

MARKAL-MED model runs of long term carbon reduction targets in the UK

Phase 2

Final report to Committee on Climate Change

Restricted Commercial

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Executive summary

During the course of 2008, AEA, in association with PSI, has been supporting the work of the Committee on Climate Change on long term target setting, using MARKAL energy systems modelling. This is the Phase 2 report, focusing on a range of sensitivity analysis, and critically using a less optimistic transport sector baseline than under Phase 1.

This modelling analysis has focused on the techno-economic impacts of:

- Higher renewable electricity generation targets, in view of the European Climate and Energy Proposals
- Higher fossil fuel prices
- Inclusion of the international aviation sector in the carbon budgets
- Restricting the uptake of low carbon generation technologies
- Short term investment decision making
- Alternative reduction target trajectories

The key findings and messages emerging from the analysis are provided below.

Transport sector constraints

Under the Phase 1 analysis, an optimistic view of transport technology uptake meant that short term reduction targets (in 2020) were easily met. This was because the transport sector baseline had lower emissions due to the assumed efficiency improvements, as a result of the large scale uptake of hybrids. The imposition of constraints on hybrid / PHEV uptake meant that the additional costs of meeting the 2020 target were now significantly higher, due to higher emissions in the baseline. By 2030, with constraints again relaxed, the impact on the system under the reduction trajectory are similar to those observed in the comparative Phase 1 analysis.

A constraint was also removed that had been imposed on electric vehicles. This demonstrated that such vehicles have an important role to play in future years (post-2040), particularly using the low carbon electricity that will be available.

Renewable electricity generation targets

The high renewable energy targets for the UK under the European Energy and Climate Proposals will inevitably mean that the contribution from renewable electricity generation will have to increase. In this analysis, using a 32% target for renewable electricity generation by 2020, a large increase in wind generation is observed to meet this target. In the later years, the target has less of an impact due to the high level of renewable generation required anyway. However, some additional generation is observed, coming from biomass and marine generation sources.

Costs are particularly higher in the near term. Sensitivity analysis was undertaken to explore the impact of carbon credits being available at a given price. Uptake of credits was most apparent in the near term, as credit availability ensured that mitigation costs were reduced.

High fossil fuel prices

Higher prices result in lower use of fossil fuels under the baseline, resulting in a lower carbon baseline. This means the mitigation requirements (and therefore costs) across the time horizon are lower.

The key impact on technology-energy choice appears to be on the generation mix, where nuclear generation plays an increasingly important role. Gas CCS disappears from the mix, due to the impact of increasing gas prices on the cost-effectiveness of this technology. In the near term, road transport technology evolution occurs more rapidly, due to the higher prices of oil, and therefore plays a more significant role in mitigation efforts under the 2020 target.

International aviation

Including international aviation sector in the reduction targets results in an increase in the abatement action required in other sectors, pushing non-aviation targets in 2050 to between 84-87%, as opposed

to 80%. Mitigation costs increase significantly to, with marginal costs in 2050 increasing from £150 /tCO₂ to between £250-300 /tCO₂.

The international aviation sector itself contributes around half of the required abatement through the use of bio-kerosene and demand response. However, if life cycle emissions are attributed to bio-kerosene, this mitigation options is no longer taken, and mitigation requirements in non-aviation sectors increase. Costs could be significantly higher if a) life cycle emissions were considered for biofuels, b) higher CO₂ warming impacts of high altitude emissions were taken into account and c) a less optimistic view of technology efficiency improvements in the baseline was considered.

Low carbon technology sensitivities

Nuclear, CCS and wind have been shown to be key low carbon technologies for meeting increasingly stringent CO₂ reduction targets. Restricting any uptake of CCS does not appear to have a significant impact on system costs and the system's ability to meet reduction targets, as nuclear effectively meets the gap.

Restricting both nuclear and CCS has much more significant impacts, significantly increasing costs as the generation sector moves to a gas / wind dominated mix, and additional abatement is required in other sectors. Under the 38/90 case, costs are particularly high, with a generation system dominated by marine and wind generation (including some storage).

Two stage 'reduced foresight' analysis

An important aspect of this work was to consider what investment decisions might be made if the model's foresight was limited to short term targets, and how this would impact on the model's ability to meet the longer term targets. This in a sense reflects the situation where investors in energy technologies do not consider the longer term targets, perhaps due to regulatory uncertainty, policy failure or technology unavailability / cost.

The analysis indicates that costs increase if the 'wrong' investment decisions are made. The size of the cost increase depends on the difference between the investor's perceived target and the actual target.

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1 Introduction

Under the proposed Climate Change Bill, legislation will be introduced that will require the UK to meet carbon reduction targets (to be determined) out to 2050. The Bill proposes the setting up of an independent Committee on Climate Change (CCC), to advise Government on the level at which to set nearer and long term carbon budgets, with at least a 60% reduction proposed in 2050 (relative to 1990 levels). In addition, the CCC needs to advise on domestic versus international action to meet the targets, and effort by different sectors of the economy (traded versus non-traded).

During the course of 2008, AEA, in association with the Policy Studies Institute (PSI), have been undertaking a range of analysis using the UK's MARKAL Elastic Demand model (MED) to support the work of the Committee, in particular to inform the recommendations on budget setting made in their first report to Government, due in December 2008.¹

The MARKAL model is an integrated energy systems model that can be used to explore the future development of the energy system, based on the demand within the economy for energy services. Using exogenous projected demands for a range of energy services, it optimises to establish the cost-optimal pathway for meeting these energy needs, within a set of constraints. An important constraint in the context of this work is the level of carbon emissions permitted in a given year (or period).

The model therefore provides a powerful framework for understanding the techno-economic implications of different carbon budgets that the CCC would like to assess in the longer term. It provides a range of insights on the types of low carbon technologies that might be needed in future years to meet a given target, and the additional costs that might be incurred. It can also be used to consider a range of sensitivities around the informed assumptions used in the model e.g. on technology availability or price. Finally, unlike other assessment approaches, it is an integrated systems approach, and therefore captures the interplay and trade-offs across and between different sectors.

AEA and PSI completed a first set of modelling runs for the CCC, reported in *MARKAL-MED model runs of long term carbon reduction targets in the UK* (now revised and renamed *Phase 1*). Since completion of that initial analysis, the CCC has asked AEA to undertake additional analysis. This has been undertaken to assess the following:

- A less *technology-optimistic* baseline for the transport sector, and the resulting implications for overall costs / technology choices
- Higher renewable electricity generation targets, in view of the European Climate and Energy Proposals
- Higher fossil fuel prices
- Inclusion of the international aviation sector in the carbon budgets
- Other sensitivity analysis on modelling assumptions

All model runs undertaken for this analysis use the new transport constraints, as described in the first bullet point.

This final report presents the key findings from this modelling analysis phase, structured according to the bullet points listed above. A full listing of the model runs undertaken can be found in Annex 1.

Following the Phase 1 analysis, Dr. Neil Strachan of KCL undertook a peer review, highlighting some issues and made a number of recommendations. A number of the issues have been considered, but not pursued under Phase 2 as they were not expected to influence the key messages emerging from the report (costs, technical feasibility and key technologies) in ways that could not be predicted off-model, such as alternate international CO₂ prices and enhanced bio-energy imports.

At the same time, other issues would have entailed considerable and additional modelling complexity. These included:

¹ Committee on Climate Change recently provided advice to Government to reduce Greenhouse gas emissions in the UK by at least 80% by 2050, see <http://www.theccc.org.uk/>

- Modelling of CCS retrofit
- Alternate treatment of intermittency, using a 'capacity credit' approach
- Alternate demand elasticities and floor levels

While we believe that the current representation is valid, these are areas in which the modelling could be further improved. Therefore, care should be taken over the treating the results in these regards as definitive.

In this report, where appropriate, we have tried to take account of the issues raised by the peer review. Some of the comments relate to development of the model or modelling approach, or are beyond the scope of this work, and have therefore not been included in the report. However, we recognise the importance of such comments in the development of future MARKAL analysis.

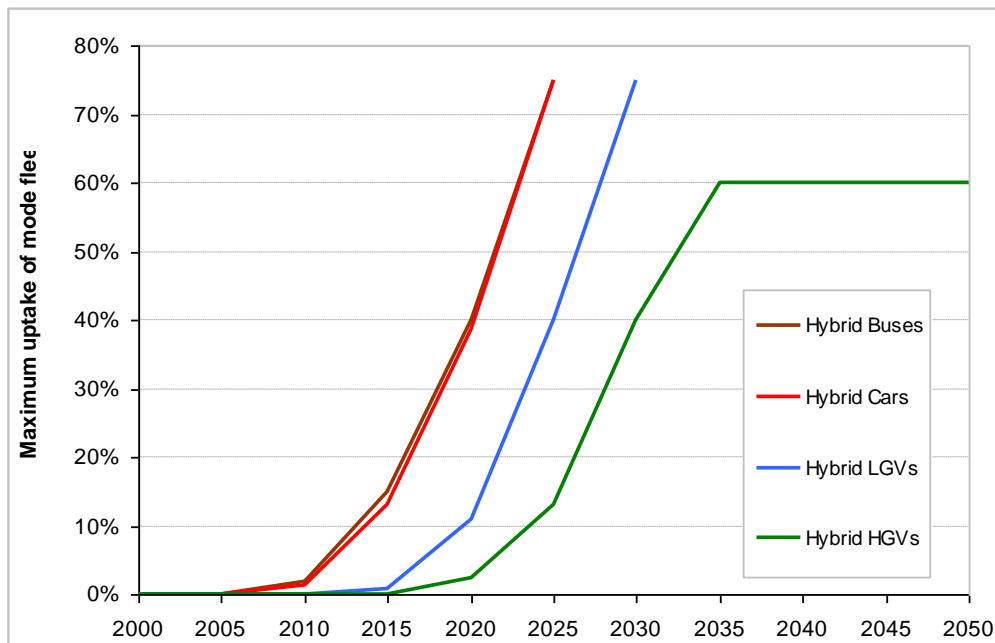
2 Transport sector constraints

From the Phase 1 analysis, a view was formed that the uptake of specific transport technologies in the baseline, particularly in the near term (2010-2020), appeared somewhat optimistic. This particularly related to the uptake of hybrid vehicles in the car fleet. As an optimisation model, this early uptake is driven by more cost-effective (fuel efficient) vehicles being available, countered by any constraints on fleet turnover.

The balance between optimisation on the one hand and real life barriers on the other needed to be re-considered. As a result, a number of additional constraints were introduced to reduce uptake of specific technologies, particularly hybrid vehicles, producing a *less optimistic* baseline. The new transport constraints were based on outputs of recent work led by AEA to develop a transport MACC for the CCC. For this cost curve analysis, we used the maximum (high-high) feasible constraints for deployment to 2020 of new transport technologies.

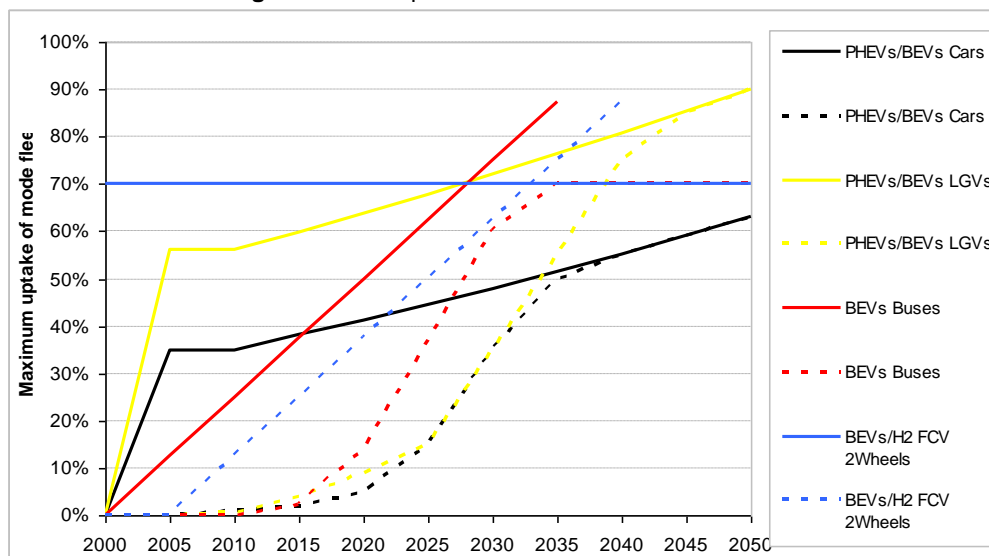
The new constraints on technology uptake by mode are shown in Figure 2.1 and Figure 2.2.

