants associated only with wind and marine technologies. This simply reflects a difference in data availability: LCA data were readily available for wind technologies for this impact category but not for the others. Inclusion of heavy metal emissions, particularly lead and mercury, seems likely to be dominated by the coal fuel chain, though this is not evident from the results presented. This clearly has an effect on the aggregation of estimates of external costs, discussed elsewhere in this report.

Figure 15: Scenario analysis of the generation stage for electricity production technologies, mitigation scenario compared to baseline 2.

		Nuclear (0%) Note 2	Nuclear (3%) Note 2	Coal without CCS	CCGT without CCS	OCGT without CCS	Coal with CCS	CCGT with CCS	Biomass	Onshore wind	Offshore wind	Marine	Other renewables
	Total output 2012-2030, TWh, Baseline 2	698	698	2653	3045	0.00	0	0	44	86	15	0	0
	Total output 2012-2030, TWh, Medium mitigation	1770	1770	707	1906	0.14	268	142	459	642	920	45	72
	Total output 2012-2030, TWh, Medium - baseline 2	1071	1071	-1946	-1139	0.14	268	142	414	557	904	45	72
Generation stage: Human health	Diet												
	Lifestyle												
	Psycho-Social environment (e.g. stress, crime)												
	Housing Conditions (e.g. cold, damp, indoor air quality)												
	Major accident risk	-113	-56										
	Occupational health	-30	-28	17	6		-2	-1	-2	-75	-117	-5	-1
	Water pollution - health	note 1	note 1	+	+		-	-	-	-	-	-	-
	Air quality	-62	-1	2839	217		-128	-32	-301				
	Air quality: effects outside UK	note 1	note 1	+ +	+ +		- -	- -	- -				
	Hazardous waste generation	-23	0	+	+		-	-					
	Geophysical factors (e.g. uv light, radiation)												
	Noise	-	-	206	+		-28	-	-54	-38			
	Infection	-	-	+	+		-	-	-				
Generation stage: Environment	Hazardous waste generation	- -	- -	+			-	-					
	Solid waste generation (non-hazardous)	-	-	+			-	-	-				
	Air quality	-	-	+ +	+ +		- -	- -	- -				
	Heavy metals and other trace pollutants	-	-	63	+		-9	-	-14				
	Materials damage from air pollution			+	+		-	-	-				
	Landscape												
	Land take												
	Water abstraction			644	175		-88	-23	-143				
	Water pollution	-	-	+	+		-	-	-				
	Bioversity and ecosystems			+	+		-	-	-	-	-		
	Subsidence												
	Soil erosion/fertility												
	Resource use (metals/minerals)	see datasheet		see datasheet	see datasheet	see datasheet	see datasheet	see datasheet	see datasheet				

Notes: See power sector spreadsheet for explanation of notes

Figure 16: Scenario analysis of the other lifecycle stages for electricity production technologies, mitigation scenario compared to baseline2.

		Nuclear (0%) Note 2	Nuclear (3%) Note 2	Coal without CCS	CCGT without CCS	OCGT without CCS	Coal with CCS	CCGT with CCS	Biomass	Onshore wind	Offshore wind	Marine	Other renewables
	Total output 2012-2030, TWh, Baseline 2	698	698	2653	3045	0.00	0	0	44	86	15	0	0
	Total output 2012-2030, TWh, Medium mitigation	1770	1770	707	1906	0.14	268	142	459	642	920	45	72
	Total output 2012-2030, TWh, Medium - baseline 2	1071	1071	-1946	-1139	0.14	268	142	414	557	904	45	72
Other life-cycle stages: Health	Diet												
	Lifestyle				+			-					
	Psycho-Social environment (e.g. stress, crime)				+			-					
	Housing Conditions (e.g. cold, damp, indoor air quality)												
	Major accident risk	-	-	1,287	10		-175	-1					
	Occupational health	-56	-56	193	51		-26	-7	-1	-38	-59	-3	-9
	Road accidents	-	-	+	+		-	-	-	-49	-76	-4	-
	Water pollution	-	-	+	+		-	-	-	-	-	-	-
	Air quality	-178	-178	+	+		-	-	-286	-162	-328	-15	-39
	Hazardous waste generation	-10,154	-3	+	+		-	-	-	-	-	-	-11
	Geophysical factors (e.g. uv light, radon)												
	Noise	-	-	35	+		-5	-	-	-	-	-	-
	Infection												
Other life-cycle stages: Environment	Hazardous waste generation	-	-	+	+		-	-	-	-	-	-	-
	Solid waste generation (non-hazardous)	-	-	+	+		-	-	-	-	-	-	-
	Greenhouse gases	Being assessed elsewhere: outside project scope											
	Air quality	-	-	+	+		-	-	- -	-	-	-	-
	Heavy metals and other trace pollutants	note 1	note 1	+	+		-	-	-	-24	-39	-2	
	Materials damage from air pollution	-	-	+	+		-	-	-	-	-	-	-
	Landscape	-	-	+	+		-	-	+	- -	- -	- -	-
	Land take	-	-	+	+		-	-	-	- -?	- -?	-	
	Water abstraction	-	-	+	+		-	-	+/-	-	-	- -?	-
	Water pollution	note 1	note 1	+	+		-	-	-	-	-	-	-
	Bioversity and ecosystems	-	-	+	+		-	-	-	-	-	- -?	-
	Subsidence	-	-	+	+		-	-					
	Congestion	-	-	+	+		-	-	-	-			
	Soil erosion/fertility	-	-						-	-			
	Resource use (metals/minerals)	-	-	+	+		-	-	-	-	-	-	- -?

Notes: See power sector spreadsheet for explanation of notes

4.1.3 Discussion and interpretation of results

All power generation technologies have some type of negative impact, and so the CCC abatement scenario results in trade-offs between different impacts. There will be a significant decrease in air quality related costs as a result of the switch from coal and gas-fired generation to nuclear and renewables, but this is set against an increase in the risk of nuclear accidents and the impacts of nuclear fuel production and waste disposal, and increased landscape impact from deployment of onshore wind power. Methods of mitigating the negative impacts are discussed in section 4.1.4.

The impacts of carbon capture and storage technology are currently uncertain: some emissions (SO_2) are likely to decrease while others (NO_x, NH_3) could increase: There will also be an increase in upstream impacts associated with increased fuel production to power the carbon capture process, and additional impacts associated with solvent manufacture and waste solvent disposal.

The following sections discuss specific issues related to major accidents, occupational health, air quality, noise and water abstraction.

Major accidents: generation phase

This impact category is only potentially significant for nuclear at the generation phase (another option with significant potential for impact would be large scale hydro as a consequence of catastrophic dam failure, but this is not under consideration here). The estimate for nuclear is derived by multiplying the consequences of a major accident involving release of core material (which are very large) by the estimated probability of an accident (which is very low). Leaving aside uncertainties in quantification of either parameter it is useful to reflect on what the final output represents and hence how informative it is for decision making.

Given the very low probabilities involved, the estimates provided are most useful when dealing with a large number of nuclear power stations operating over a long time. The CCC scenario, however, deals with a small change in the number of power stations operating over only 20 years. Actual potential outcomes with respect to major accidents are as follows:

Table 4.1 Damages associated with major nuclear accidents – probabilised assessment vs actual outcomes

Outcome	Probability	Cost	Timescale
No major accidents over the 20 years of the scenario	Very likely	£0	-
Modelled outcome equivalent to 0.001 accidents in 20 years	*Theoretical outcome only*	*In the order of £100 million*	*Indefinite*
One major accident in the 20 year period	Very low	In the order of £100 billion	Indefinite
More than one major accident in the 20 year period	Very unlikely	>>£100 billion	Indefinite

The modelled outcome (second row of data) is described as being theoretical only, as the number of accidents clearly has to be an integer (0, 1, 2…). The analysis here has taken no account of internalisation of the costs of a nuclear accident, as this appears to be very limited for a major event (currently set at £140 million under the Nuclear Installations Act 1965, though with a proposal for this figure to be increased to €1.2 billion)[12].

[12] World Nuclear Association (2013) Liability for Nuclear Damage. http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Liability-for-Nuclear-Damage/#.UYt2DIJc9UM

It is clear from this discussion that the 'expected' result (i.e. the modelled outcome) only tells part of the story. Decision makers therefore need to be informed about the way that the expected result is generated and the alternative positions that could be adopted.

Occupational health

One of the surprising results from the study is the high estimates for occupational health effects of wind and marine technologies, higher per kWh than coal for example, where the hazards of mining are widely recognised. The externalities estimates for occupational health risks of wind were originally based on studies from the mid to late 1990s. Since then there has been a large expansion in UK wind capacity, both on- and off-shore, providing a more substantive evidence base for the analysis (though admittedly one that is still very limited compared to the amount of data available for, e.g., coal). The updated figures broadly supported the original estimates for onshore wind power, though indicated that results for offshore wind (and other marine technologies) were pessimistic. Results have been updated to reflect the new data.

Air quality effects on health and ecosystems

Results for air pollution effects on human health, crops and materials have been calculated externally, combining results from:

- A separate analysis performed at Imperial College (H. ApSimon, personal communication) in which emissions of regional air pollutants (SO_2, NOx, fine particles) linked to the CCC scenarios were determined, and
- The IGCB (Interdepartmental Group on Costs and Benefits) tool[13] containing UK government approved values for air pollution damages per tonne emission.

So far as primary particle emissions are concerned, the IGCB approach for particulate matter is referenced against PM10 (albeit on the assumption that emission changes are mostly in the PM2.5 size fraction). The approach taken in the current study is, however, to provide quantification referenced against PM10 but also to provide an estimate referenced against PM2.5[14]. This shows that quantification directly against PM2.5 generates substantially lower damage estimates for certain measures e.g. fuel switching for heat provision.

It is however likely that the IGCB approach takes a conservative approach to quantification in other areas, and may underestimate actual air pollution damage for the following reasons:

- The damage/tonne estimates do not account for damage caused by emissions from the UK in other countries (for which reason a separate line has been added to the assessment sheets for these effects).
- The set of functions describing morbidity effects is very limited.
- Effects on ecosystems are not yet factored into the damage costs.

Two projects led by WHO-Europe (REVIHAAP/HRAPIE[15]) are currently reconsidering the health evidence with a view to recommending revised functions for health impact assessment for the European Commission. The project teams involve a large number of experts from Europe (including the UK) and North America. Once those studies are complete in summer 2013 it would be appropriate to reconsider the estimates for air quality impacts across all sectors. This would, however, leave effects on ecosystems outside of the analysis, though research to factor them into the analysis is underway, both for Defra and the European Commission.

---

[13] IGCB (2008) Damage cost calculator. Interdepartmental Group on Costs and Benefits. http://archive.defra.gov.uk/environment/quality/air/airquality/panels/igcb/documents/igcb-damage-cost-calculator.xls.

[14] Values presented in the current report are in most instances referenced against PM10 in accordance with the analysis by Imperial College. However, for comparison, the accompanying spreadsheets also include estimates referenced against PM2.5.

[15] http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/air-quality/activities/evidence-on-health-aspects-of-air-pollution-to-review-eu-policies-the-revihaap-project

Noise effects

One particularly counter-intuitive result is that the estimate used here for the unit (per kWh) damage related to noise is higher for coal than for wind. The noise impacts for coal derive from the rail transport stage. For the former, noise is not regarded as an issue at all, whilst for the latter it generates a great amount of debate. Results are based on real case study information so cannot be dismissed lightly. One possible problem with the results is that valuation of noise is based on analysis linked to house prices. It may be that such results are more applicable to urban settings with higher background noise than rural settings.