Figure 2.1 Revised transport constraints for new hybrid vehicles for use in Phase 2 modelling



* Where lines are discontinued, constraints no longer apply to that technology set

Figure 2.2 Revised transport constraints (dashed lines) for new non-hybrid vehicles for use in Phase 2 modelling. Bold lines represent old constraints.



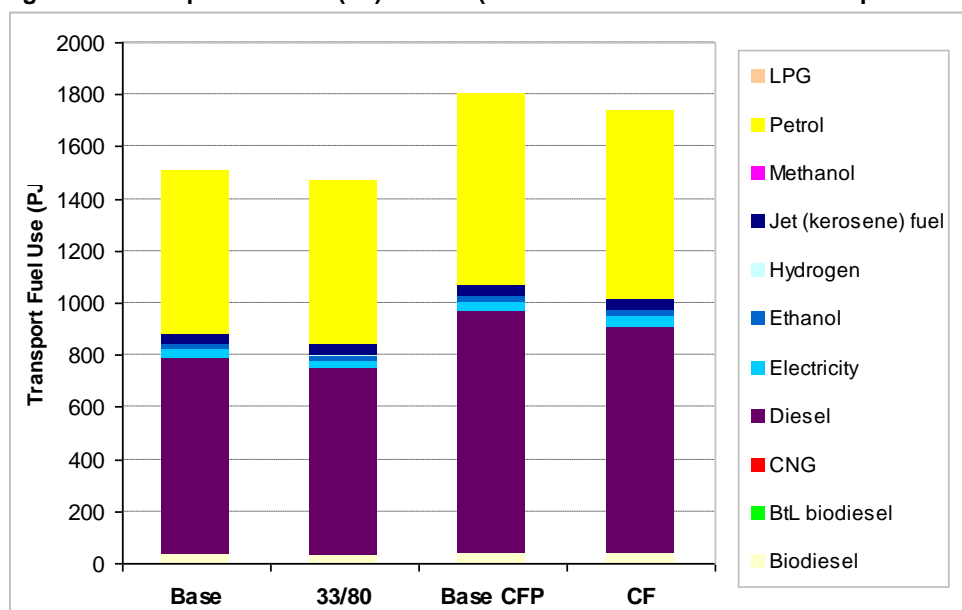
* Where lines are discontinued, constraints no longer apply to that technology set

In addition, very stringent constraints on the uptake of LGV electric vehicles (previously 5% maximum market share to 2050) have been removed. These previous limits were based on a unreasonably pessimistic view of battery technology, and as a suitable replacement for other vehicle technologies.

Energy consumption and technology uptake in the transport sector

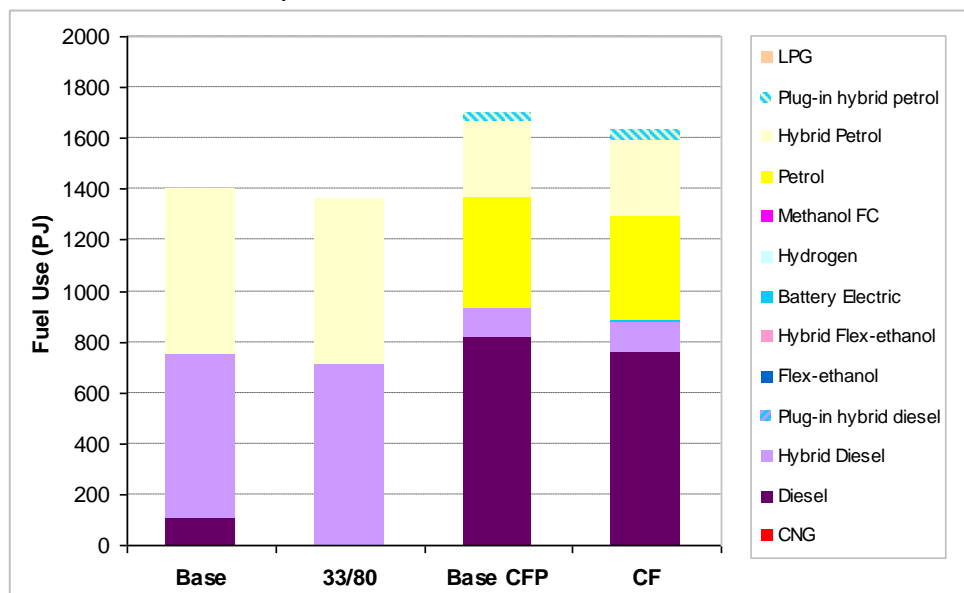
The impact of including new constraints in the sector is most evident in 2020, as this is the period where constraints on rates of uptake have been most tightened. An overall reduction in efficiency across the road transport fleet results in higher levels of petrol and diesel consumption (Figure 2.3). Conventional petrol and diesel ICE vehicles dominate, not the hybrids observed in the Phase 1 runs (Figure 2.4). Hybrid vehicles do penetrate the vehicle stock by 2020 but at much lower levels. It is interesting to observe a very low level of petrol PHEV penetration, potentially due to restrictions on maximum take-up of other modes. (This is not due to the introduction of a carbon constraint as this technology is taken up in both the base and constrained cases).

Figure 2.3 Transport fuel use (PJ) in 2020 (with and without additional transport constraints)



* BASE and 33/80 are Phase 1 runs without new transport constraints. BASE CFP and CF are the comparative runs with new transport constraints.

Figure 2.4 Fuel use (PJ) in 2020 by road transport technology (with and without additional transport constraints)

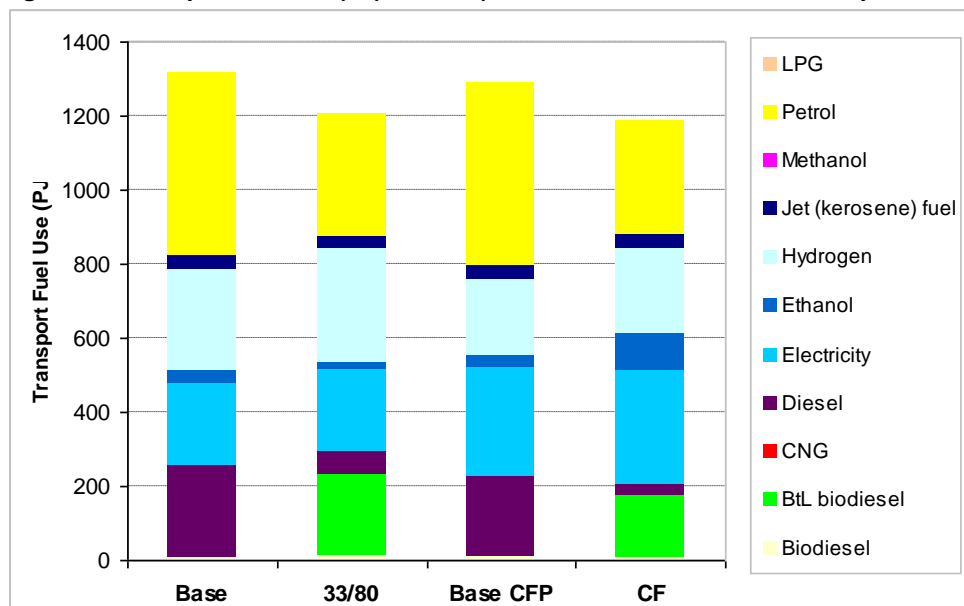


* BASE and 33/80 are Phase 1 runs without new transport constraints. BASE CFP and CF are the comparative runs with new transport constraints.

The baseline in 2050 (Base vs. BASE CFP), presented in Figure 2.5, shows a significant level of decarbonisation in the sector, despite no constraints, due to cost-efficiency savings in future vehicle technologies. Compared to the earlier baseline, a higher level of electricity use can be observed, whilst lower levels of diesel and hydrogen. This is primarily due to the relaxing of constraints on LGV uptake of electric vehicles, which dominate that mode in 2050, in place of hydrogen and diesel PHEVs.

In the constrained cases in 2050, a similar pattern can be observed vis-à-vis previous and new model runs. In addition, ethanol plays an increasing role, while hybrid diesels also have a larger market share, with the model choosing electric vehicles or diesel hybrids, rather than diesel PHEVs. The level of decarbonisation in this sector (by 2050) is at similar levels as observed under the Phase 1 analysis (without new constraints).

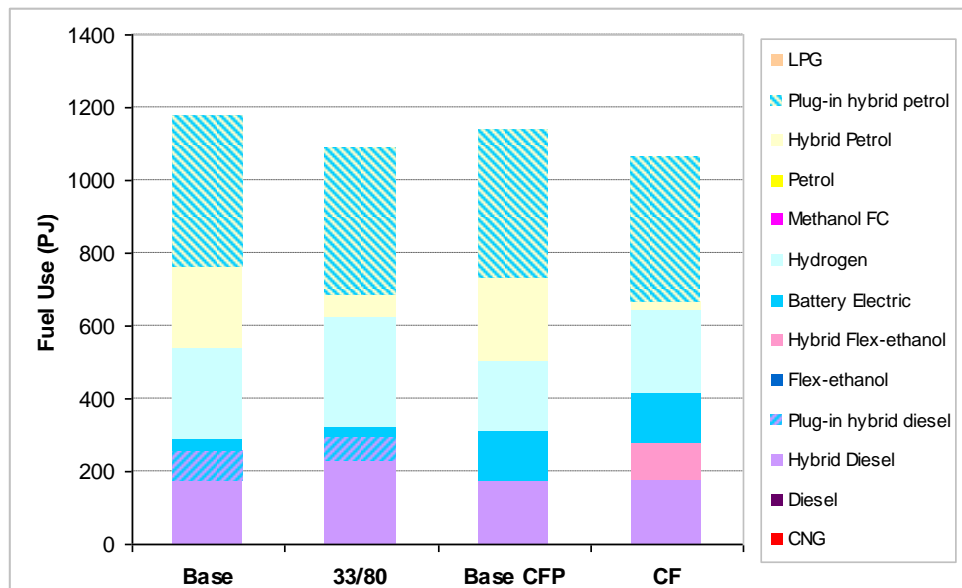
Figure 2.5 Transport fuel use (PJ) in 2020 (with and without additional transport constraints)



* BASE and 33/80 are Phase 1 runs without new transport constraints. BASE CFP and CF are the comparative runs with new transport constraints.

The corresponding vehicle technology splits are shown in Figure 2.6.

Figure 2.6 Fuel use (PJ) in 2050 by road transport technology (with and without additional transport constraints)



* BASE and 33/80 are Phase 1 runs without new transport constraints. BASE CFP and CF are the comparative runs with new transport constraints.

Transport sector contribution to mitigation targets

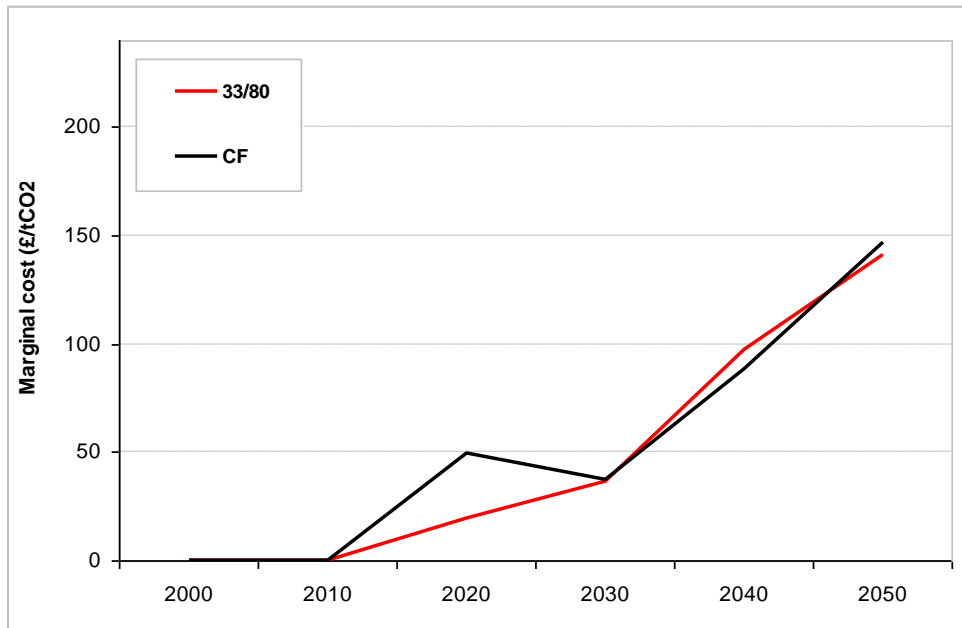
The transport sector decarbonises to a large extent (as discussed previously) under the baseline due to a move to increasingly cost-effective vehicles. Therefore, the additional emission saving under the baseline appears lower for this sector (at ~13% of the total in 2050). This contribution of the transport sector to mitigation targets occurs primarily post 2030.

In 2050, with the introduction of new constraints, the level of transport sector decarbonisation is broadly similar to that observed in the case without additional constraints. The transport sector does have higher emissions in 2020 (by about 20 MtCO₂); with the same requirement to meet a 33% reduction target; therefore, an increasing contribution from electricity, residential and industrial sectors to abatement levels is observed. For example, in the electricity sector, there is a slightly lower level of conventional coal new build and generation with very limited uptake of new coal CCS (equivalent to a new 1 GW plant). In the residential sector, limited uptake of biomass use in place of gas is observed.

Impact on costs of *less technology-optimistic* transport sector

The impact on the costs of the new constraints can be seen in Figure 2.7. In 2020, the marginal costs go up significantly with the imposition of these constraints, resulting in a higher emission baseline, and the requirement for larger CO₂ reductions.

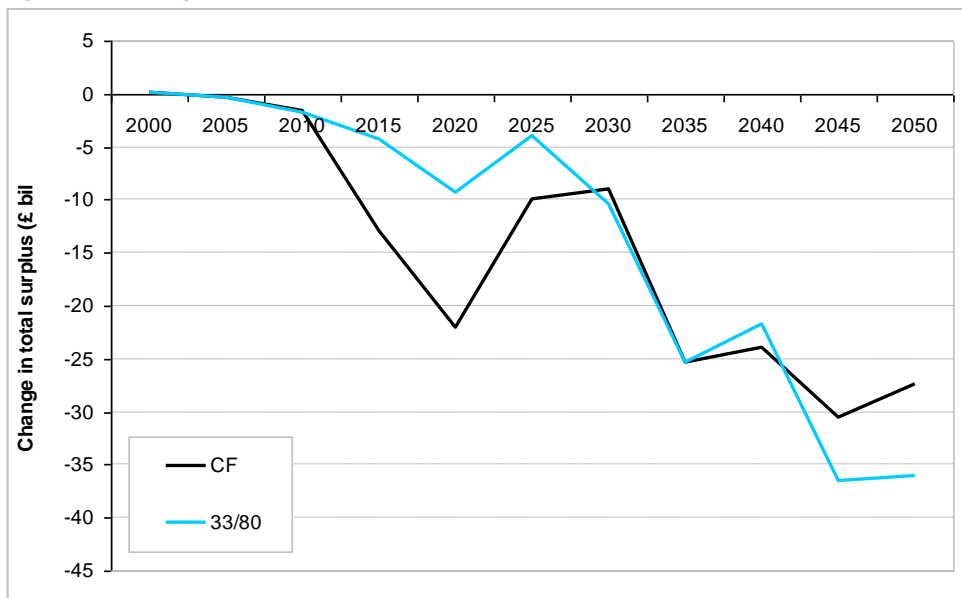
Figure 2.7 Marginal abatement costs (£/tCO₂) – 33/80 cases with and without transport constraints



* 33/80 case is the Phase 1 run without new transport constraints, while CF is the comparative run with new transport constraints.

Change in total economic surplus (as a result of carbon reduction targets) is shown in Figure 2.8 below. The most noticeable difference is in 2020, where losses are much higher due to the imposition of additional transport constraints (case CF). In the later period, the smaller losses could be part explained by the relaxation of constraints on specific transport types e.g. electric LGVs, but also by the longer lived mitigation options invested in 2020 e.g. in electricity generation sector.

Figure 2.8 Change in economic surplus (£ billion) – 33/80 cases with and without transport constraints



* 33/80 case is the Phase 1 run without new transport constraints, while CF is the comparative run with new transport constraints.

Total (cumulative) discounted losses in producer and consumer surplus equal £121.2 billion under the 33/80 case without new constraints compared to £123.6 billion with constraints.

3 Renewable electricity generation targets

The recent proposals by the European Commission, as presented in the recent Climate and Energy Proposals² will require the UK to significantly increase its use of renewable energy. The 2020 target of 15% renewable energy use will mean that the contribution by the electricity sector will need to be much higher than that considered in recent years (for example under the Renewables Obligation (RO)).

To consider the impact of a higher renewable generation target, a set of model analysis was undertaken, setting the renewable generation target at 32% by 2020 and in subsequent periods (rather than 15%, which has been used in all other model analysis to reflect the RO level at the time of the 2006 Energy Review).

Results for the following runs have been presented in this section of the report (graph name in brackets):

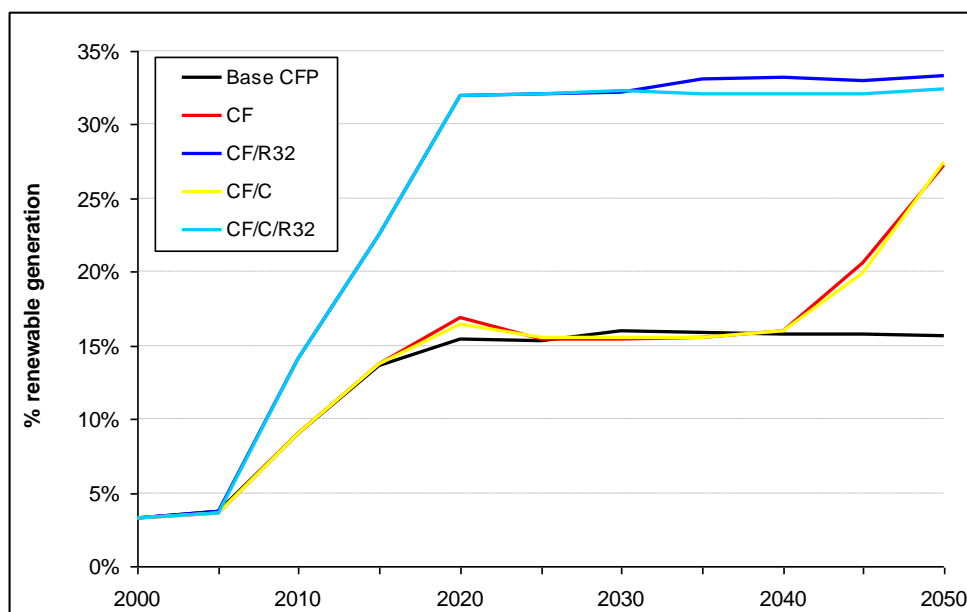
- 33/80, without credits (33/80 + TC)
- 33/80, without credits and REN32 (CF/R32)
- 33/80, with credits (CF/C)
- 33/80, with credits and REN32 (CF/C/R32)³

Where relevant, in this analysis all constrained runs using the 32% renewable generation level are compared to a baseline based on a 15% renewable generation target.

Renewable electricity generation levels

Figure 3.1 shows the level of renewable generation as a % of total generation for the different runs being considered. Interesting findings include a lower renewable generation level post-2030 in the REN32 cases as a result of international credits being available, and the significant increase in renewable generation post-2040 in the non-REN32 cases, due to the 80% constraint, and the importance of the contribution of renewable electricity generation to CO₂ mitigation.

Figure 3.1 Levels of renewable electricity generation in 33/80 runs at 15%/32% target levels and with / without international credits



* In the series labels, all non-base cases use 33/80 trajectory. 'C' implies 'with credits', 'CF' implies 'central fossil fuel prices' and 'REN32' implies use of 32% renewable generation target by 2020

² 20/20/20 by 2020: Europe's climate change opportunity, http://ec.europa.eu/environment/climat/climate_action.htm

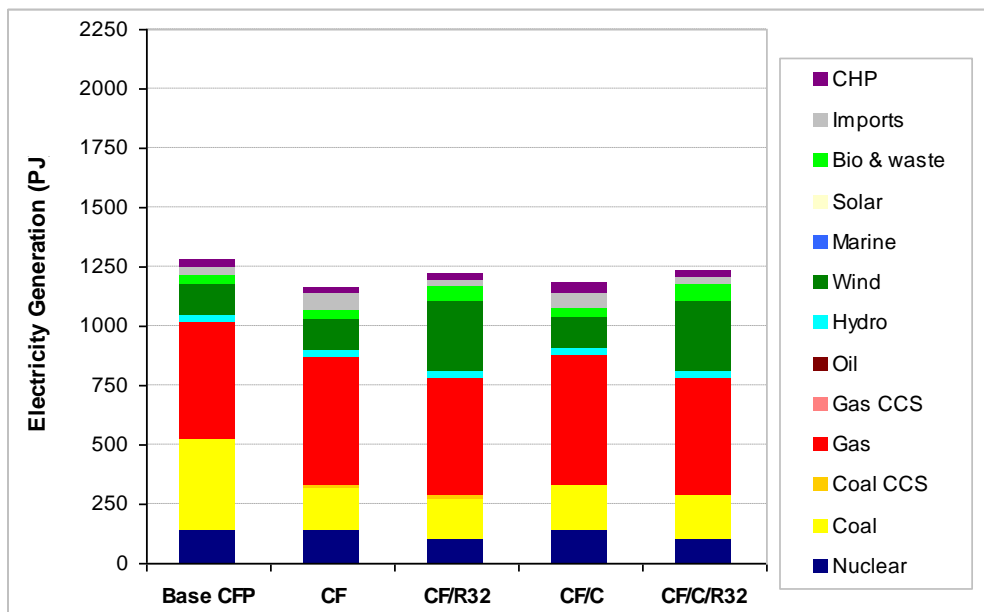
³ Bracketed text is the label used in the graphs; 'C' implies 'with credits', 'CF' implies 'central fossil fuel prices' and 'REN32' implies use of 32% renewable generation target by 2020.

Figure 3.2 provides an understanding of the type of renewable generation that is selected in the model to meet the 32% target. In 2020, it is primarily additional wind generation and some additional biomass generation that ensures the target is met. Nuclear and gas generation levels are reduced as a consequence, with overall generation levels slightly increased.

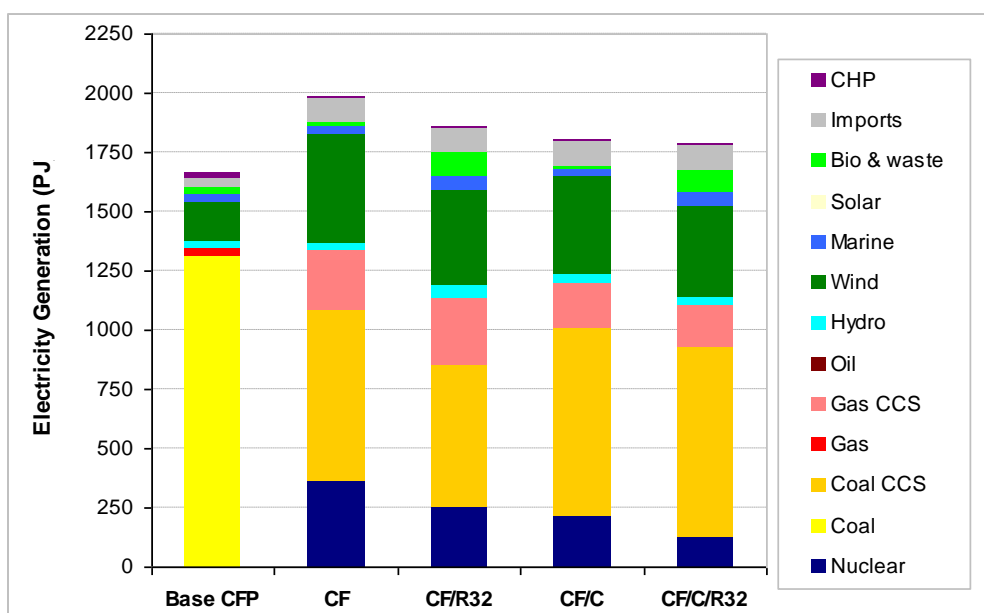
In 2050, renewable generation levels are still higher, with similar levels of wind generation but higher biomass / marine generation. Overall levels of generation are also lower in 2050, potentially reflecting the higher cost of electricity, and impact on demand for this energy type. The introduction of international credits allows the generation sector (in 2050) to provide more coal CCS generation and reduce the levels of lower carbon generation (nuclear and gas CCS).