It is also possible that sites with wind turbines that have generated noise complaints may not be typical of modern facilities, or may be built using substandard equipment. Many wind turbines seem to add nothing at all appreciable to noise levels (especially given that when they are operating there will be a reasonably high level of background noise from the wind itself). Resolution of this issue would require independent assessors to visit sites where turbine noise is problematic and sites where it is not, to understand why this problem arises – whether it is something that can be avoided or not. This could provide information very relevant to setting planning conditions to ensure that such problems are avoided altogether in the future, as seems possible.

Irrespective of these issues the estimated externalities associated with noise are amongst the lowest of those quantified (though doubtless larger than many of those that have been quantified). In part this reflects the low housing density typical of areas where large industrial facilities and wind turbines are located. The fact that estimates are small may of course obscure distributional issues, where society as a whole experiences a quite insignificant effect, but some individuals are seriously affected.

Water abstraction

Estimates for water abstraction for cooling are based on a single source[16]. The initial view was that associated effects would be insignificant, as the availability of water for cooling would be a factor in an operator's decision to build a plant at a specific location, and would be further considered during the planning process. Results at the scenario level, however, indicate that over the 20 years of the scenario a net benefit of around £150 million would be generated from reduced water consumption through reduced CCGT capacity countered by additional capacity of other fossil technologies. Although further information on forecast water consumption would be useful, this part of the assessment is likely to be reasonably robust, more so than the cost/unit abstraction estimate. Hence whilst it appears reasonably certain that water abstraction would be reduced the precise magnitude of benefits is more uncertain.

No estimate was provided for water abstraction for nuclear facilities as these are almost exclusively sited at the coast, using sea water for cooling.

4.1.4 Policy implications

The power sector is different to the others considered in this study in the sense that the options explored involve replacement of technologies by others with a different impact spectrum. Hence some of the burdens of 'old' coal or gas generation such as air pollutant emissions are in effect replaced by other burdens, such as visual intrusion of wind turbines.

Significant uncertainty is linked to effects of nuclear and wind power. This is not simply the view of the present study's authors: A report for DTI (2006)[17] notes a range for the probability of major accidents (core meltdown plus containment failure) from $2x10^{-6}$ in France, to $4x10^{-9}$ in the UK. On this basis the probability adjusted estimates provided in this study could be

[16] Morris, J. and Camino, M. (2011) UK Naional Ecosystem Assessment Working Paper. Economic assessment of freshwater, wetland and floodplain (FWF) Ecosystem Services. http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=lVLEq%2BxAI%2BQ%3D&tabid=82.

[17] DTI (2006) NUCLEAR POWER GENERATION COST BENEFIT ANALYSIShttp://webarchive.nationalarchives.gov.uk/+/http://www.dti.gov.uk/files/file31938.pdf

taken to be pessimistic, at least for the UK. However, do we take it from this statement that UK nuclear plant are 500 times safer than French ones? Or that the French take an overly pessimistic view? Or that the UK analysis is in some important way restricted? This project is not the place for a full assessment of nuclear risks. However, the example usefully highlights the fact that there are significant differences of opinion between experts working in different places and that confidence in decision making will increase if these issues are seen to be investigated in depth and reasons for differences understood.

With respect to wind the substantial concern over visual impacts of large scale wind developments has been noted. A major problem for assessment concerns a lack of information on the true extent of wind farms. Much information could be gained from a systematic modelling and mapping exercise that provides information on how much land would need to be used for wind farms, where it could be located, the extent to which sensitive landscapes can be avoided and so on. Given the high profile of this issue in the press we note with interest the conclusions of studies by RICS on house values[18] and for the Scottish Government[19]. RICS found little evidence for an effect on house price, whilst the Scottish study indicated that most people were not concerned about wind farms, with many actively in favour of them. The study investigated features of wind farms that influence public opinion, with one finding being that people would prefer a few large wind farms to many smaller or medium sized farms. This would also have benefits in terms of the broader infrastructure (transmission lines) with requirements clearly being more limited if site numbers are reduced.

In addition to some additional negative externalities (as discussed above) of the options considered, there are also some positive externalities that have not been quantified. The most significant of these probably relate to emissions of regional air pollutants. A limited quantification of impacts to the UK population, in line with Defra/IGCB guidance indicates significant benefits. These would be enhanced if the analysis were extended to include other effects on morbidity and effects outside the UK. Further information on these points will be forthcoming later in 2013 when the results of two studies led by WHO-Europe (REVIHAAP and HRAPIE) in the context of the review of the European Commission’s Thematic Strategy on Air Pollution, are published. Air pollution impacts on ecosystems are also an important omission, with exceedance of thresholds for damage noted across Europe, especially for nitrogen deposition linked to emission of NOx.

The existing externalities literature says little about the impacts of carbon capture and storage in form that could be integrated with this study. The assessment of CCS is thus limited to a large extent to effects arising from the change in output efficiency of power plants. We recommend that a systematic appraisal of the externalities of CCS technologies is undertaken following the framework of the ExternE Project. Original appraisal of this type was beyond the scope of the present study.

The main policy implications of this research for the power sector, reflecting these issues are as follows:

1. The potential for negative effects of GHG mitigation policies is real.
2. Uncertainty in assessment needs to be recognised. This issue is discussed in greater depth in other outputs of the study for each impact.
3. Whilst negative effects could be substantial, their identification is a first step to mitigation. For selected impacts, some further discussion on the potential for mitigation is provided below.
4. In the event that negative effects can be effectively controlled there could be significant net co-benefits of the climate actions for the power sector

[18] RICS (2012) How nearby wind farms affect your health and the price of your property. Royal Institute of Chartered Surveyors. http://www.rics.org/uk/knowledge/more-services/guides-advice/wind-farms/

[19] Scottish Natural Heritage (2012) Assessing the cumulative impact of onshore wind energy development. http://www.snh.gov.uk/docs/A675503.pdf
Scottish Natural Heritage (2002-2012) Various reports on landscape effects of wind farms. http://www.snh.gov.uk/planning-and-development/renewable-energy/onshore-wind/landscape-impacts-guidance/

Mitigation of nuclear accident risks

For nuclear power, major accident risks may be expected to increase under the CCC scenario as it meets a growing share of electricity demand. Given the consequences of major accidents, there is a clear imperative to ensure the highest standards are in place. Fortunately, the technology, knowledge and management systems for avoiding accidents or reducing associated impacts are proven. Most nuclear power stations, including those of the same design as the Chernobyl plant, have not gone to meltdown with significant release of radionuclides. However, there are examples of inappropriate actions taken by owners, operators and designers that have led to major accidents. The Fukushima Disaster in Japan is on the one hand a result of an unusually severe natural event, but on the other hand not one that may be considered off the probability scale in Japan. More effective mitigation may involve:

- Firmer regulatory action, preventing continued operation where safety violations have been identified
- Independent review and challenge to the safety systems and scenarios developed by operators of nuclear facilities that pose substantial hazards to avoid habituation to risk
- Learning from experience of cases where major accidents (or near-misses) have occurred, putting aside the ‘it couldn’t happen here’ mentality
- Investment in fourth generation nuclear power plant with advanced passive safety features, though it is uncertain whether this could be deployed on the timescale required and with reasonable costs.

Mitigation of the visual impacts of wind turbines

The planning system should operate in such a way as to protect communities and society against unwarranted levels of development or intrusion. It will be particularly important for large scale development of wind power with respect to impacts on landscape and of noise. With respect to noise it appears that wind turbines can operate at very low levels, insufficient to be evident to most listeners given other noise related to wind, when the wind is strong enough to turn the blades of the turbine. However, this has not prevented problems arising at some sites. It is clearly appropriate to ask why this should be, whether it is a function of local geography, poor quality construction or some other factor. Where agreed specifications are not met, planning authorities should take appropriate action to ensure full remedial action is taken. The power of isolated and unusual cases to undermine public perception of new technologies is not to be underestimated.

Visual intrusion by onshore wind farms and associated infrastructure is a major concern for renewable energy policies. However, in Cornwall there is extensive windfarm development that is not excessively intrusive. The size of the turbines deployed in Cornwall, however, is small compared to many modern designs, with the result that turbines are not visible over long ranges in the rolling Cornish countryside. It may be asked how large these turbines could be and how widely they would need to be deployed in the area before they are perceived as a blot on the landscape. It is notable that wind turbines in a number of places (e.g. Whitelee Wind Farm outside Glasgow and Scroby Sands in Great Yarmouth[20]) attract significant numbers of tourists, indicating that they are not automatically regarded as unattractive by a large portion of the population. A study for the Scottish Government came to the following conclusion:

“this research set out to establish if meeting targets on renewables would significantly impact on the possibility of meeting tourism targets. Our overall conclusion is that the effects are so small that, provided planning and marketing are carried out effectively, there is no reason why the two are incompatible[21]”

[20] Whitelee Wind Farm: http://www.whiteleewindfarm.com/. Scroby Sands Visitor Centre: http://www.eon-uk.com/generation/scrobysands.aspx.
[21] The Economic Impacts of Wind Farms on Scottish Tourism. http://www.scotland.gov.uk/Publications/2008/03/07113554/0.

The study provides useful methodological information on understanding attitudes to wind farms. The use of computer simulations of the appearance of wind farms in real landscapes greatly aids understanding. Information on how much land would be used, and the area over which such farms would be visible is also important to properly assess public response. This cannot be gauged from a series of isolated studies for individual windfarms as people need to understand the bigger picture: they may like or be ambivalent to the sight of a wind farm, but equally may not want to see them everywhere. A key conclusion regarding mitigation of the impact of windfarms on landscapes is that a few large wind farms would be preferable to a large number of small or medium sized farms.

Further to this, experience from Denmark suggests that community involvement in renewable energy schemes has a strong effect on acceptability.

4.2 Primary fuel production

4.2.1 Scenario projection

Under the CCC's medium abatement scenario, the consumption of primary fuels will change in the following ways:

- Decrease in consumption of coal, oil and gas
- Increase in consumption of bioenergy

The changes in consumption of these fuels in each year can be multiplied by the external cost values described above in order to estimate the net external costs and benefits associated with the mitigation scenario.

4.2.2 Valuation of external costs

The impacts have been quantified as follows.

- The net change in the consumption of each of the fuels has been derived from the CCC's medium abatement scenario, for the industry, heat, residential and non-residential building sectors (fuel consumption in the transport and power production sectors were assessed separately).
- The change in total fuel consumption in each year was multiplied by the external cost values derived for each respective fuel, assuming the values were representative of the fuel and supply chains within the CCC's scenario
- The Net Present Value over the period 2008-2030 was calculated from these figures, using a discount rate of 3.5%.

The impacts that were quantified were mainly derived by updating figures from the ExternE project. The values used are shown in Figure 17. It should be noted that the ExternE figures are applicable to average production methods in the UK and elsewhere in Europe at the time of the research. As a large proportion of fuel used in the UK is imported, often from countries with lower environmental standards or more damaging production methods, the actual impacts may be greater than shown. This also implies that a proportion of the impacts will occur overseas, although impacts such as air quality and biodiversity loss can have global significance.

The external cost estimates exclude damages associated with climate change. These impacts are potentially significant but outside of the scope of the current study.

Figure 17: Damage cost values used in the assessment of upstream fuel production impacts

Upstream oil effects	Damage, £/tonne oil
Air pollution	-5.55
Occupational health	-1.46
Hazardous waste	-0.47

Major accident risk	-0.08

Upstream natural gas	Damage, £/1000m3 gas
Major accidents	-0.08
Occupational health	-0.37

Upstream coal effects	Damage, £/tonne of coal
Major accident risk	-2.30
Occupational health	-0.34
Noise	-0.08

Other impacts were identified but not quantified due to lack of data. These include landscape, land take, water pollution, water abstraction, waste disposal and biodiversity impacts. For open cast coal mining, for example, we could not quantify the landscape, land take and associated biodiversity impacts. For deep coal mining, we could not quantify the effects of subsidence and the effects of acidic mine drainage on water pollution, with associated biodiversity loss. For oil production, there is considerable uncertainty over the impacts of oil spills, and biodiversity impacts may well be underestimated (see sections 5.1.2 and 5.1.4 for further discussion). For gas production and transport, the impact of fugitive methane emissions on air quality was omitted: methane is now known to be a significant source of health impacts and crop losses via its role as a precursor to ground-level ozone formation[22]. Impacts associated with climate change have also been excluded, as they are outside of the scope of the current study.

The quantified estimates presented in the tables below are therefore incomplete, and the totals should be taken only as an illustrative estimate of the scale of the impacts. As all the omitted fuel production impacts are negative, the tables will underestimate the benefits of reduced fuel use.

The table also includes a commentary on the cost elements that are likely to arise in the UK and outside of the UK

Table 2: Present value of quantified external benefits from changes in fuel consumption, by fuel type

<table>
<tr><th>Fuel</th><th>Total NPV, £M</th><th>Arising inside the UK</th><th>Arising outside of the UK</th></tr>
<tr><td rowspan="2">Oil</td><td rowspan="2">379</td><td>Impacts from reduction in air quality emissions from refineries</td><td></td></tr>
<tr><td colspan="2">Major accidents and oil spills may arise both at UK and non UK facilities</td></tr>
<tr><td>Gas</td><td>113</td><td colspan="2">Major accidents at gas production facilities may arise both at UK and non UK facilities</td></tr>
<tr><td>Coal</td><td>45</td><td></td><td>Large proportion of coal is imported so majority of accident and occupational impacts likely to be overseas.</td></tr>
<tr><td>Bioenergy</td><td>Not estimated</td><td></td><td></td></tr>
<tr><td>TOTAL</td><td>537</td><td></td><td></td></tr>
</table>

[22] One study estimated that cutting global methane emissions by 20% would prevent around 30,000 premature deaths from ozone pollution annually by 2030. West, Jason, Arlene Fiore, Larry Horowitz and Denise Mauzerall (2006) 'Global health benefits of mitigating ozone pollution with methane emission controls'. *Proceedings of the National Academy of Sciences* 103(11):3988-3993

4.2.3 Discussion and interpretation of results

There are significant net benefits associated with the changes in fuel consumption that will arise from the CCC's mitigation scenario, based on the external cost values identified in the literature. In total, the benefits that have been quantified amount to around £540 million from 2005 to 2030, with an annual cost in 2030 of £60 million. However, because not all impacts have been quantified (see previous section), this provides only a minimum estimate.

A large proportion of these benefits are associated with efficiency savings, reducing fuel consumption (although much of this is likely to occur outside the UK) and increasing use of low-carbon electricity. However, other benefits will arise from fuel switching to bioenergy. These latter impacts are less certain as it has not been possible to quantify and value the impacts associated with the production of bioenergy. Therefore, any external costs or benefits associated with bioenergy production are not included in the analysis. The assumption has been made, in accordance with the CCC's Bioenergy review, that biomass will be sourced from sustainable sources. This assumption will help to mitigate the external costs associated with bioenergy consumption in the UK. However, the definition of sustainability is key and important health and environmental impacts may still be associated with bioenergy sources.

Bioenergy impacts are highly dependent on the source of biomass. Biofuels derived from waste material tend to have beneficial impacts, through reducing the impacts of waste disposal such as methane emissions, odour, litter, vermin, visual impact and land take (for landfill sites) or air quality (for incinerators). Biofuels derived from energy crops will have large land take impacts, but the impacts on landscape, soil quality, water quality, water scarcity and biodiversity can be either positive or negative depending on the type of crop planted, the former use of the land, the need for irrigation, the use of agro-chemicals and individual opinions on landscape.

While research is underway to better understand the environmental impacts of bioenergy, the extension of this work to consider the economic value of these impacts, as well as any health externalities would be a valuable addition. It would also allow a more like for like comparison of the full costs and benefits of different fuels, as well as helping ensure that bioenergy support policies take into account the full social costs and benefits.

4.2.4 Policy implications

The environmental and health impacts of fuel production are generally well known for conventional sources. However, as the fuel mix diversifies to consider unconventional sources (e.g. shale gas) and the further exploitation of bio resources, then the relative environmental and health impacts will be more uncertain. As unconventional sources such as shale gas, tar sands or oil from sensitive regions such as the Arctic tend to have greater environmental impacts, the benefits of energy-saving measures could increase. The regulatory regime can adapt to help to partly mitigate any negative impacts (and promote any positive impacts), but it may require a more flexible approach underpinned by additional research into the different fuel sources.

For bioenergy, as noted above, the impacts depend on the source of the biomass. Benefits can be maximised by encouraging conversion of waste to bioenergy where possible, provided that this does not take priority over waste avoidance. For bioenergy crops, benefits can generally maximised and negative impacts minimised by avoiding conversion of land of high biodiversity or landscape value, and by choosing crop types and cultivation methods that minimise the need for irrigation (in water-scarce areas) or agrochemical input, and provide habitat and food sources for native species.

4.3 Surface transport

4.3.1 Scenario projection

The CCC's medium abatement scenario includes the following measures:

- Increased penetration of electric vehicles, plug-in hybrids and hydrogen fuel cell buses
- Uptake of biofuels
- Increased efficiency of new vehicles
- 'Smarter choices' – this comprises three sub-measures which have been assessed separately: walking and cycling instead of driving; demand reduction through avoiding trips; and a shift from car use to public transport. Together these are envisaged to reduce car vehicle kilometres by 5%. We assumed that this reduction was split equally between the three different sub-measures (see next section).
- A reduction in HGV vehicle kilometres due to improved logistics
- Eco-driving and strict enforcement of the 70mph speed limit on motorways.

4.3.2 Valuation of external costs

The impact of the CCC medium abatement scenario for the transport sector has been analysed as follows:

- For each measure, the impact per vehicle kilometre travelled (in £2012) was estimated quantitatively where possible, using data from existing studies
- For each measure, the difference in the vehicle kilometres travelled or avoided in the CCC's medium abatement scenario compared to the baseline scenario was calculated for each year from 2008 to 2030, from data provided by the CCC. (For this sector, the contribution of each measure in the baseline scenario is assumed to be effectively zero).
- The impact in each year was estimated by multiplying the impact per vehicle kilometre by the change in vehicle kilometres.
- The Net Present Value over the period 2008-2030 was calculated from these figures, using a discount rate of 3.5%.

The NPV values were copied into the Scenario Impacts sheet. Where no quantitative estimate was possible, a qualitative judgement of the scale of the impact was made, resulting in a score of + (benefit), ++ (significant benefit), +/- (mixed evidence), - (negative externality) or - - (significant negative externality).

Estimates of the impacts of active travel were based on a study by Woodcock et al[23] which estimated the health, air quality and accident impacts of a 27% reduction in car kilometres as a result of increased walking and cycling. Woodcock et al chose to model the maximum feasible reduction, based on the rates of walking and cycling already achieved in Copenhagen, Amsterdam and some other European cities. This equates to an average distance of 3.4 km / day cycled and 1.6 km/ day walked for young men aged 15-29, with smaller distances for most other population groups. The reduction assumed in the CCC scenario is far smaller than this – a 1.7% shift from car to active travel, only 6% of the reduction modelled by Woodcock et al – and therefore should be easily achievable in theory, though behavioural change is always challenging. However, it should be noted that we have used the data from Woodcock et al (impacts per million population) for the whole UK, whereas the study applied to London. It could be more challenging to achieve the same level of travel reduction in rural areas, where typical journey distances could be longer. This is an area where further refinement of the estimates would be useful.

[23] Woodcock et al (2009) 'Public health benefits of strategies to reduce greenhouse gas emissions: urban land transport.' Lancet 374:1930-43

Travel by public transport usually involves additional walking or cycling compared to car use.[24] We assumed that the additional distance walked or cycled was 10% of that in the active travel scenario.

For other health and environmental impacts, the main data source was a study by CE Delft, which provided data on average costs per km travelled.[25] For congestion and road accidents, however, we used UK-specific figures from the Department for Transport, for the marginal cost of accidents and congestion per vehicle km travelled.[26] The two datasets are not strictly comparable, as one provides average costs and one provides marginal costs. The DfT marginal congestion costs are considerably higher than the average congestion costs in the CE Delft study for Europe. It is not clear how much of this difference is attributable to different traffic conditions in the UK, and how much might be due to the different basis of assessment (average vs marginal). It could be useful to address this in future studies, given the size of the congestion benefits (see next section).

The scenario analysis for the use (driving) phase is shown in Figure 18 and that for other life cycle stages in Figure 19.

[24] Around 90% of all public transport trips are connected with a walk trip in the US and 70% in Germany (Pucher and Buehler, (2010) 'Walking and Cycling for Healthy Cities'. Built Environment 36, 391–414

[25] CE Delft (2011) External costs of transport in Europe http://ecocalc-test.ecotransit.org/CE_Delft_4215_External_Costs_of_Transport_in_Europe_def.pdf

[26] The exception being the estimates of the accident impacts of walking and cycling, which we based on the Woodcock et al study

Figure 18: Scenario analysis of the driving phase for surface transport measures

							Smarter choices					
	Click on abatement options to move to worksheets containing full details	Electric cars and vans	Plug in hybrid cars and vans	Hydrogen buses	Biofuels	Improved vehicle efficiency	Walking/cycling	Demand reduction	Public transport	HGV logistics savings	Eco driving all vehicles	Speed limiting cars and vans
	Total vehicle km 2012-2030, baseline (billi	0	0	0								
	Total vehicle km 2012-2030, mitigation (bi	307	551	1			-118	-118	-112	-12		
	Difference (billion vkm)	307	551	1			-118	-118	-112	-12		
Driving: Health	Diet											
	Lifestyle						23,728	+?	2,373			
	Psycho-Social environment (e.g. stress, crime)						+		+/-		?	?
	Housing Conditions (e.g. cold, damp, indoor air quality)											
	Major accident risk											
	Occupational health											
	Road accidents						-1,591	1,620	1,373	129	+	++
	Water pollution											
	Air quality	124	+	13		+	136	136	38	31	+	+
	Air quality - outside UK	+	+	+		+	+ +	+ +	+	+	+	+
	Hazardous waste											
	Noise	341	+	+		+	209	209	66	123	+	+
	Infection								-			
	Geophysical factors (UV, radon)											
Driving: Environment	Hazardous waste generation											
	Solid waste generation (non-hazardous)											
	Greenhouse gases	Being assessed elsewhere: outside project scope										
	Regional air pollutants (NH_3, NO_X, PM, SO_2, VOCs)	+	+	+		+	+	+	+	0	+	+
	Heavy metals and other trace pollutants	79	+	+		+	34	34	-41	38	+	+
	Materials damage from air pollution	+	+	+		+	+	+	+	+	+	+
	Landscape											
	Land take											
	Water abstraction											
	Water pollution											
	Bioversity and ecosystems						68	68	41	33		+
	Subsidence											
	Congestion						14,643	14,643	12,734	6,431	+	+
	Soil erosion/fertility											
	Resource use (metals/minerals)											