Figure 3.2 Electricity generation levels (PJ) in 2020 / 2050 for model runs with and without 32% renewable generation target

2020



2050

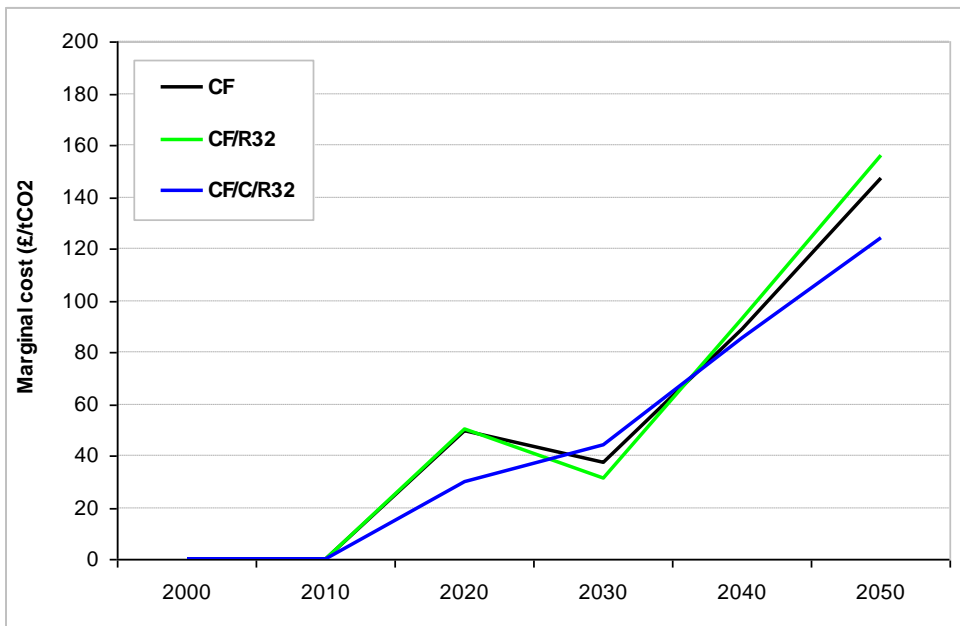


* In the series labels, all non-base cases use 33/80 trajectory. 'C' implies 'with credits', 'CF' implies 'central fossil fuel prices' and 'REN32' implies use of 32% renewable generation target by 2020

The costs of higher renewable generation

A 32% target in 2020 does not appear to increase the system marginal cost because the marginal technology does not change; in the electricity generation sector, no new technologies appear in the mix, but increased deployment of the same technology. In 2030, the marginal cost is lower but then slightly higher post 2035. This reflects differences in the timing of investments in this sector across different periods. The availability of credits results in lower marginal costs in those periods where the credit price is lower than the system marginal costs (all periods except 2030).

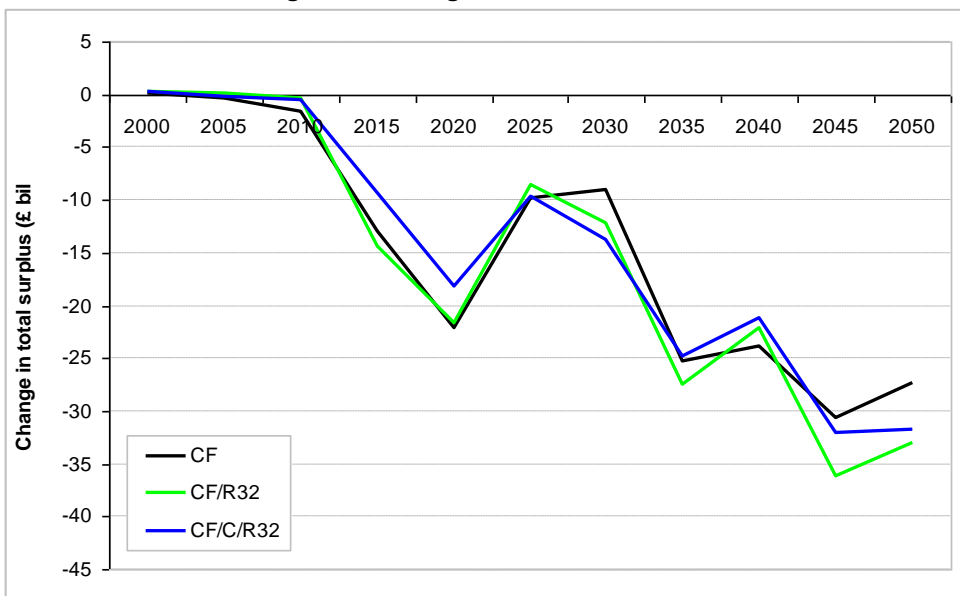
Figure 3.3 Marginal costs (£/tCO₂) associated with and without a higher 2020 renewables generation target



* In the series labels, all cases use 33/80 trajectory. 'C' implies 'with credits', 'CF' implies 'central fossil fuel prices' and 'REN32' implies use of 32% renewable generation target by 2020

Total discount losses in producer and consumer surplus equal to £123.6 billion under the CF (standard 33/80) case compared to £143.8 billion with REN32; with credits this loss is lower at £137.4 billion.

Figure 3.4 Annual change in economic surplus (£ billion) associated with and without a higher 2020 renewables generation target



* In the series labels, all cases use 33/80 trajectory. 'C' implies 'with credits', 'CF' implies 'central fossil fuel prices' and 'REN32' implies use of 32% renewable generation target by 2020

Impacts of a higher renewable target on other sectors, and their contribution to abatement

Using an integrated systems model allows for the effect of the imposition of a target on one sector to be seen across the wider system.

With a higher renewable target, primary energy use is reduced post 2020, as less fossil fuels are used in the electricity generation sector, plus a small increase in electricity production (used in end use sectors) results in slightly less gas use. The contribution to emission reductions is similar across sectors in 2020 and 2050. Limited changes are therefore seen in uptake of technology options across the different end use sectors.

The availability of credits in the REN32 case does result in a number of differences. There are higher overall levels of energy use in 2020 and 2050. As observed in other *with credits* cases, the required domestic contribution to reduction targets is reduced; in this case we can observe a lower contribution to abatement levels in 2050 across all sectors, particularly from transport and residential sectors. In addition, there are lower levels of low carbon technologies in the electricity generation sector by 2050 (nuclear / gas CCS), but not for Coal CCS. In the transport sector, lower levels of hybrid diesel and higher levels of flex-ethanol technologies in 2050 for credit cases are observed. There is also no use of BtL biodiesel in hybrid diesels, compared to 100% use in cases where no credits are available.

4 High fossil fuel prices

BERR produced a revised set of fossil fuel price projections in May 2008.⁴ The majority of the model runs undertaken in this analysis use the central fossil fuel price assumptions. In this section of the report, we present the results of a set of analysis using *High High* fossil fuel price, focussing on the impacts on technology choice and system costs. This is a particularly relevant sensitivity analysis in view of the high energy prices experienced in recent months.

The following runs were considered (all with *high high* fossil fuel prices):

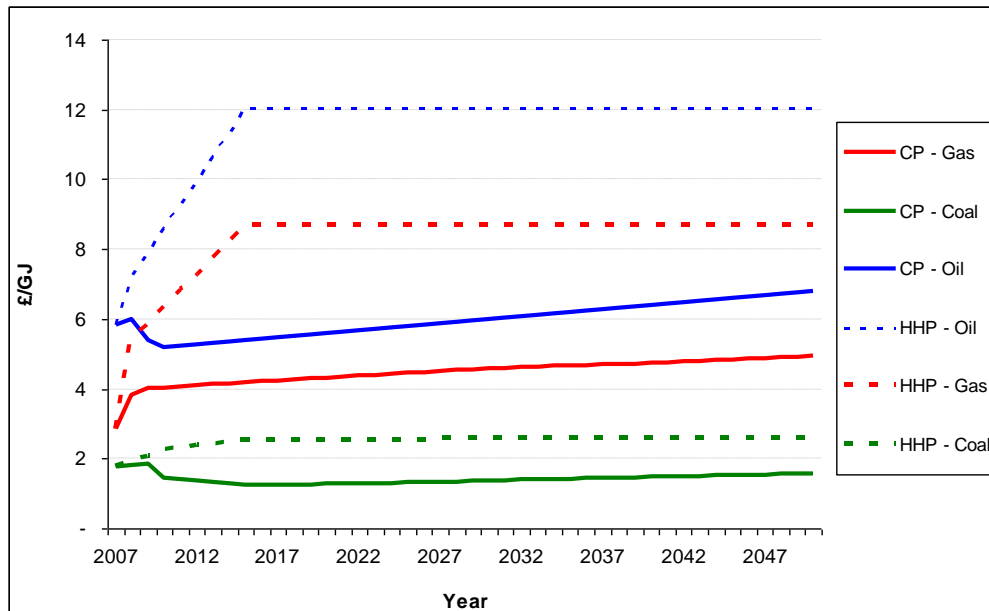
- Base standard (HHF Base)
- 33/80, without credits (HHF 33/80)
- 38/90, without credits (HHF 38/90)

In modelling the impacts of this higher fossil fuel price case, consideration has to be given to the differences between domestic production, characterised in the model on a production cost basis, and fuel imports reflecting prices of delivered energy based on global fossil prices. When implementing the higher prices, it is only the import prices that are scaled, as it is difficult to scale the domestic production costs. To ensure that the model does not shift completely to domestic production, some of the higher cost domestic production tranches for liquid fuels, not used by the model in the standard 33/80 cases, are switched off.

Although the upstream choices of domestic production versus import are important, the focus of the analysis is to assess the impact of increased prices on technology choices in downstream sectors rather than shifts in the balance between imports, exports and domestic production upstream.

The changes in price from central to a high-high case are shown in Figure 4.1.

Figure 4.1 Fossil fuel prices (£/GJ) for central (CP) and high-high (HHP) cases as used in the analysis



* The high-high oil price is consistent with a price of \$150 per bbl (from 2015 onwards).

Impact of higher fossil fuel prices on energy demand

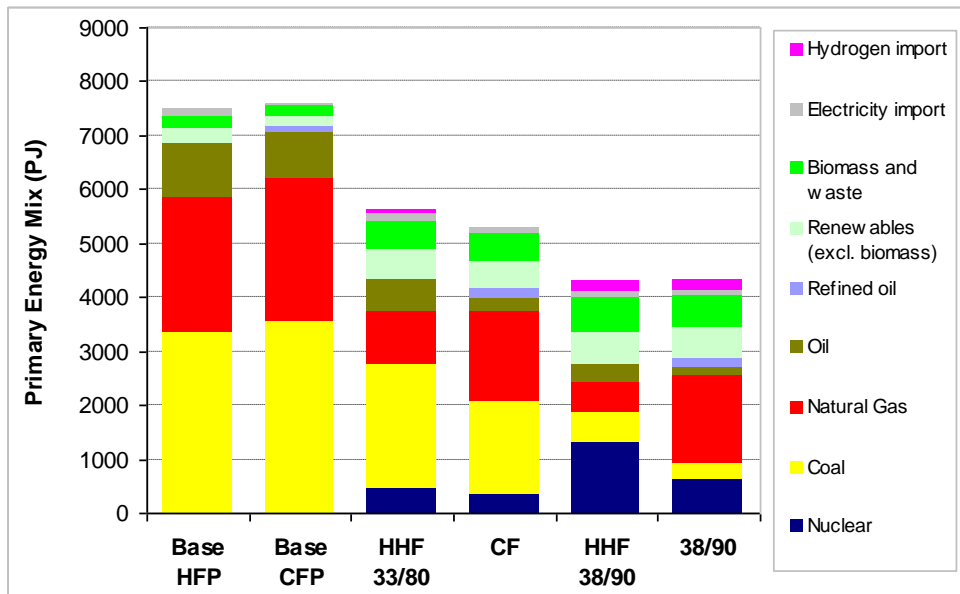
Under the high price baseline (and compared to the central price baseline), slightly higher levels of overall primary energy use out to 2030 can be observed; post-2030, the levels are slightly lower. Pre-2030, the slightly higher levels are due to increased domestic refining of oil products and lower levels

⁴ COMMUNICATION ON BERR FOSSIL FUEL PRICE ASSUMPTIONS - Update to present the latest fossil fuel price assumptions following the January 2008 Call for Evidence, BERR, May 2008

of imported refined products. As discussed above, this is driven by the relative higher import prices now used versus domestic production costs. The differences are only observed in the upstream sector; final energy use levels are comparable across the time series.

In 2050, differences in primary energy demand are shown in Figure 4.2. Under the 33/80 case, we can observe higher levels of coal use and lower levels of gas use, due to the impact of the relative price differentials on electricity generation (CCS) choices. In the 38/90 case, nuclear generation increases at the expense of gas CCS, with a small increase in coal generation. Most of the main energy demand changes are driven by choices in the electricity generation sector. End use sector use of gas, for example, does not change significantly.

Figure 4.2 Primary energy demand (PJ) for high fossil fuel price cases in 2050



* HHF /HFP are the equivalent high-high fossil fuel price cases; CF is the 33/80 case

Impact on costs of higher fossil fuel prices

Higher fossil fuel prices do not appear to drive increases in marginal costs of abatement (as shown in Figure 4.3). This is primarily due to a lower level of baseline CO₂ emissions, and consequently mitigation action required. The emission reductions required across the model time horizon are shown in Figure 4.4.

Figure 4.3 Marginal costs (£/tCO₂) associated with higher fossil fuel prices

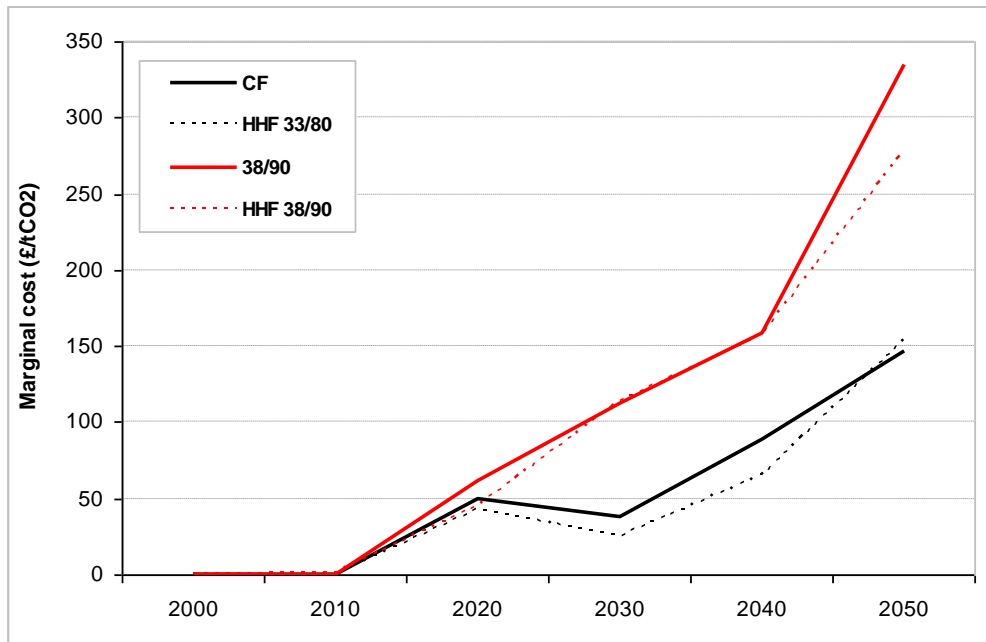
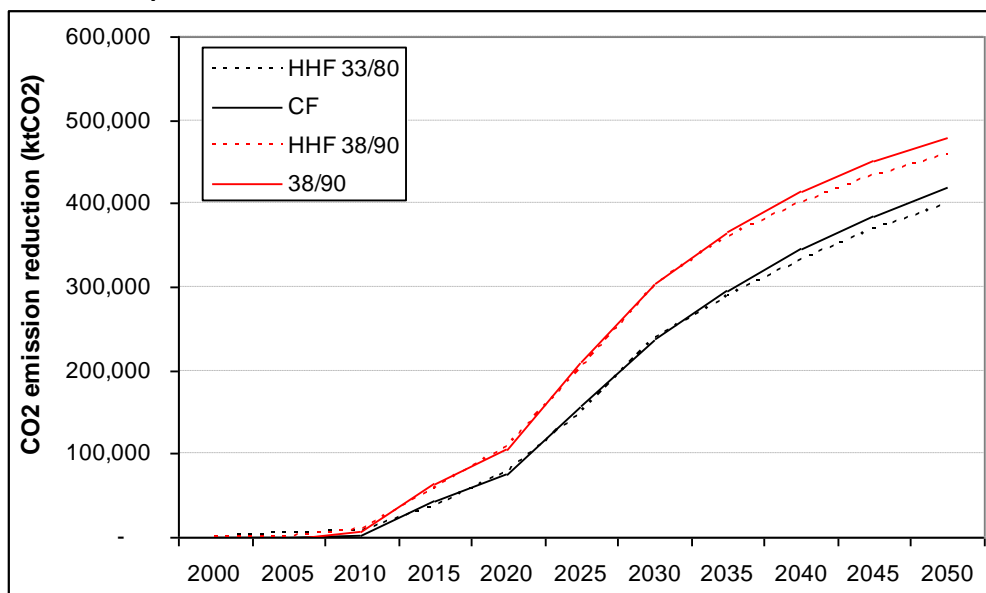
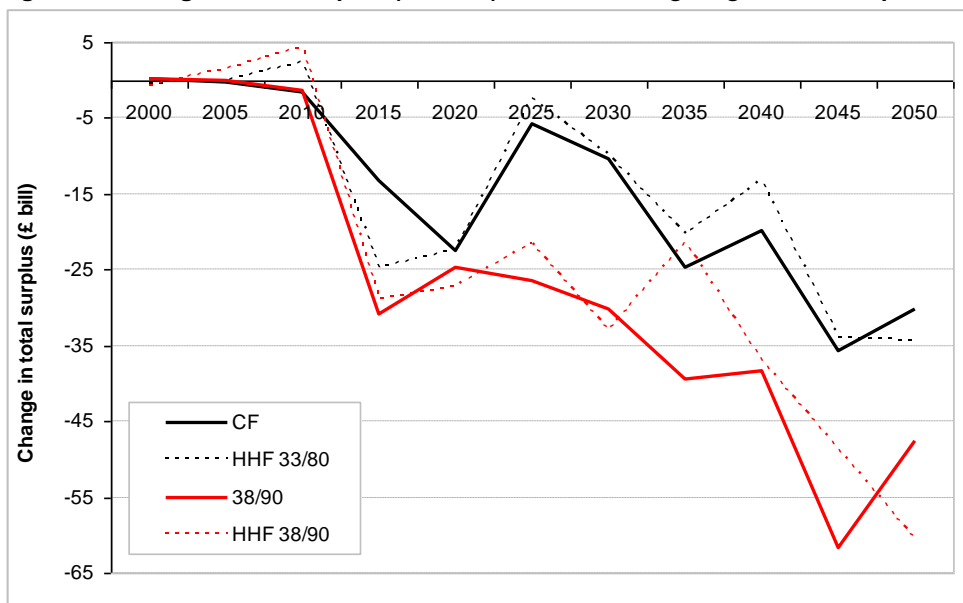


Figure 4.4 CO₂ emission reductions (ktCO₂) between 2000 and 2050 for high fossil price vs. central fossil price cases



Compared to the central fossil price case, the losses in economic surplus are smaller, primarily due to the lower emission baseline and the consequent lower reduction requirements. The discounted loss in surplus over the model time horizon for the central fossil price 33/80 case (CF) was £123.6 billion compared to £99.4 billion. Under the 38/90 central price case, discounted losses amount to £241.1 billion compared to £200.9 billion under high fossil price case. The annual undiscounted losses are shown in Figure 4.5, and in most periods show lower losses under the high fossil cases.

Figure 4.5 Change in total surplus (£ billion) for selected *high high* fossil fuel price cases

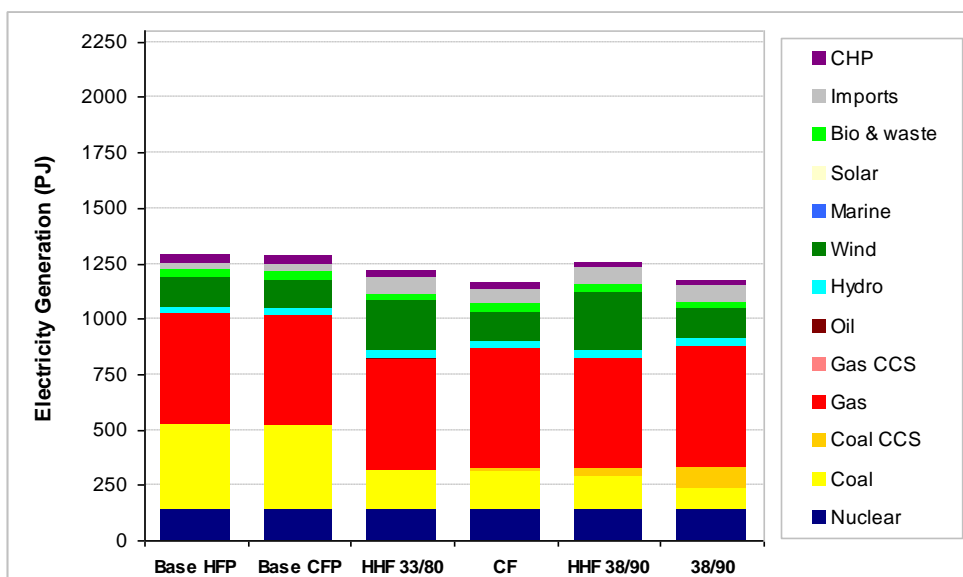


Changes to technology pathways

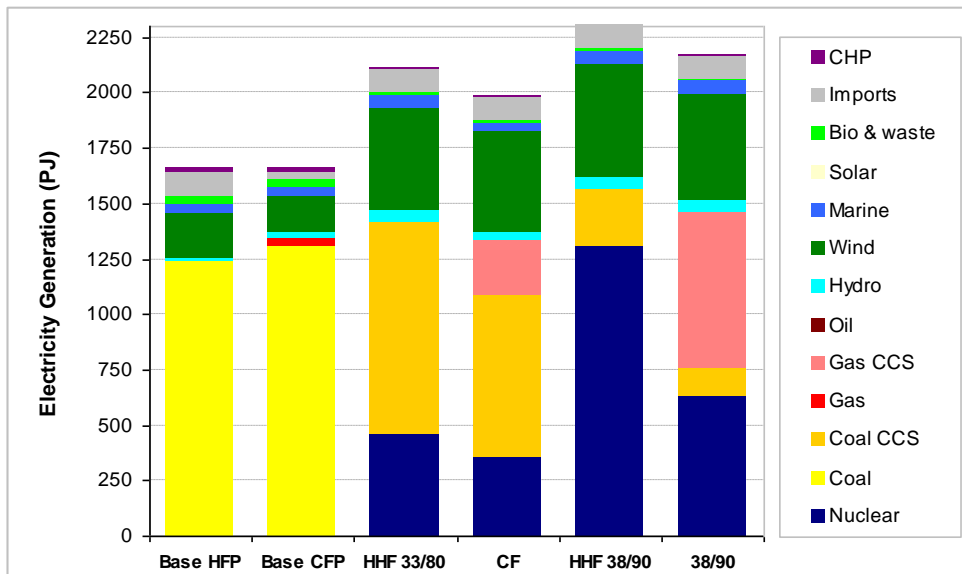
Electricity generation sector is a key driver of changes in primary energy demand under a high fossil fuel price assumption. The generation mix under the central and high fossil price cases is shown below in Figure 4.6. In 2020, higher fossil prices result in a doubling of wind generation, with reduced generation from gas and a slightly higher overall production level. Mitigation from this sector comes from the increased wind generation, with no coal CCS or lower levels of CCS technology uptake. Nuclear does not play an increased role in 2020 due to near term bounds on generation share.