Figure 19: Scenario analysis of the other lifecycle stages for surface transport measures

							Smarter choices					
	Click on abatement options to move to worksheets containing full details	Electric cars and vans	Plug in hybrid cars and vans	Hydrogen buses	Biofuels	Improved vehicle efficiency	Walking/cycling	Demand reduction	Public transport	HGV logistics savings	Eco driving all vehicles	Speed limiting cars and vans
	Total vehicle km 2012-2030, baseline (billi	0	0	0								
	Total vehicle km 2012-2030, mitigation (bi	307	551	1			-118	-118	-112	-12		
	Difference (billion vkm)	307	551	1			-118	-118	-112	-12		
Other life-cycle stages: Health	Diet											
	Lifestyle											
	Psycho-Social environment (e.g. stress, crime)											
	Housing Conditions (e.g. cold, damp, indoor air quality)											
	Major accident risk	+/-	+/-	+/-	+	+ +	0.3	0.3	+	+	0.1	+
	Occupational health	+/-	+/-	+/-	+/-	+ +	6	6	+	+	2	+
	Road accidents											
	Water pollution											
	Air quality	+/-	+/-	+/-	+	+ +	22	22	+	+	6	+
	Hazardous waste											
	Noise											
	Infection											
	Geophysical factors (UV, radon)											
Other life-cycle stages: Environment	Hazardous waste generation	+/-	+/-				1.9	1.9	+		0.5	
	Solid waste generation (non-hazardous)	-	-									
	Greenhouse gases	Being assessed elsewhere: outside project scope										
	Regional air pollutants (NH_3, NO_X, PM, SO_2, VOCs)	+/-	+/-	+/-	+/-	+ +	+	+	+	+	+	+
	Heavy metals and other trace pollutants	+/-	+/-	+/-	+/-	+ +	+	+	+	+	+	+
	Materials damage from air pollution	+/-	+/-	+/-	+/-	+ +	+	+	+	+	+	+
	Landscape	+/-	+/-	+/-	+/-		+	+	+	+		
	Land take	+/-	+/-	+/-	+/-		+	+	+	+		
	Water abstraction	-	-		-							
	Water pollution	+/-	+/-	+/-	+/-	+ +	+	+	+	+	+	+
	Bioversity and ecosystems	+/-	+/-	+/-	+/-	+ +	+	+	+	+	+	+
	Subsidence	-										
	Congestion											
	Soil erosion/fertility				+/-							
	Resource use (metals/minerals)	-	-				+	+	+	+		

4.3.3 Discussion and interpretation of results

From these tables, the largest quantifiable impacts are immediately apparent. The health benefits of walking and cycling instead of driving are estimated as £2.3 billion in 2030, with a net present value of around £24 billion from 2008 to 2030. The congestion benefits of all three active travel options plus improved HGV logistics are estimated as £4.5 billion in 2030, with a net present value of £48 billion from 2008 to 2030.

It may come as a surprise that these impacts are far greater than the estimates of air quality benefits. The large health benefit from increased walking and cycling reflects the significant health impact of sedentary lifestyles in the UK. Two-thirds of attributable deaths in high income countries are due to unhealthy diet and lack of exercise, and heart disease and strokes are the leading cause of death for people over 45.[27] In the UK, obesity levels rose by 38% from 2003 to 2007.[28] The economic costs are considerable – both in direct healthcare and in lost working days. One study estimates that physical inactivity cost the UK National Health Service almost £11 billion per year.[29]

The large benefits from reduced congestion arise simply from avoided car journeys, and reflect the high marginal cost of congestion provided by the DfT (see previous section), which is based on the economic value of time lost due to traffic delays. Obviously the impacts of congestion are highly dependent on the time and place of the avoided journey. Benefits will be larger for travel at peak times and in busy areas, but lower for off-peak travel on quiet roads.

It is interesting to look at the road accident impacts. Demand reduction and a shift to public transport each achieve benefits worth over £1 billion, but for active travel there is a significant increase in accident costs because walkers and cyclists are more vulnerable to road accidents. Although these accident costs are far outweighed by the health benefits of increased exercise, they are still a highly undesirable trade-off and efforts should be made to mitigate this (see below).

Air quality and noise benefits are assessed qualitatively as being significant, and some values have been provided based on parallel work carried out by Defra and Imperial College. Imperial College estimate the air quality benefits of five measures (electric cars and vans, hydrogen buses, smarter choices and HGV logistics) as £105 million in 2030, with a net present value of £600 million from 2010 to 2030. Further air quality benefits could arise from more efficient vehicles, speed limiting and eco-driving.

We estimate that noise reduction from smarter choices gives benefits of £84 million in 2030, with a net present value of over £600 million from 2008 to 2030. Based on work by Defra, noise reduction from the use of electric vehicles is worth between £26 and £75 million (2002 prices) in 2030, equivalent to a net present value of £341 million. Further noise benefits (not quantified) will arise from the use of plug-in hybrid vehicles and hydrogen buses, and from speed limiting and eco-driving.

There is an extensive range of upstream benefits related to avoided extraction and refining of oil. Most of these benefits are very hard to quantify, though some data are available from the ExternE project (see previous section). In many cases the data are in the form of £ per tonne of oil extracted, and further data and analysis would be required to translate this into £ per vehicle kilometre. Assessment of this type of impact would merit further work.

4.3.4 Policy implications

As the health benefits of walking and cycling are so great, this is a clear area for policy intervention. The negative accident impacts of walking and cycling are therefore a critical

---

[27] World Health Organisation (2009) *Global Health Risks: Mortality and burden of disease attributable to selected major risks*. Geneva: World Health Organization. Online at www.who.int/evidence/bod

[28] Sustainable Development Commission (2009) *Setting the Table: Advice to Government on priority elements of sustainable diets*. London: Sustainable Development Commission. Online at http://www.sd-commission.org.uk/publications.php?id=1033

[29] Sustainable Development Commission (2007) *Healthy Futures 5: Sustainable transport and active travel.* London: Sustainable Development Commission.

area for policy-makers. However, there is significant potential for the accident impacts to be reduced by investment in safer walking and cycling infrastructure, traffic calming and other measures such as driver training. A number of studies have highlighted successful measures to improve safety, and there are many examples of towns and cities that have managed to increase cycling and walking rates at the same time as reducing accidents.[30]

The significant co-benefit of avoided congestion costs should provide a further impetus for policy-makers to focus on promoting smarter transport choices, and should justify higher levels of investment in these options. These benefits can be maximised by focusing support measures (such as construction of safe cycle paths) in highly congested areas. It is likely that this would also maximise the opportunity to reduce accident risks.

It is also worth noting that the benefits of a shift to public transport are offset in part by additional noise and pollution impact from trains and buses. The spreadsheet highlights the options for reducing these trade-offs by investing in cleaner, quieter and more efficient public transport vehicles.

Finally, speed limit enforcement may have a significant co-benefit in reducing road accidents, reducing noise levels and improving air quality (CE Delft, 2010)[31]. Furthermore, where congestion impedes traffic flow, speed management can smooth the flow of traffic, reducing congestion[32]. This can result in benefits including reduced journey times, improved vehicle efficiency and increased carrying capacity of infrastructure. However there are also important rebound effects from reducing congestion, including increasing the attractiveness, and hence volume, of travel.

4.4 Aviation and shipping

4.4.1 Scenario projection

The CCC Medium Abatement scenario assumes that a reduction in GHGs is achieved that is consistent with DfT forecasts for returning aviation emissions to 2005 levels by 2050. This is assumed to be achieved by a mix of measures including:

- Demand reduction through a combination of setting a carbon price, avoiding travel through video conferencing, modal shift to high speed rail and limiting air travel capacity;
- Improvements to air traffic management and operations;
- Improved engine & airframe efficiency;
- Switch to biofuels.

For shipping, the scenario assumes implementation of the Energy Efficiency Design Index (EEDI). The EEDI was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships, under amendments to MARPOL Annex VI adopted in 2011. These amendments entered into force on 1 January 2013.

For this study, we assessed only the impact of speed reduction of ships. Power consumption is proportional to the cube of speed, so by operating at lower speeds, ships significantly reduce their power requirement and hence their fuel consumption. For example, one study showed that reducing speed from 15 knots to 10 knots cut fuel consumption by a factor of

[30] Pucher, John, Jennifer Dill and Susan Handy (2009) 'Infrastructure, programs, and policies to increase bicycling: An international review', *Preventive Medicine* 50:S106–S125. Online at http://policy.rutgers.edu/faculty/pucher/Pucher_Dill_Handy10.pdf

[31] Pilot study on the climate gains of motorway speed reduction. CE Delft, 2010

[32] This outcome is not applicable in all circumstances, and is also affected by local circumstances. For instance, introducing 80-kilometre zones in the Dutch agglomeration Randstad induced an increase in congestion in some places and a decrease in others (CE Delft, 2010)

five.[33] This measure is considered to be one of the most cost-effective measures for ships to employ in order to meet the EEDI.

4.4.2 Valuation of external costs

There were insufficient data to provide quantitative estimates of the external costs associated with the abatement measures for these sectors. Previous studies (such as Miola et al[34]) have identified the external costs associated with current shipping activities, where air quality impacts dominate the cost estimates. However, evidence on the external costs specific to the mitigation measures considered in the study is more limited.

A qualitative assessment has been carried out to indicate the approximate significance of the co-benefits or trade-offs for the CCC Medium Abatement scenario. This analysis is provided in the accompanying spreadsheet. A discussion on the key results is provided below.

4.4.3 Discussion and interpretation of results

Substantial co-benefits arise from the air quality impacts of avoided fuel combustion. The benefits are large for shipping because of the high sulphur content of marine fuels. Significant benefits could also arise around UK airports, especially at Heathrow where air quality limits for NOx are regularly exceeded.

Reduced aircraft movements could also have significant noise reduction co-benefits. If there was a sufficient reduction in flights, the need for expansion of UK airport capacity would be avoided, which would have significant benefits in terms of land take, landscape and potentially biodiversity depending on the site.

Benefits of slow steaming could include reduced collisions with marine mammals. Ship collisions are the main cause of mortality for the last few hundred North Atlantic right whales, for example, but the risk of a collision proving fatal is greatly reduced at slower speeds. There could also be benefits from reduced noise, which has damaging impacts for marine life. Slow steaming greatly reduces fuel consumption and associated polluting emissions as well as providing significant economic benefits from reduced fuel costs.

4.4.4 Policy implications

Operational measures to limit flights and flying time, including capacity constraints, were considered to have the greatest potential impact, with benefits for air quality, noise and potential benefits from avoided airport expansion. Behavioural change such as avoided flights through videoconferencing or through voluntary reductions in leisure travel can also achieve these impacts, though previous work (Holland et al) indicates that these measures could have limited uptake in the UK, compared to enforced capacity reductions. If flights are avoided through switching to rail then the impacts of rail travel will offset the benefits to some extent.

Technical improvements were thought to offer fewer benefits, partly because UK aircraft are already close to the best available efficiency, and partly because environmental gains for this option are partly offset by increased impacts associated with scrapping older aircraft and replacing them with new ones. This will create waste (old aircraft) and emissions (from the manufacturing process), and use extra resources, with associated impacts from mining and processing of metals. These impacts could be mitigated by recycling old aircraft parts and materials, and ensuring that the manufacturing process is as clean and efficient as possible.

Switching to biofuels offers fewer benefits, with air quality impacts being fairly similar to those from conventional fuels (except for reduced heavy metal emissions), and with no reduction in

[33] Klanac et al 2010 Economic and environmental impact of ship speed reduction for AFRAMax http://www.academia.edu/349884/ECONOMICS_AND_ENVIRONMENTAL_IMPACT_OF_SHIP_SPEED_REDUCTION_FOR_AFRAMax_TANKERS tankers, Proceedings of XIX SORTA Conference 2010,

[34] A. Miola, V. Paccagnan, I., Mannino, A. Massarutto, A. Perujo, M. Turvani (2009) External costs of Transportation Case study: maritime transport. European Commission. Joint Research Centre. Institute for Environment and Sustainability

noise or land take. Impacts from biofuel cultivation must also be offset against the benefits. Although biofuels can also offer benefits in some circumstances, e.g. when derived from waste or from energy crops planted on degraded land (see section 4.2 above), this may be less applicable in the aviation sector. The finding that the greatest potential benefits for greenhouse gas reductions and air quality, noise and land take derive from capacity reductions has an important policy implication in the light of recently renewed calls for airport expansion, which would obviously increase capacity.

In relation to shipping, measures sure as slow steaming are also associated with significant co-benefits both from a private perspective (where financial savings from fuel efficiency are delivered) but also from a social perspective in relation to the reduced air quality and other environmental imapcts.

4.5 Industry, buildings and heat

4.5.1 Scenario projection

For industry, the CCC Medium Abatement scenario includes:

- Process improvements across a range of industry sectors, including efficiency improvements to motors and other appliances, increased recycling of steel in electric arc furnaces, and improvements to refinery processes.
- CCS (carbon capture and storage) applied to industrial processes.
- A switch from cement and steel to wood for construction.

For residential buildings the scenario includes:

- Fabric improvements: loft insulation, cavity wall insulation, solid wall insulation, paper-type solid wall insulation, floor insulation, pipework insulation and glazing improvements (single glazing to double glazing, and old to new double glazing).
- Measures to improve air tightness, including draft exclusion around windows and doors, as well as measures designed to move homes towards passive house status.
- Installation of thermostatic heating controls.
- Installation of more efficient wet appliances (fridges, freezers).
- More efficient electronic appliances.
- Behavioural measures: turning down the thermostat, turning off unnecessary lights, washing clothes at lower temperatures.

For non-residential buildings the scenario includes:

- Heat efficiency measures: most efficient boiler, more efficient air conditioning, insulation and glazing.
- Heat management: programmable thermostats, reducing room temperature.
- Light and appliance management: sunrise-sunset timers, light detectors, computer management.
- Lights and appliances: more efficient lights, fridges, freezers, monitors.
- Process efficiency: compressed air, variable speed drives.

For heat generation in buildings and industry, the scenario includes:

- Installation of ground source and air source heat pumps.
- Solar thermal heating.
- Biomass boilers or for district heating.
- Biogas use in heating.

4.5.2 Valuation of external costs

For industry, process improvements for all the different sectors are broadly similar in that they are energy-saving measures. We therefore combined the process improvements for different sectors into a single generic "process improvement" measure. We analysed two further options separately: CCS, and a switch from cement to wood.

For buildings, we combined the different measures into groups as shown in the previous section, e.g. grouping all the fabric improvements together, all the behavioural measures together, etc. We also split the biomass option into biomass from waste and biomass from energy crops.

For all these sectors, we were able to quantify the amount of primary fuel saved for the whole scenario (though not split by individual measure), and the upstream benefits arising from these fuel savings, which were discussed in section 4.2. The economic value external benefits from changes in fuel consumption, by sector, is shown in Table 3 below.

Table 3: Present value of quantified external benefits from changes in fuel consumption, by sector

Sector	Total NPV, £M
Heat	297
Industry	45
Residential	81
Non-residential	46
TOTAL	469

For other impacts there were insufficient data to provide quantitative estimates of co-benefits. A qualitative assessment has been carried out to indicate the approximate significance of the co-benefits for the CCC Medium Abatement scenario. These results are provided in the accompanying spreadsheet, with some discussion on the results below.

4.5.3 Discussion and interpretation of results

The main co-benefits in these sectors are related to avoided use of fuels and electricity, through energy efficiency measures. The most significant co-benefits are related to air quality improvements from avoided fuel combustion. There is also a wide range of co-benefits associated with the avoided upstream impacts of fuel and electricity production, as mentioned in sections 4.1 and 4.2. These avoided impacts include the risk of major accidents (oil and gas rig blow-outs, nuclear accidents, coal mine accidents), water pollution (e.g. from coal mine drainage or oil spills), air pollution from gas flaring or oil refineries, and landscape impacts of coal mining or wind turbines.

However, some other important impacts arise. Energy efficiency in buildings can potentially improve living conditions and reduce fuel poverty, with significant benefits for health and well-being, as well as associated savings in healthcare costs. Benefits of improved insulation and draughtproofing include reduced exposure to cold, damp, mould and draughts, reduced noise levels and reduced exposure to outdoor pollution. Set against this, there is a potential risk of increased exposure to radon in certain areas of the country where natural radon levels are high, which means that additional ventilation may be necessary. We have not quantified these impacts but this is an important area for further study. Some data is available from the study by Wilkinson et al in 2009[35] which could be used as a basis for analysis.

In the industry sector, the CCC medium abatement scenario relies mainly on energy-saving measures. However, many efficiency improvements may also result in other benefits. More efficient motors, for example, can generate less noise, heat and vibration, and require less maintenance, leading to improvements in working conditions that can result in productivity improvements, as well as cost savings. Measures that include recycling, such as increased

[35] Wilkinson, Paul, Kirk Smith, Michael Davies et al (2009) 'Public health benefits of strategies to reduce greenhouse-gas emissions: household energy'. *The Lancet* 374(9705):1917-1929.

use of recycled steel or glass, have additional benefits for resource security as well as avoided impacts of raw material extraction. The specific nature of the measures in the CCC's scenario were not defined, so it was not possible to explore these impacts in more detail.

Going beyond the CCC medium scenario, recent studies[36] highlight the need for material efficiency as well as energy efficiency in order to achieve carbon reduction targets. An ambitious move towards a zero-waste economy and closed-loop manufacturing could result in far greater economic and environmental co-benefits from avoided resource extraction, avoided waste disposal costs, avoided energy and water costs, avoided effluent generation and productivity improvements.

Measures requiring a switch to more efficient appliances could deliver wider resource efficiency improvements beyond climate mitigation. However, it may also result in additional impacts from increased resource use and disposal of old appliances. This can be mitigated by discouraging premature replacement and maximising recycling of old appliances.

Behaviour change such as switching off unused lights is a cheap, instantaneous, simple and effective measure that achieves all the upstream benefits of avoided fuel use without generating any adverse impacts.

For measures involving a switch to bioenergy, the benefits of avoided fossil fuel use must be offset against the impacts of bioenergy production, as discussed in section 4.2. The relative impacts of biofuel combustion and fossil fuel combustion must also be considered. Data on bioenergy combustion emissions are relatively poor, and emissions depend strongly on the type of combustion device. Biomass produces no more particle emissions than coal or oil, when burnt in the same boiler, and produces lower emissions of heavy metals, but it does produce more particle emissions than natural gas. For this reason, UK government guidelines recommend a switch to biomass only for properties where the alternative is oil or coal, and only in rural areas.[37] However, if this option is deployed more extensively then more facilities may be located in urban centres, where the high population density will lead to greater health impacts. The transport burdens imposed by vehicles delivering biomass could also be significant. Ways of reducing this impact are considered in the next section.

For solar thermal heating, there are large air quality benefits.

For heat pumps, the benefits of avoided fuel combustion must be offset against the need for additional power generation. These impacts can be mitigated by a switch to power sources with lower external costs.

As for the power sector, the impacts of CCS are not yet clear. There may be some benefit for air quality due to the need to minimise SO_2 emissions, but this could be offset by higher NOx emissions, and the increased energy requirement of the whole process, as well as by the impacts of solvent production and waste solvent disposal.

4.5.4 Policy implications

As discussed above, the energy-saving measures in this sector achieve significant air quality benefits and also avoid upstream fuel production impacts. Added benefits include comfort improvements in buildings through insulation and draughtproofing, and process improvements in industry that can lead to resource savings, reduce waste, and improve working conditions.

For options involving a switch to biofuels, the air quality benefits are partly offset by the combustion emissions, as discussed in the previous section, and these impacts could be significant if large numbers of small scale biomass burners are located in urban areas. These emissions can be mitigated in various ways:

---

[36] Allwood, J, Jonathan Cullen and Rachel Milford (2010) 'Options for achieving a 50% cut in industrial carbon emissions by 2050'. *Environmental Science and Technology* 44(6):1888-1894.

[37] Environmental Protection UK and LACORS (2009) *Biomass and Air Quality Guidance for Local Authorities: England and Wales.* Brighton: Environmental Protection UK. Online at http://www.environmental-protection.org.uk/biomass/

- A requirement for the highest standards of emission control, both for the combustion plant and for the delivery vehicles. This can be easier to implement for large, centralised heat plant rather than for small domestic-scale plant. The Industrial Emissions Directive of the EU requires large combustion plant (and increasingly smaller plant as well) to apply standards defined through the BREF[38] notes released through the European IPPC Bureau. These define acceptable ranges for operation of plant. There is a tendency to apply the upper end of these ranges (the law does not require operators to go further) irrespective of estimated costs and benefits of proceeding to the lower bound of the range. A move towards the lower end of the range could help to maximise air quality benefits.
- Promotion of combined heat and power plants, where the emissions per unit of delivered energy are considerably lower than for heat or power produced in isolation;
- Construction of heating plant somewhere more remote from urban areas. This may incur a higher a cost if it required installing pipes over long distances, though some of this could be countered by the lower cost for constructing the heat facility on a non-urban site;
- A proactive policy of identifying businesses and other developments outside of urban centres that could use a significant amount of heat (and also of identifying significant existing sources of waste heat that are not being exploited).

The impacts of CCS merit further study, as discussed above. Finally, energy savings measures applied to these sectors will also reduce negative externalities associated with the power generation sector.

4.6 Agriculture and forestry

4.6.1 Scenario projection

The CCC Medium Abatement scenario assumes that greenhouse gas emissions from the agriculture sector are reduced by 4.5MtCO_{2e} by 2020 (consistent with DECC Low Carbon Transition Plan scaled up from England to the UK) and by a further 5.45MtCO_{2e} by 2030, using an unspecified mix of the following measures:

- Timing of fertiliser application
- Avoiding excess fertiliser
- Improved genetics in beef/dairy cattle
- Improved fertility in dairy cattle
- Use of propionate precursors in beef/dairy cattle feed
- Use of maize silage for dairy cattle feed
- Anaerobic digestion at poultry farms
- Species introduction (nitrogen-efficient plants)
- Anaerobic digestion at pig farms
- Coverage of slurry tanks & lagoons at beef/dairy farms
- Afforestation

In addition, 10,000 hectares per year of woodland are assumed to be created, in line with the scenario in the 2009 Forestry Commission Read Report.