In 2050, the main changes observed include an increased role for nuclear, significantly under the 38/90 case, no role for gas CCS and slightly higher levels of coal CCS. This illustrates the significant impact on the cost effectiveness of gas generation technologies from changes in fuel price. In both 2020 and 2050, total generation levels are higher, with small increases in demand across all end use sectors.

Figure 4.6 Electricity generation (PJ) for selected central and high fossil model runs 2020

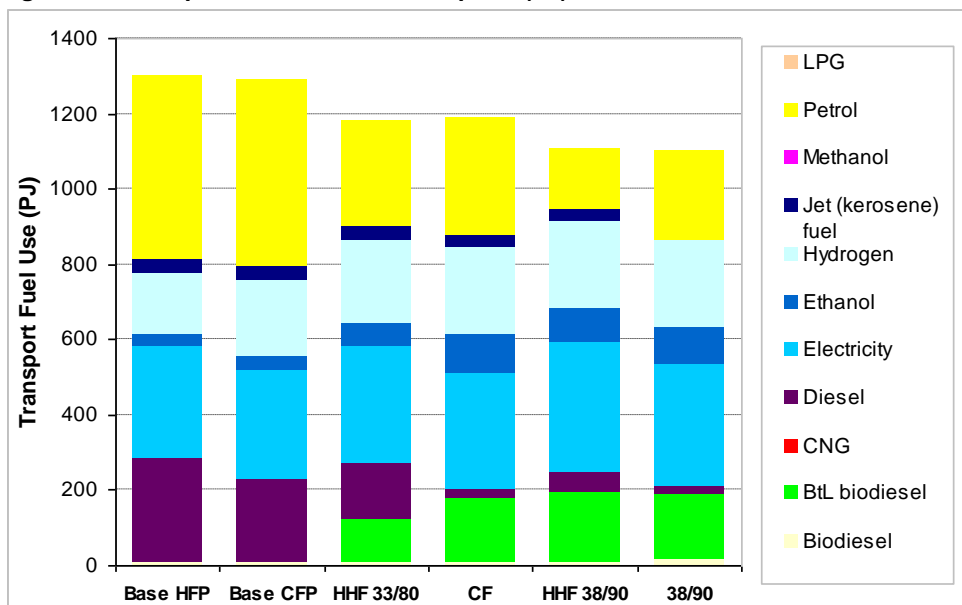


2050



The higher oil prices in the model result in a limited penetration of hydrogen and second generation biodiesel by 2020 for both the 33/80 and 38/90 cases. In 2050 (as shown in Figure 4.7), diesel use is significantly higher under the 33/80 trajectory, with lower use of biofuels, reflecting the lower mitigation requirements. The same is true of the 38/90 case, although the increased diesel / reduction in biofuels use are less significant.

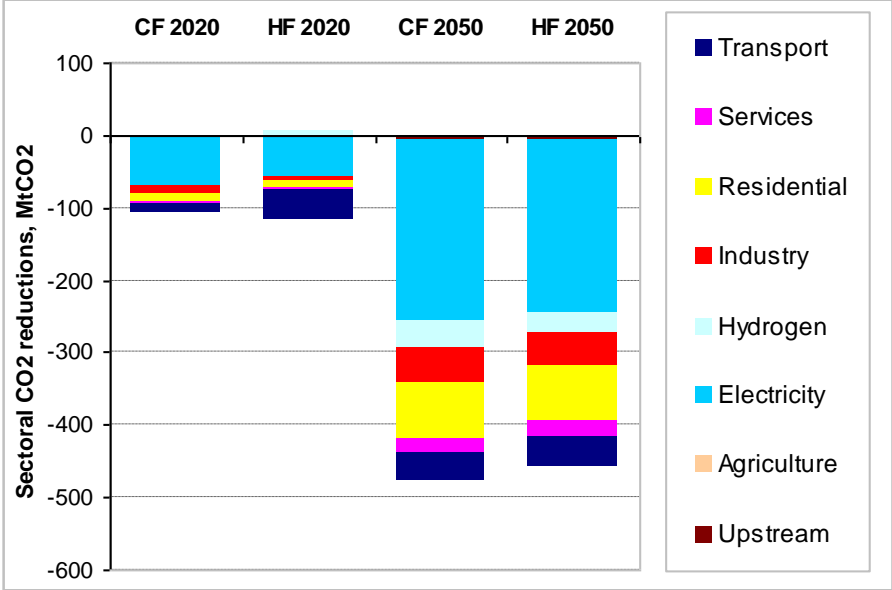
Figure 4.7 Transport sector fuel consumption (PJ) in 2050 for selected central and high fossil model runs



Mitigation efforts by sector under high fossil price cases

Mitigation efforts differ between the central and high fossil prices cases only to a limited extent (see Figure 4.8). In 2020, mitigation required (in absolute terms) is slightly higher under the high price case. Transport sector contribution increases significantly in this year, due to the reduction in the use of conventional liquid fuels. In 2050, less fossil fuel use in the baseline (in electricity and hydrogen production sectors) results in lower emissions and lower mitigation requirements. As a result, in 2050, higher levels of mitigation in the electricity sector are apparent in the CF case.

Figure 4.8 CO₂ emission reductions (MtCO₂) by sector in 2020 and 2050 for high and central fossil price cases under a 38/90 trajectory



5 International aviation

An issue currently under consideration by the CCC is whether to recommend the inclusion of the international aviation sector in the 2050 target. At present, this sector is not formally included in the reduction targets under the Kyoto Protocol, and is not included in the minimum 2050 target of 60% recommended in the draft Climate Change Bill.

This section of the report considers the impacts on choice of abatement options and costs of including the international aviation sector in long term reduction targets. The UK MARKAL model (Macro version) has been used previously to assess such impacts previously.⁵ In this analysis, we have used the definition of international aviation used in the Defra analysis (2007), where projections are consistent with the national aviation bunker fuel consumption and CO₂ emissions, i.e. they only account for the first legs of departing (outward) flights from the UK.

Updated passenger kilometres data projected to 2050 have been provided by Department for Transport, and provide the basis for energy service demands used in the model. These projections do take account of capacity constraints that are may be incurred in the absence of rapid airport expansion. The 1990 emission reduction trajectory is based on a total 15.7 MtCO₂ for the international aviation emissions (on a bunker fuels basis).

Three model runs have been undertaken in this section of the report – a revised baseline to include the international aviation sector, a constrained run using 33/80 reduction target trajectory, and an equivalent constrained run except with life cycle emissions attributed to bio-kerosene use.

Impacts on the international aviation sector

A key factor in the assessment of international aviation is the limited characterisation of technologies to meet sectoral energy service demands. MARKAL contains three technologies for international aviation:

- Conventional aircraft using kerosene
- Advanced aircraft using kerosene (such as Blended Wing Body (BWB) design)
- Hydrogen-fuelled aircraft

Conventional and advanced kerosene aircraft are also able to use bio-kerosene in the model, either imported or domestically produced, using Fischer-Tropsch processes. In the model, this and other biofuels are considered carbon-free i.e. lifecycle emissions are not accounted for; however, a sensitivity has been undertaken to attribute life cycle emissions to bio-kerosene at 50% of conventional kerosene levels, based on an understanding of the life cycle emissions associated with 2nd generation bio-kerosene production. This provides insights into how the model decision making changes when life cycle emissions are considered.

Under the baseline scenario, kerosene remains the predominant technology between 2000 and 2050. However, significant uptake of advanced kerosene aircraft can be observed post-2030, rising to 46% of total demand by 2050. This reflects the uptake of a more cost-effective technology that would be taken up even in the absence of a CO₂ constraint.

The uptake of international aviation technologies is similar under the 33/80 constrained case. The only difference is that the uptake of the advanced kerosene technology occurs faster out to 2030, before slowing down and reaching a maximum of 47% in 2050. (Uptake of advanced kerosene aircraft is limited to 50% of total demand provision). No hydrogen is used in either case.

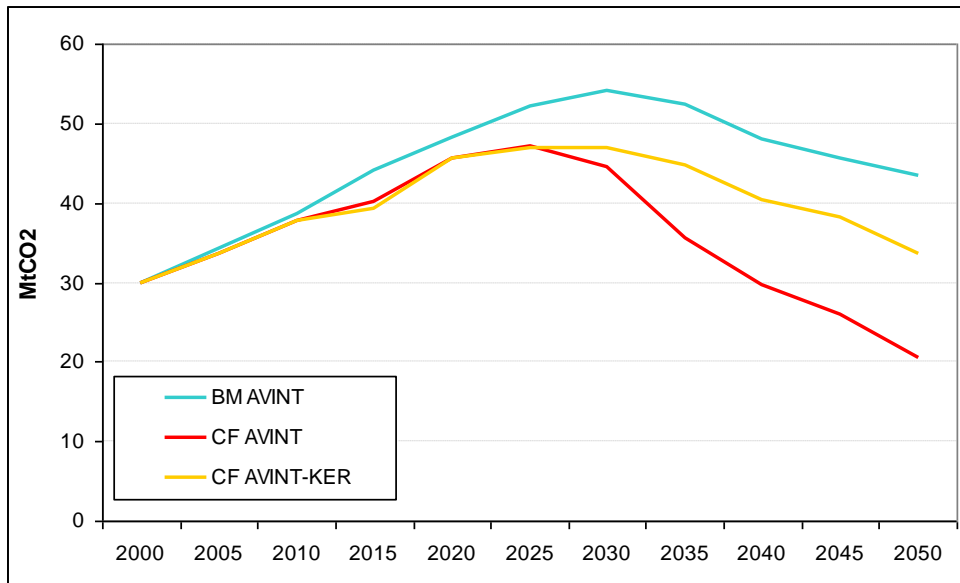
⁵ See 1) IPPR / WWF, 2007, 2050 Vision: How can the UK play its part in avoiding dangerous climate change, Institute for Public Policy Research / World Wildlife Foundation UK, <http://www.ippr.org.uk/publicationsandreports/publication.asp?id=572> and 2) DEFRA, 2007b, MARKAL Macro analysis of long run costs of climate change mitigation targets, Analysis by AEA Energy and Environment, Available at: www.defra.gov.uk/environment/climatechange/research/index.htm

CO₂ emissions and mitigation options

CO₂ emissions from international aviation under the baseline and constrained case are shown in Figure 5.1. It is important to note that the CO₂ emission projections presented are model outputs, and are not DfT emissions projections.

In this analysis and in line with current inventory accounting, no adjustment has been made to the GWP of CO₂ emitted from international aviation to account for release at high altitude. It can be observed that in the baseline emission rise significantly to 2035. The uptake of advanced kerosene aircraft (to near 50% of the fleet) results in a gradual decline in emissions to 2050.

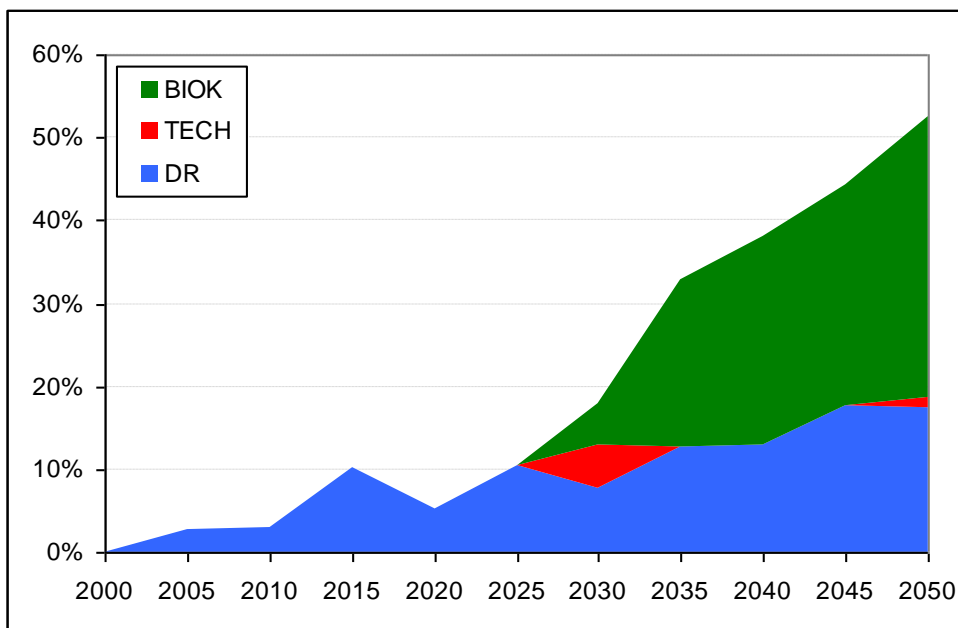
Figure 5.1 CO₂ emissions (MtCO₂) from the international aviation sector, 2000-2050



* BM AVINT is the with international aviation baseline, CF AVINT is international aviation case with 33/80 constraint, and CF AVINT-KER is the case with CO₂ emissions attributed to bio-kerosene

Under the constrained run (CF AVINT), by 2050 sectoral emissions have been reduced by 53% of the baseline level. As shown in Figure 5.2, 17% of this reduction is accounted for by demand reduction (through the model's price response function) while the remaining is from switching from kerosene to bio-kerosene. This increase in bio-kerosene uptake directly results in a lower uptake of second generation biodiesel in the road transport sector. In a number of earlier periods, there is also a contribution from increased uptake of advanced kerosene aircraft, relative to the baseline.