The CCC also assessed three additional scenarios to investigate the impact of dietary change (reducing meat consumption), in conjunction with Cranfield University[39]. These were not part of the Medium Abatement scenario, but were speculative “what-if” assessments. One of these additional scenarios has been assessed (see next section).

[38] BAT (Best Available Techniques) Reference notes. See http://eippcb.jrc.es/reference/.
[39] Audsley et al 2011, “Food, land and greenhouse gases”, Cranfield University report for the CCC.

4.6.2 Valuation of external costs

Because the CCC scenario does not quantify the extent of the individual measures for the agriculture sector, it was not possible to provide quantitative estimates of co-benefits.

However, we were able to estimate the health benefits of one of the additional dietary change scenarios. In Cranfield's Scenario 1, which assumed a 50% reduction in the supply of animal products in the UK, to be replaced by plant-based food products. We based our analysis on a paper by Friel et al.[40], which modelled the impact of a 30% reduction in intake of saturated fats from animal products. We scaled the impacts by a factor of 50/30 to account for the difference in animal product consumption between the two scenarios. This may be an over-estimate, as the impacts are not necessarily linear. Friel et al used two different calculation methods which gave different results: we took the mid-point of these results, giving an estimate of £11 billion annual savings from health benefits in 2030, and a net present value of £162 billion from 2008 to 2012. For comparison, if we assumed that the benefits were no greater than the Friel scenario with the 30% reduction, the benefits would be £6.7 billion in 2030 with a net present value of £97 billion.

For other impacts, a qualitative assessment has been carried out. These results are captured in the accompanying spreadsheet.

4.6.3 Discussion and interpretation of results

For the measures in the core Medium Abatement scenario, significant benefits arise from reduced fertiliser use, via techniques such as improved timing to minimise run-off, or more targeted application. This will reduce both air and water pollution, with benefits for health and ecosystems. Fertiliser application leads to emissions of nitrous oxide, nitrogen oxides and ammonia. Nitrous oxide is now the main cause of damage to the ozone layer, which leads to more cases of skin cancer. Nitrogen oxides and ammonia are directly damaging to health, as well as leading to the formation of secondary particulate pollution, and nitrogen oxides also contribute to the formation of ground-level ozone. In addition, run-off of excess fertiliser from agricultural land is a major source of nitrate and phosphate water pollution, which can lead to acidification and eutrophication of surface water with associated biodiversity loss. Nitrate in water can have impacts for human health above certain levels, and must be removed by water companies to meet the EU standard of 50mg nitrate per litre.

Anaerobic digestion has a wide range of co-benefits, including reduced emissions of methane, ammonia, hydrogen sulphide and nitrogen oxides from slurry and manure storage, as well as benefits arising from biogas displacing other fuels, and from use of the digestate as a soil improver. Economic benefits can also accrue to farmers from sale or use of the biogas and digestate.

Afforestation has potentially large co-benefits for landscape, biodiversity, soil protection and air quality, but these depend on the type of trees planted and the former use of the land. Co-benefits can often be maximised by planting a mix of native species and avoiding conversion of land with high biodiversity or landscape value.

Although not part of the core CCC abatement scenario, the most prominent impact in this sector is the huge co-benefit from the health impacts of halving consumption of animal products, as discussed above. As livestock farming has large environmental impacts, this scenario will also provide substantial co-benefits from reduced water and land use, as well as reduced water and air pollution from avoided fertiliser use, which will provide benefits for biodiversity, food security and health.

4.6.4 Policy implications

The large potential health and environmental benefits of a reduction in consumption of animal products, although not part of the core scenario, are probably the most significant impact in this sector and certainly merit further investigation. A reduction in animal produce

[40] Friel et al (2009) "Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture". Lancet Nov 25 2009

consumption of this magnitude would be hard to achieve, but the size of the potential benefits implies that even a lesser reduction could have significant benefits.

However, there could be important effects on the UK farming economy, rural communities and landscape. Farmers may need support to facilitate a switch from production of animal produce to plant-based alternatives. It is also important to consider what plant-based products would replace the animal produce, and how and where these would be produced. Plant-based protein such as pulses and beans is not traditionally produced in great quantities in the UK, and there could therefore be an increase in imports. To maximise benefits and minimise any adverse effects, it will be necessary to ensure that plant-based alternatives are produced sustainably, with minimal use of agrochemicals. If it is considered desirable to preserve traditional farming landscapes such as extensively grazed upland sheep pasture, measures could be taken to support this type of farming.

The wide range of benefits from the use of anaerobic digestion and reductions in fertiliser use also seem to indicate that these measures merit policy support.

The benefits or impacts of afforestation, as mentioned above, can also be optimised through policy decisions governing the type of trees planted, cultivation techniques and selection of suitable sites.

4.7 Overall results

For those impacts where it has been possible to estimate the value of the external costs, it is clear that the scale of these costs and benefits is potentially significant. A summary of the cost estimates is provided in Table *4* and Table 5 that follow, with impacts for the use stage shown separately to impacts for other life cycle stages.

This includes a number of significant co-benefits associated with the use stage of the measures in relation to impacts on congestion, lifestyle, air quality, road accidents, noise, and water abstraction. However, some important costs were also identified in relation to occupational health and accident risks, as well as noise impacts and impacts associated with heavy metals.

A number of important external costs are associated with other stages in the lifecycle. In particular, measures that reduce fuel consumption have the potential to reduce negative externalities associated with the upstream fuel cycle. At the same time changes in the mix of power generating technologies will lead to increases in certain upstream or downstream costs.

It is important to note that the coverage is not complete, even within a given sector, and the table is therefore an imperfect representation of the total costs and benefits. A simple addition of all of the numbers in the tables will not therefore generate a true ‘total’ for the externalities within the scope of this study.

Table 4. Main quantified external health and environmental impacts of the CCC's Medium Abatement scenario relative to the baseline during the use stage. Values presented as Net Present Value over the period 2008-2030[41](£$_{2012}$, million), annual cost in 2030 in brackets.

	Power VS BL2	Power VS BL1	Road transport	Industry	Heat	Residential buildings	Non-residential buildings	Agriculture	Comment
Diet								*162,516 (11,258)*	* Reduced fat intake from halving consumption of meat and dairy produce (not part of core scenario)
Lifestyle			26,101 (2,548)						* Increased walking & cycling in place of car journeys * Recreational benefits of new forests
Major accident risk	-56 (-16)	-54 (-13)							* Increase in nuclear power
Occupational health	-208 (-31)	-58 (-16)							* Increase in offshore and onshore wind, and also nuclear power
Road Accidents			1,531 (231)						* Smarter choices & HGV logistics reduce accident rates * Small increase in accidents from more walking & cycling
Air quality (based on PM10)	2275 (466)	93 (64)	600 (106)	869 (134)	1,114 (297)	642 (78)	138 (14)		* Energy saving and shift to renewables and nuclear cut fossil fuel emissions from power generation and buildings *Smarter choices and HGV logistics reduce vehicle km * Electric vehicles, hydrogen buses reduce emissions intensity
Noise	86 (22)	-34 (-4)	947 (148)			4,905 (383)			* Electric vehicles and smarter choices reduce noise levels from traffic * Glazing measures reduce exposure to noise.

[41] Except for power sector where the period is 2012-2030

	Power VS BL2	Power VS BL1	Road transport	Industry	Heat	Residential buildings	Non-residential buildings	Agriculture	Comment
Heavy metals	40 (8)	-9 (-1)	144 (34)						* Smarter choices and HGV logistics reduce vehicle km * Electric vehicles, hydrogen buses reduce emissions intensity
Water abstraction	565 (122)	155 (46)							Certain measure will consume greater levels of abstracted water
Biodiversity and ecosystems			210 (27)						* Smarter choices and HGV logistics reduce vehicle km, and reduce habitat loss and fragmentation
Congestion			48,450 (8,423)						* Smarter choices and HGV logistics reduce vehicle km , and associated congestion
Total for quantified impacts, use phase	**2,702**	**94**	**77,984**	**869**	**1,114**	**5,547**	**138**	***162,516***	

Notes: Coverage is not complete, even within sectors

No quantitative estimates have been derived for the aviation and shipping sectors

Totals should be interpreted with caution because many significant impacts are not quantified.

Air quality estimates are based on analysis carried out by Imperial College and are presented using a damage cost for particulates referenced against PM10, and quantified over the period 2020 to 2030.

+ +	+	+/-	-	- -	
Significant benefit	Benefit	Benefit or cost	Cost	Significant cost	No effect

Table 5. Main quantified external health and environmental impacts of the CCC's Medium Abatement scenario relative to the baseline during the other life-cycle stages. Values presented as Net Present Value over the period 2008 to 2030[42]($£_{2012}$, million), annual cost in 2030 in brackets

	Power, BL2	Power, BL1	Road transport	Industry	Heat	Residential buildings	Non-residential buildings	*Agriculture*	Comment
Major accident risk	1121 (193)	-152 (-12)	1 (0.1)	21 (3)	31 (4)	7 (1)	2 (0.2)		* Reduction in coal power means lower risk of cost of coal mining accident
Occupational health	47 (11)	-25 (-5)	13 (1)	12 (1)	101 (16)	27 (3)	15 (1)		* Increase in occupational health risk from nuclear, wind and CCS is more than offset by decrease in risk from coal * Switch from fossil fuels in end-sue sectors reduces risk from coal and oil
Road Accidents	-129 (-17)	-25 (-7)							* Increase in wind drives increases in cost, but based on incomplete analysis of risks for other power technologies
Air quality, R-AEA estimates (based on PM2.5)	-1,008 (-148)	-307 (-77)	50 (5)	10 (1)	151 (25)	46 (2)	26 (2)		* Biomass, wind and nuclear all increase the relative air quality emissions associated with the supply chain * Switch from fossil fuels in end-use sectors reduces risk from coal and oil
Hazardous waste/nuclear	-14 (-1)	-3 (-1)							* Increase in hazardous waste from nuclear
Noise	30 (5)	-4 (-0.4)		1	1				* Reduction in coal use decreases noise from mining and coal transport

[42] Except for the power sector where the period is 2012-2030

	Power, BL2	Power, BL1	Road transport	Industry	Heat	Residential buildings	Non-residential buildings	*Agriculture*	Comment
Hazardous waste/other			4 (0.4)	1	13 (2)	2 (0.2)	2 (2)		* Decrease in oil use in end use sectors reduces hazardous waste generation
Heavy metals	-65	-13							* Power - incomplete estimate: includes increase in emissions from supply of wind farm components but not emissions from other sectors, which could not be quantified
Total for quantified impacts, other life cycle phase	-18	-528	69	45	297	81	46		
Total quantified effects for the sector	2,683	-434	78,052	914	1,411	5,629	184		

Notes: Coverage is not complete, even within sectors

No quantitative estimates have been derived for the aviation and shipping sectors

Totals should be interpreted with caution because many significant impacts are not quantified.

Air quality estimates are based on analysis carried out by the project team and are presented using a damage cost for particulates referenced against PM2.5.

+ +	+	+/-	-	- -	
Significant benefit	Benefit	Benefit or cost	Cost	Significant cost	No effect

5 Overall conclusions

This chapter summarises the overall conclusions from the analysis. It also summarises the priorities for future research that were identified during the implementation of the study.

5.1 Key findings and major issues

5.1.1 Identification of prominent externalities

There is a wide variety of externalities linked to measures to reduce greenhouse gases. Some of these are co-benefits that add to the benefits of climate policy, others involve trade-offs that will reduce the benefit of climate actions.

The following table identifies the impacts that are concluded to have the potential to be most significant for each sector (note that we seek to differentiate between 'impacts' and 'externalities' at this point, recognising that some of the impacts shown will, to a degree at least, be internalised).

Table 6: Main external health and environmental impacts of the CCC's Medium Abatement scenario

	Negative impacts (costs)	Positive impacts (benefits)	Mixed or uncertain impacts (costs or benefits)
Power	• Risk of major accidents at nuclear power plants • Risks associated with nuclear waste management, uranium mining and fuel processing • Landscape impacts of dispersed renewable technologies • Impacts of additional fuel production, solvent production and waste generation for Carbon Capture and Storage	• Air quality benefits of a switch from fossil fuels to nuclear and renewables, for both health and the environment • Benefits from avoided coal and gas production from switch to renewables and nuclear- see 'upstream fuel production', below	
Road transport	• Potential road accident increase from walking and cycling if extra safety measures not implemented • Upstream impacts of increased electricity production for electric vehicles	• Health (exercise) benefits of active transport • Congestion benefits of smarter choices and HGV logistics • Road accident benefits of demand reduction and HGV logistics (and possibly speed limiting) • Air quality benefits of more efficient, electric, hybrid and fuel cell vehicles. • Noise reduction from the use of electric vehicles • Benefits of avoided oil production - see 'upstream fuel production', below	
Aviation and shipping		• Noise reduction from improved efficiency in aviation • Air quality impacts around airports • Air quality impacts of limiting shipping speeds • Benefits from avoided oil production - see 'upstream fuel production', below	
Heat	• Possible air quality impact of switching from gas to biomass • Upstream impact of increased electricity	• Air quality benefits from switching from fossil fuels to solar heating and heat pumps	• Biodiversity, landscape and soil fertility impacts of energy crops

	production for heat pumps	• Benefits of biogas and biomass from waste in avoiding the costs and impacts of waste disposal (land take, odour, emissions etc) • Benefits from avoided fossil fuel production - see 'upstream fuel production', below	
Domestic, non-residential and industrial energy use	• Impacts of additional fuel production, solvent production and waste generation for CCS in industry	• Air quality benefits of avoided fuel combustion from energy efficiency and behaviour change • Health and social benefits of improved insulation etc in housing • Benefits from avoided fossil fuel production from energy efficiency and behaviour change - see 'upstream fuel production', below	
Agriculture and forestry		• Human health benefits of dietary change (very large benefit) • Land take benefits from dietary change • Water quality benefits (e.g. from more efficient fertiliser application and dietary change) • Air pollution benefits (e.g. from anaerobic digestion, dietary change, reduced fertiliser use)	• Biodiversity, land and water impacts of afforestation
Upstream fuel production	**(most measures result in a reduction of these impacts, with the exception of land take for biofuels)** • Occupational health in coal mining, oil production, etc. • Major accidents from coal mining, oil and gas extraction (including oil spills) • Air pollutant emissions from oil and gas extraction and processing • Greenhouse gas emissions • Land take for biofuel production		

5.1.2 Variability in the importance of impacts

This is a very difficult issue for the study, given that the importance of impacts is a function of several factors, including, but doubtless not limited to:

- Human perception
- Magnitude of an impact per unit of activity
- The amount of activity undertaken
- The regulatory framework controlling impacts
- Local conditions
- Variability in all of the above.

To illustrate with some examples:

- In most cases the noise from wind farms appears not noticeable. However, there are cases[43] where individuals appear to have suffered a significant loss of amenity as a result of living near new turbine developments.
- The risks of underground coal mining can be managed effectively, drawing on centuries of experience with deep mining. However, poor practice exists and it is particularly notable that there have been a number of major accidents in recent years in mines in Western countries[44] (leaving aside Chinese mines). A common factor in these accidents is mismanagement, sometimes coupled with ineffective regulation.

The significance of impacts is also scenario dependent (the third bullet in the above list). Hence an effect that is normally considered serious may be of little interest if associated technologies do not feature to a significant degree in the scenario under investigation.

The breadth of the study creates a problem when dealing with issues that may be nationally insignificant but locally important. One example, relates to the impacts of wind turbines on landscape. This is further complicated by the issue of scaling, where the size of the impacts may not scale in a linear way with the further introduction of the measures. The study for the Scottish Government referred to above is relevant here in its conclusion that a few large wind farms have a lower impact than a large number of small ones.

For some impacts, the size and scale of the external costs will be very site or context specific. For example, the use of biomass for domestic heating will have limited impacts on air quality if carried out in rural areas. However, extending the use of biomass would bring it into towns and cities with much higher population densities. The damage per unit energy consumption would increase very significantly simply because more people would be exposed to emissions.

To some extent these issues are addressed through the commentary around impacts, but this will not be evident if one only considers the high level ratings given in the summary sheets. This issue could be addressed in further follow-on work, identifying more clearly under what conditions effects may become important. The present study would provide a basis for selecting the impacts that need to be considered in this way.

We have sought to provide a typical rating of the importance of impacts, separating those we consider likely to be more important from those that are less important. We acknowledge that others may have different views on specific impacts, but it is to be hoped that the contextual information provided in the study outputs at least provides a rationale to demonstrate how our conclusions have been reached.

---

43 E.g. http://www.bbc.co.uk/news/uk-england-lincolnshire-15964338

44 Including the Upper Big Branch Mine in West Virginia USA in 2010 in which 39 men died, the Pike River Mine Disaster in New Zealand in 2010 in which 29 died and the Gleision Colliery Disaster in Wales in 2011 in which 4 men died. It is understood that all three cases are subject to legal proceedings against operators.

Discussion within the project team highlighted differences in opinion about the consequences for estimates of external costs of two recent major accidents – Fukushima in Japan and Deepwater Horizon in the Gulf of Mexico. Both are associated with extensive environmental harm. Both were of a magnitude sufficiently rare that use of the long-term accident rate as an indication of risk is unreliable. From one perspective, both highlight that the operators and perhaps regulators underestimated risk. Fukushima was clearly unprepared for an earthquake and tsunami of the magnitude faced in March 2011, despite Japan being in one of the most seismologically active regions on the planet. Debate as to the underlying causes and hence the responsibility of different parties involved with Deepwater Horizon is likely to continue for a long time to come. From another perspective, both will have gone some way to reduce future risk by highlighting the potential for design, operation and management failures. Fukushima has led to a reassessment of nuclear risks around the world that goes beyond preparedness for major earthquakes. For example, in the UK, the Weightman Report[45] looked at the implications of the Japanese earthquake and tsunami for the UK Nuclear Industry. This included, amongst others, a consideration of technological, regulatory and human factors. The costs of Deepwater Horizon appear to have been met by the site operator through various means (payment for clean-up, compensation to those directly affected, fines levied by US Courts), implying that associated costs were internalised to a significant degree. It is also clear that the costs to BP are of a magnitude that will have made oil industry executives around the world consider their own liabilities and ways of mitigating them in more detail. Both perspectives have some validity.

5.1.3 Internalisation

Various mechanisms exist for internalisation of impacts. Taking the Deepwater Horizon disaster as an example, impacts will be internalised to some degree by the site operators through payment of compensation to affected people, through clean-up costs and through fines levied by the US authorities. Closer to home, the planning system mitigates some externalities by providing opportunity to debate effects of proposed developments. Developers may then be required to amend (or abandon) proposals, or provide the local community with funding for local improvements.

The question arises of the effectiveness of internalisation mechanisms. This will also vary greatly from place to place, depending for example on the link between those likely to be most affected and those in a position to take action. Within this project it has not been possible to resolve these issues; it should therefore be recognised that whilst internalisation potential exists it is not always fully successful.

5.1.4 Air quality benefits

One of the most important beneficial externalities of the mitigation scenario concerns air quality benefits quantified here using information on changes in emissions provided in a companion project by Imperial College (results are summarised in Appendix 1). The quantification of benefits is based on the methods approved by the IGCB and data contained within their online tool[46].

So far as primary particle emissions are concerned, the IGCB approach for particulate matter is referenced against PM10 (albeit on the assumption that emission changes are mostly in the PM2.5 size fraction). The approach taken in the current study is, however, to provide quantification referenced against PM10 but also to provide an estimate referenced against PM2.5[47]. This shows that quantification directly against PM2.5 generates substantially lower damage estimates for certain measures e.g. fuel switching for heat provision.

---

[45] Japanese earthquake and tsunami: Implications for the UK Nuclear Industry. Office for Nuclear Regulation. http://www.hse.gov.uk/nuclear/fukushima/interim-report.pdf

[46] IGCB Damage Cost Calculater, updated November 2008. http://archive.defra.gov.uk/environment/quality/air/airquality/panels/igcb/documents/igcb-damage-cost-calculator.xls.

[47] Values presented in the current report are in most instances referenced against PM10 in accordance with the analysis by Imperial College. However, for comparison, the accompanying spreadsheets also include estimates referenced against PM2.5.

It is however likely that the IGCB approach takes a conservative approach to quantification in other areas, and may underestimate actual air pollution damage for the following reasons:

- They exclude damage of UK emissions in neighbouring countries
- They exclude ecosystem damage linked to acidification and eutrophication
- They consider a limited set of response functions for morbidity compared to other sources
- There may be some bias to overestimation of exposure to nitrogenous pollutants (ammonia and NOx) in other current estimates.

Irrespective of the final point in this list, there is clearly potential for the estimates provided here to underestimate damage associated with air quality burdens.

5.1.5 How meaningful are estimates?

In some cases the usefulness of estimates of impacts is questionable. The best example probably concerns major accidents in the nuclear sector. There is a strong probability, based on past experience, that over the timeframe considered here there would be no major accidents (e.g. on the scale of the Fukushima disaster) at UK plant, with the result that the most likely estimate of damage is zero. However, there is a small possibility of an accident with costs in the order of billions of pounds. Taking a probability adjusted value, as recommended in the externalities literature, gives an estimate of damage at some point towards the lower end of this range. However, this may be considered something of a statistical artefact, given that the actual costs will be either zero or £billions. The approach of using a probability adjusted estimate of damage per kWh is appropriate when considering a large number of plant operating over an indefinite time period. However, its applicability to the present situation where timescale is limited to 20 years and the number of plant considered is small, is clearly questionable.

There are also two divergent views on the aggregation of estimates of externalities when a number of effects, particularly those that are considered likely to be significant, cannot be quantified. A simple total of the effects that have been quantified is clearly flawed. However, it does provide some guidance on the overall scale of effects and some indication of the balance of positive and negative externalities. It can also be made more meaningful by adding a discussion of the limitations of the quantification, for example providing an overview of the more significant effects that have been omitted from analysis and the likely direction of the bias that this imposes on quantified estimates.

5.2 Mitigation of negative impacts and enhancement of positive impacts

Although many climate abatement measures result in co-benefits such as improved air quality, we have also identified a number of negative impacts, as discussed in section 4. Careful policy design can often mitigate the negative impacts and enhance the co-benefits.