Figure 5.2 Contribution (% of total sector emissions) to international aviation sector abatement levels under constrained 33/80 case, 2000-2050



* In the legend, BIOC is bio-kerosene mitigation, while TECH is improved aircraft design and DR is demand response

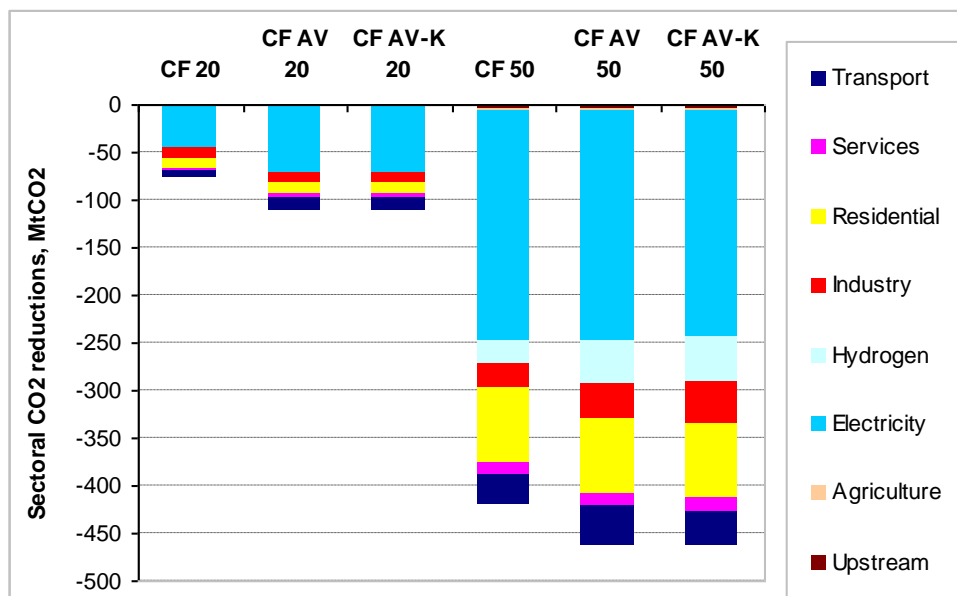
When CO₂ emissions are allocated to bio-kerosene, it is no longer used as a fuel type. All sector mitigation is due to demand response within the sector, with slightly higher levels of advanced kerosene aircraft than observed in the baseline.

The introduction of international aviation results in additional reduction of 45 MtCO₂ required. In the two cases, the international aviation sector reduces its own emissions by 23 and 10 MtCO₂ (in the bio-kerosene emissions case). This inevitably means that additional reductions are required across other sectors.

The additional mitigation required in the non-aviation sectors results in a more challenging sets of targets than those under the 33/80 trajectory. Under the constrained case, the reduction required by non-aviation sectors in 2050 is 84%; when CO₂ emissions are allocated to bio-kerosene, the reduction required is 87%.

Figure 5.3 below illustrates the level of emission reduction across different sectors for the *with* and *without international aviation* cases. Whilst these figures are not exactly comparable (due to different baselines), they provide an indication of where additional mitigation efforts are taking place. (This assumes that the technology choices in the *with international aviation* baseline for other sectors are similar to those in the *without international aviation* baseline).

Figure 5.3 CO₂ emission reductions (MtCO₂) under cases with and without international aviation sector included



* CF AV is international aviation case with 33/80 constraint, and CF AVK is the case with CO₂ emissions attributed to bio-kerosene. CF is the standard 33/80 case.

In 2050, specific changes in other sectors result from the need for increased mitigation in the CFAV and CFAVBK (with bio-kerosene emission) runs. Most additional mitigation is from the following:

- Switching to electrolysis in the hydrogen production sector instead of gas SMR
- Increase generation of low carbon electricity (due to hydrogen production sector demand)
- Increase demand reduction in the industrial sector, and higher electricity use

In comparison to the CFAV case, under CFAVBK where more non-aviation sector mitigation is required higher electricity generation levels are observed, with increased demand in industry and services sector. The road transport sector also uses less petrol, replaced by increased levels of hybrid diesel using second generation biodiesel.

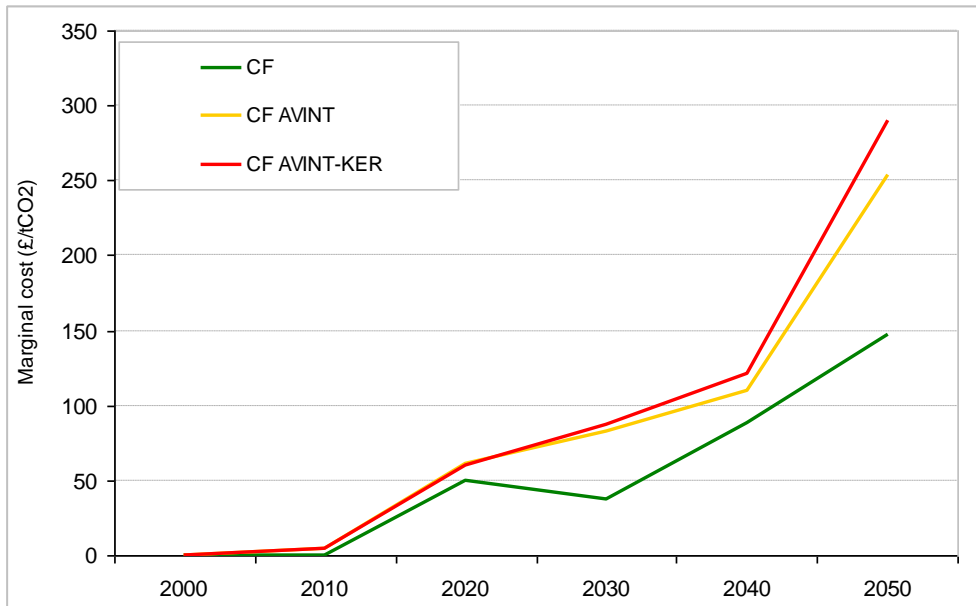
Mitigation required across other sectors would of course be much higher if demand was more inelastic for this sector, and there was a reduced the role of biofuels,⁶ both critical mitigation routes for this sector in our analysis.

Impacts on the wider energy system costs

It is important to understand the cost implications of the including international aviation under a longer term target. This can be observed through analysing the marginal abatement cost of CO₂ relative to the costs under the same trajectory (33/80) without the international aviation sector included. By 2050, marginal costs exceed £250/tCO₂, compared to just under £150/tCO₂ under the standard 33/80 case. This is intuitive given that the absolute reduction level required is greater, and that options to reduce emissions from this additional sector are not particularly cost-effective (relative to other sectors).

⁶ Concerning biofuels, there are many issues around sustainability and the effect of life cycle emissions on the role of biofuels as part of a robust mitigation strategy. Therefore, some care has to be taken in determining what their future role might be within climate policy.

Figure 5.4 Marginal costs (£/tCO₂) associated with the inclusion of the international aviation sector

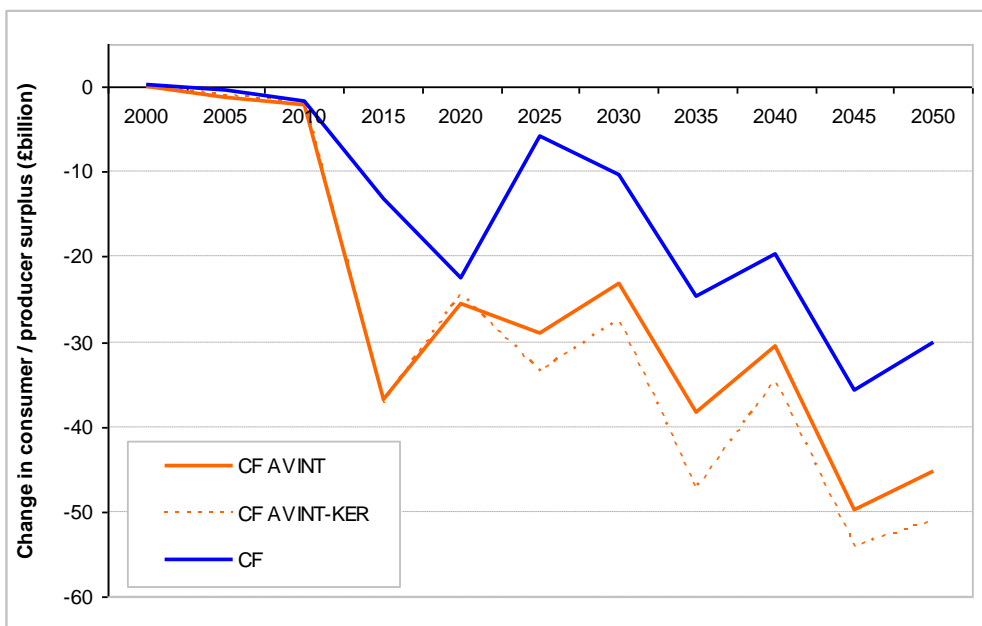


* CF AVINT is international aviation case with 33/80 constraint, and CF AVINT-KER is the case with CO₂ emissions attributed to bio-kerosene. CF is the standard 33/80 case.

Total loss in discounted economic surplus is equal to £189.2 billion in the case where international aviation is included and £228.1 billion in the *with biokerosene emissions* case (compared to £123.6 billion in the standard 33/80 trajectory case). Note that this is the discounted cumulative loss relative to the baselines (which are different for both cases). The inclusion of international aviation therefore results in a 50% increase in discounted losses, and this could be higher if life cycle emissions were accounted for, a less optimistic technology outlook was used, and higher impacts of high altitude emissions were considered.

The annual reduction in economic surplus (as compared to the relevant baselines), which feed into the discounted cumulative surplus losses, is shown in Figure 5.5 below.

Figure 5.5 Reduction in economic surplus (£ billion) associated with the inclusion of the international aviation sector



6 Other sensitivity analysis

A wide range of other sensitivity analyses have also been undertaken under this phase of the work, providing additional insight on a range of model assumptions. They have been categorised (and presented) as follows:

- **Technology sensitivities.** These runs consider the impact of restricting key low carbon technologies, such as CCS and nuclear, and how a higher renewables target and the availability of international credits affects the costs and technology choices.
- **Alternative trajectories.** Different 2020/2050 target cases have been considered, and compared to the 33/80 case.
- **Two stage runs.** These model runs fix large scale investment based on a less stringent scenario, and then run the optimisation on a different constraint trajectory.
- **Other sensitivities.** These runs consider a range of sensitivities, from use of a lower discount rate to imposition of targets late in the model time horizon.

6.1 Low carbon technology sensitivities

The following model runs were undertaken (all using central fossil fuel prices) to explore the role of low carbon technologies on the system's ability to meet stringent long-term CO₂ reductions and renewable targets.

- 33/80, without credits and No CCS (CF/CCS)
- 33/80, without credits and No CCS/Nuclear (CF/CCS/NUC)
- 33/80, without credits, REN32 and No CCS (CF/R32/CCS)
- 33/80, without credits, REN32 and No CCS/Nuclear (CF/R32/CCS/NUC)
- 33/80, with credits and No CCS (33/80 CR CCS)
- 33/80, with credits, REN32 and No CCS (33/80 CR CCS R32)
- 38/90, without credits and no new CCS build (38/90 CCS)
- 38/90, without credits and no new nuclear or CCS build (38/90 CCS/NUC)

Electricity generation sector evolution

The sector of interest in this analysis is electricity generation, where restricting the uptake of key low carbon technologies can have major implications for the wider system and cost of mitigation. Generation by technology type is shown in Figure 6.1, in 2030 and 2050 across the range of sensitivity cases.