Below we summarise the main negative impacts that have been identified, along with potential mitigation options.

Table 7: Mitigation options for negative externalities associated with the climate abatement measures

Negative impact	Potential mitigation options
Landscape and perceived noise impacts of wind turbines	Sensitive siting; adherence to planning guidelines; early consultation with local communities; offering local communities a financial share in the benefits.
Accident risks and waste disposal problem of nuclear	Strict safety standards and independent regulation; development of fourth generation reactor designs with passive safety features

power	and lower waste production, though it is unclear whether this can be achieved within a reasonable cost and timeframe.
CCS: increased upstream fuel production to power the process, with associated impacts and emissions	Use low impact fuels to power the capture, transport and storage processes where possible, e.g. renewably generated electricity. Cannot be completely mitigated.
CCS: solvent production, use, regeneration and disposal with associated emissions e.g. ammonia	Extent of problem not yet clear: requires further research. Mitigation options not yet identified.
Bioenergy: land take, landscape, water use, air quality and biodiversity issues at production stage.	Sustainable sources and production methods: maximise production of bioenergy from waste, e.g. anaerobic digestion. Minimise production from crops, and minimise use of agrochemicals and irrigation for energy crops. Avoid conversion of land of high biodiversity or landscape value. Particular care is needed if biomass is imported, as the sustainability of the supply chain will be hard to control without strict standards and verification.
Bioenergy: combustion emissions	Avoid replacing gas with biomass in urban areas (in line with current policy). High standards of pollution control for bioenergy combustion plant. Improved efficiency of boilers, including uptake of combined heat and power.
Biomass: noise from shredding of solid biomass	Sensitive siting; soundproofing of buildings; choice of best machinery
Impacts associated with additional electricity production for electric vehicles and heat pumps	Switch to cleaner, lower impact power production e.g. renewables
Risk of increased accidents due to more people walking and cycling	Invest in road safety improvements, especially safe cycle paths separated from traffic. Other measures include improved junctions, driver training (especially for HGV and bus drivers) and traffic calming.
Health risk to cyclists from inhalation of traffic fumes	Cleaner vehicles; provision of off-road cycle routes
Afforestation: land take, landscape, water use and biodiversity issues	Minimise use of agrochemicals and irrigation. Avoid conversion of land of high biodiversity or landscape value.
Solar PV: use of rare metals	Maximise recycling of solar panels; R&D into alternative materials
Occupational health impacts of wind turbines	Strict safety regulations; raise awareness of potential safety issues
Biodiversity impacts of tidal power (habitat loss, barrier to migrating fish, damage due to turbines)	Alternatives to full-height ebb-only barrage designs (tidal lagoons, fences, reefs)
Building insulation and air tightness: Potential decrease in indoor air quality and increased risk of exposure to radon gas due to decreased natural ventilation	Install additional ventilation system if necessary (this will partly offset climate and environmental benefits)
Waste generation and increased resource usage from switch to	Avoid excessively premature discard of existing equipment; maximise reuse and recycling of old equipment; encourage

more efficient vehicles, aircraft, appliances and boilers	upgrading rather than complete replacement where possible (this is rarely possible at present but could be facilitated by encouraging a shift to modular, reusable components in future)
Hazardous waste from electric vehicle batteries	Recycling of batteries; R&D into cleaner batteries

Table 8 below lists the main opportunities we have identified for enhancement of co-benefits.

Table 8: Opportunities for enhancement of co-benefits

Co-benefit	Potential enhancement options
Health and wellbeing benefits of better home insulation	Target households in fuel poverty
Congestion and noise benefits of smarter transport choices	Target support (e.g. provision of new cycle paths) on high-traffic areas e.g. city centres
Air quality and avoided upstream fuel production benefits of shift to public transport	Cleaner and more fuel-efficient buses, coaches and trains
Health (exercise) benefits of switch to walking and cycling	Target people with sedentary lifestyles, e.g. through awareness campaigns, perhaps via GPs, or workplace incentives. Measures to improve the safety, convenience and enjoyment of walking and cycling, which would increase the uptake, include: provision of safe and pleasant cycling and walking routes; provision of secure cycle parking; better information and signposting of walking and cycling routes; cycle training; awareness campaigns to highlight the health benefits; encouraging employers to provide changing facilities; speed limiting for vehicles; cleaner vehicles (to reduce exposure to traffic fumes); smarter urban planning to enable shorter (i.e. more walkable) travel distances between home, work, school, shops and leisure activities. Health benefits will also be strongly enhanced in combination with improvements to diet.
Environmental benefits of cut in meat and dairy consumption (optional scenario), through avoided fertiliser use, land use and water use	Ensure that crops grown to replace meat and dairy component of diet are produced sustainably, with minimal use of agrochemicals and irrigation

5.3 Priorities for future research

5.3.1 Peer review or wider debate?

The findings of this research represent the views of a team with substantial expertise in the assessment of externalities of energy and transport, in particular, with additional expertise in agriculture and forestry. To the extent possible we have discussed with experts outside of the project team to gain a broader perspective, including economists and scientists within Defra. However, the research has to be seen for what it is: a short time scale exploratory assessment dealing with a vast array of technologies (from agriculture to aviation) and a similarly broad array of impacts (from landscape impacts of new developments to major accidents).

The effects identified are significant enough to have an influence on the policy process. With this in mind, it is clearly appropriate that the work is laid open to further discussion. There are two options for this, a traditional formal peer review and the use of the study materials as the basis for a workshop. Both might be considered for future work.

5.3.2 Priorities for research or debate

We select the following as priority areas for further research, in general based on the limited amount of information currently available for estimation of effects:

- Impacts
  - Air pollution impacts on health, to seek a uniform position between recommendations for policy analysis in the UK with policy analysis elsewhere
  - Internalisation of major accident risks
  - Impacts on biodiversity generally, including impacts associated with emissions to air and water, development pressures and so on
  - Impacts on landscape
- Technologies/options:
  - Carbon capture and storage
  - Hydraulic fracturing (“fracking”)
  - Behavioural measures, including diet change

With respect to air pollution impacts on health we note that the European Commission has contracted WHO-Europe to lead two studies, REVIHAAP and HRAPIE, both reporting in 2013, that are designed to provide advice on the health impacts of air pollution and response functions for quantification of impacts. Experts from many countries are included in the project teams, including some from North America as well as Europe, and several from the UK. It is possible, perhaps likely, that the two projects will propose a set of response functions that goes significantly beyond those currently adopted by the Interdepartmental Group on Costs and Benefits for UK policy advice, including some for pollutants that are not currently explicitly covered by the functions adopted in the UK (NO_2 in particular). To some extent this would not change the conclusions drawn here, that air pollution externalities are very important. However, it may further increase the profile of air pollution effects on health.

5.3.3 Internalisation

Internalisation of externalities (in other words, factoring externalities into decision making) may take a number of forms:

- Direct compensation by those causing an impact to those affected by some activity or at greater risk.
- Insurance payouts.
- Planning systems and the use of environmental impact assessment.
- Use of taxes (Pigouvian taxes) to provide an economic incentive to reduce externalities. In this case the tax need not be used to compensate those directly affected but be used for the good society in general.
- Pollution charges, fees, fines and similar payments.

A question that has arisen for several types of impact concerns the extent to which externalities may be considered to be internalised. Preferential methods for internalisation could also be discussed, noting that internalisation through avoiding negative impacts is likely always to be preferable to internalisation through insurance or other forms of compensation.

5.3.4 International dimension for future research

The results of this research should be of interest to governments in many countries facing the challenge of reducing their burdens on climate. International collaboration would be useful for further work, not least for addressing the externalities of activities in other parts of the world (e.g. coal mining, oil exploration). With this in mind the potential for further funding from international bodies (most obviously the European Commission) should be explored.

5.4 The status of this research

It must be recognised that this research has been performed on a short time scale. It has therefore been based on a review and evaluation of existing literature rather than (for the most part) new quantification of externalities. In some areas a large amount of information has been identified, in others very little. The latter includes potentially very important activities for the future such as fracking. We acknowledge that some of the sources used are now dated and others may be of questionable relevance to the UK. However, we believe that the research has succeeded in providing:

1. A benchmark for consideration of the externalities of climate mitigation activities
2. Good guidance on which externalities are likely to be most significant
3. Useful ideas for mitigating negative externalities of climate mitigation activities and for enhancing the positive externalities

Whilst the research does not provide the final word on the externalities of climate mitigation options for the UK in the next 20 years it does, therefore, provide a firm basis for future debate and an input to the policy process.

Appendix 1: Air Quality Benefits

This appendix summarises air quality benefits quantified according to the IGCB recommendations. Estimates of changes in emission were provided by Helen ApSimon of Imperial College.

Summary of environmental damage costs: (£ millions) Negative numbers indicate benefits.

	2030 No discounting	2010-2030 No discount	NPV
Power sector:			
CCC.CA	90	3145	2439
Dash for gas	154	3377	2532
NO.CA	556	6913	4714
Heat sector:			
Residential biomass	42	170`	95
Non-residential biomass	37	450	282
Industrial	227	1886	1140
Biogas	7	50	29
District heating biomass	83	775	474
TOTAL	396	3331	2022
Heat sector: fuel savings			
Residential sector	-264	-2283	-1416
Non-residential	- 52	- 512	- 321
Industry	-377	-2392	-1397
TOTAL	-693	-5187	-3134
Transport sector			
Electric cars	- 26	- 152	- 88
Electric vans	- 6	- 44	- 26
Hydrogen buses	- 6	- 23	- 12
Smarted choices	- 52	- 663	- 427
HGV logistics	- 16	- 84	- 47
TOTAL	-106	- 965	- 600
Efficiency measures			
Residential	- 78	- 986	- 642
Non-residential	- 14	- 208	- 138
Industry	-134	-1348	- 869
TOTAL	-226	-2542	-1649

Appendix 2: Noise impact

This appendix summarises noise impacts of the CCC's medium abatement scenario, as calculated by Defra.

Impacts have been quantified and monetised for two measures:

- Electric vehicles
- Double glazing

For electric vehicles, a high and low range is presented to represent different assumptions on the proportion of HGVs (ranging from 1% to 10% of the relevant traffic). As HGVs have higher noise emissions, the overall reduction in noise related costs from switching to electric cars is reduced where HGVs make up a greater proportion of the traffic, as the switch would not be noticed as much in this case.

The results are presented below. Positive values represent net benefits.

Noise benefits of electric vehicles (£million, 2002 prices)

	2010	2020	2030
Low	£0.3	£10.0	£26.2
High	£0.9	£28.7	£75.4

Using an average of the high and low values, this is equivalent to a net present value of £341 million (2012 prices) over the period 2008-2012.

The impacts of double glazing have been quantified assuming that moving from single to double glazing might reduce inside noise levels by about 10dB. The replacement of old double to new double glazing is assumed to deliver a reduction in noise levels of 5dB. In both cases, this is likely to represent a maximum reduction and the benefit would in fact be somewhere between zero and this value.

The results from the analysis of the maximum reduction benefits are presented below. Positive values represent net benefits.

Maximum noise benefits from double glazing and new double glazing (£million, 2002 prices)

	2010	2020	2030
Single to Double	£55.0	£237.6	£251.6
Double to new Double	£16.7	£54.9	£52.3

RICARDO-AEA

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR

Tel:0870 190 1900
Fax:0870 190 6318

www.ricardo-aea.com