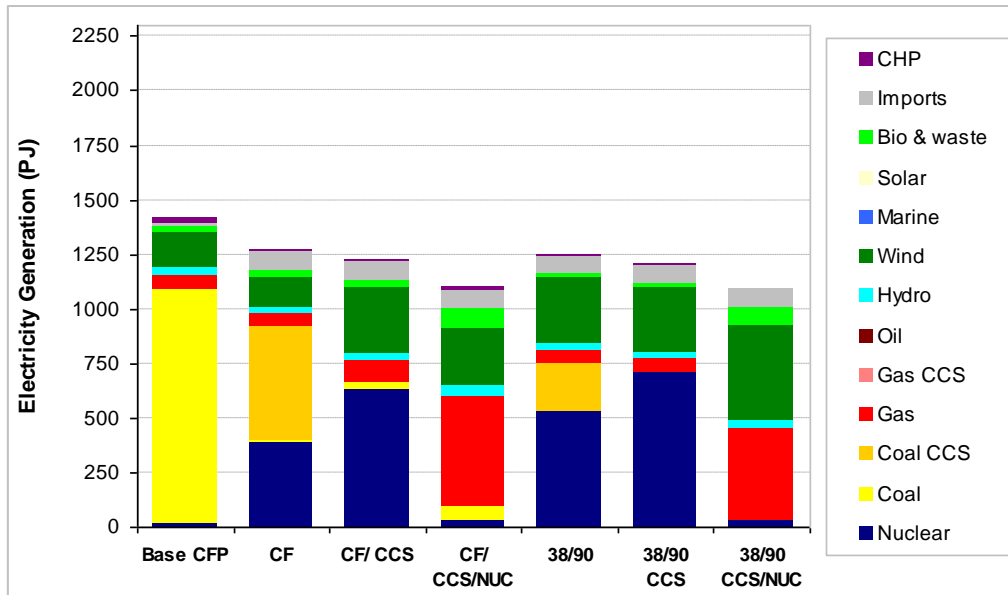
In 2030, under the 33/80 case, where no CCS is available, the electricity generation sector increases output using wind and nuclear technologies. There is also a small increase in gas generation. By 2050, all CCS is replaced by nuclear, although not to the same level; hence a reduction in overall generation levels. Where no nuclear power technologies are available, gas is the main generation technology, with a small increase in biomass. In 2050, a very different generation picture emerges, with wind, gas and marine generation technologies contributing significantly.

Under a 38/90 case, a similar trend can be observed for 2030 and 2050. Interestingly, in 2050 under the no nuclear / CCS case, generation levels drops significantly, with the sector dominated by wind (including some storage) and marine generation. In reality, there are significant questions raised in respect of the feasibility under this extreme case, in respect of electricity system operation when using high intermittent sources and dealing with peaking demand load. The simplistic characterisation of the peak demand in this MARKAL model enables such solutions. (Note that MARKAL / TIMES both have fully flexible time slicing capabilities to allow for much more detailed modelling of peak demand in the future).

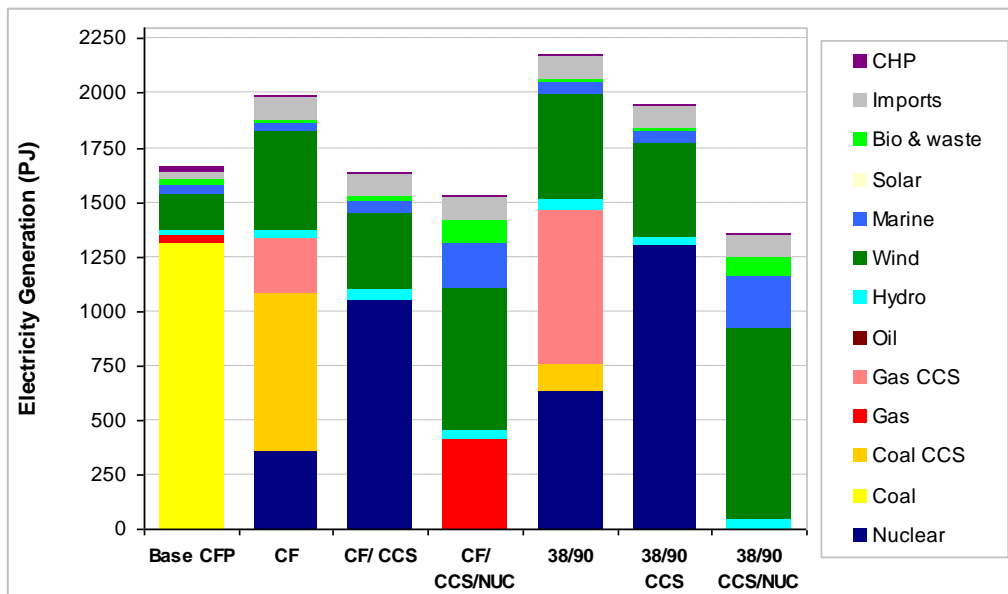
Some sensitivity runs have been undertaken to look at the impact of a higher renewable target on the 33/80 no nuclear and no nuclear /CCS cases, and credits availability on the no CCS cases. The impact of a higher renewables target is limited, due to the fact that renewable generation levels increase due to the absence of key low carbon technologies. The *with credits* cases (not shown above) for the no CCS runs have limited impact on the generation mix.

Figure 6.1 Electricity generation (PJ) in 2030 / 2050 for selected low carbon technology sensitivities (using 33/80 trajectory)

2030



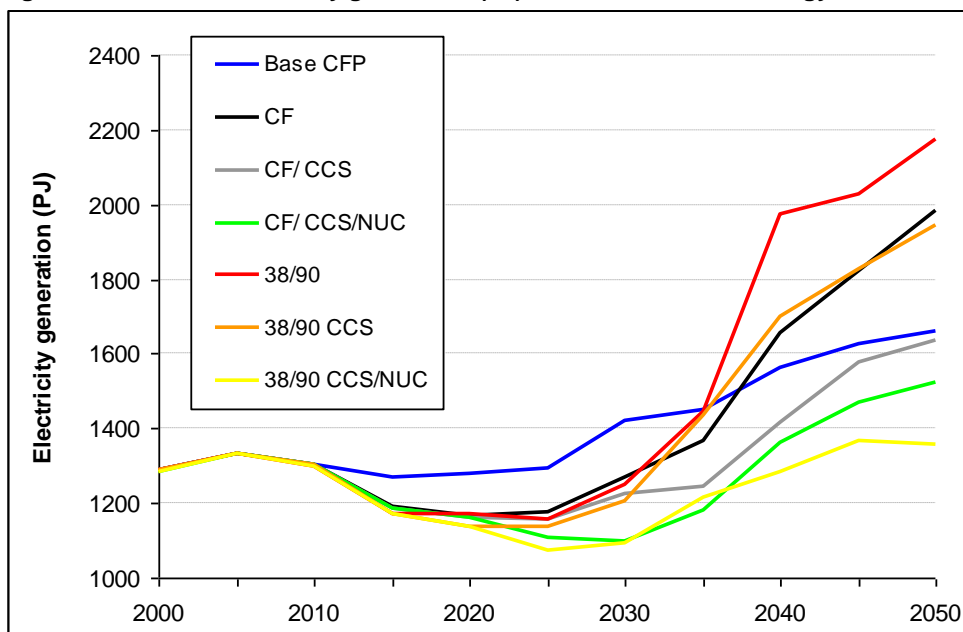
2050



* CF denotes 33/80; CCS and NUC indicate the absence of that technology option

Overall generation levels are shown in Figure 6.2 below. These particularly illustrate the differences between the standard 33/80 (CF) and 38/90 cases in 2050, and the technology sensitivities. For example, the level of generation in the 38/90 no nuclear / CCS case is almost 80% lower. It is also interesting to observe the low levels of generation between 2020 and 2040, due to the significant constraints on the system resulting in lower demand due to higher electricity prices relative to the alternative energy sources.

Figure 6.2 Levels of electricity generation (PJ) for low carbon technology sensitivities, 2000-2050

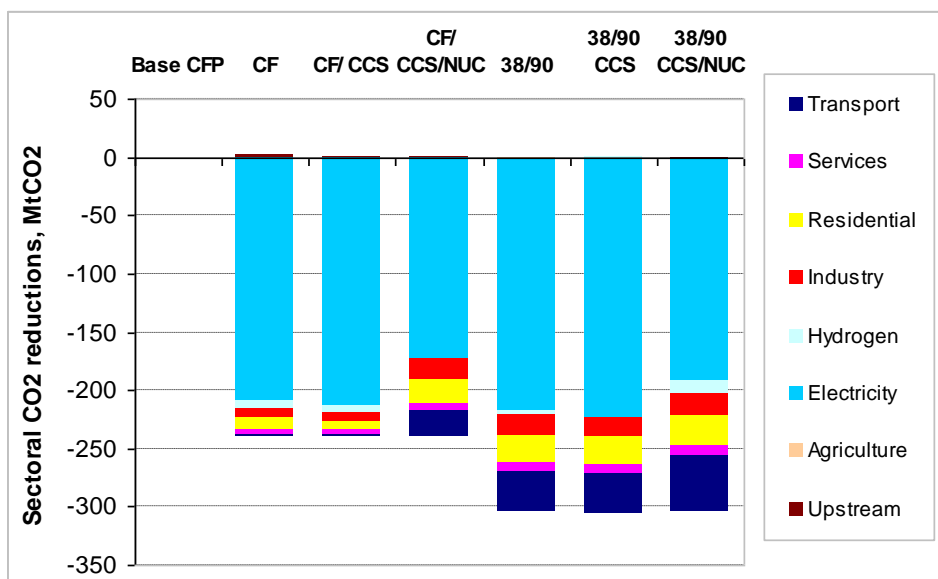


* CF denotes 33/80; CCS and NUC indicate the absence of that technology option

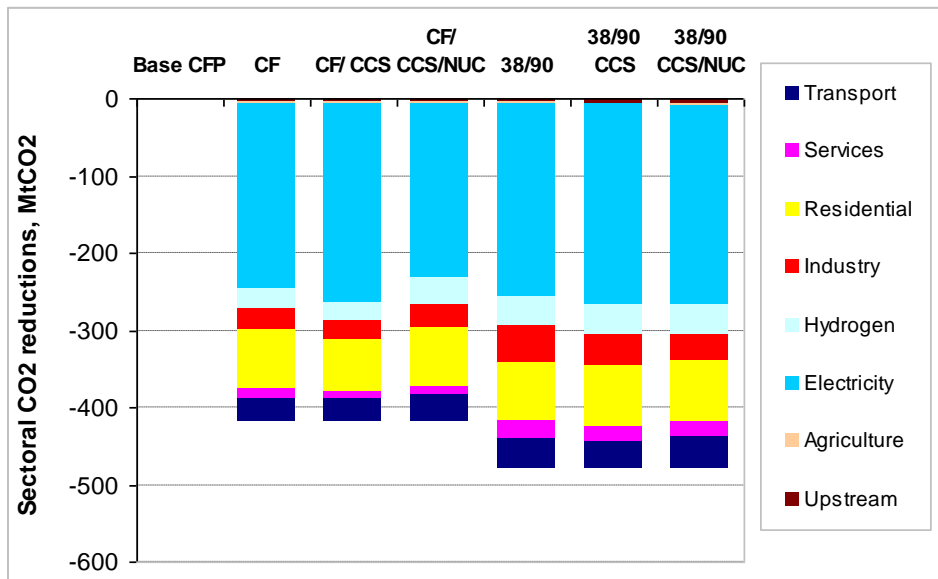
Contribution to CO₂ abatement across sectors

Restricting key low carbon options in the electricity generation sector has the potential to change the relative contribution between different sectors. In the *no CCS* cases, contribution by electricity sector slightly increases due to the replacement by completely non-carbon generation sources. In the *no CCS / nuclear* case, this is not the case, with the electricity generation sector contributing less due to the significant role of gas generation in 2030, and in 2050 under the 33/80 case. In such cases, transport (including the hydrogen production sector) and residential sector in particular contribute more.

Figure 6.3 Contribution to emission reductions (MtCO₂) from different sectors, 2030 and 2050



2050



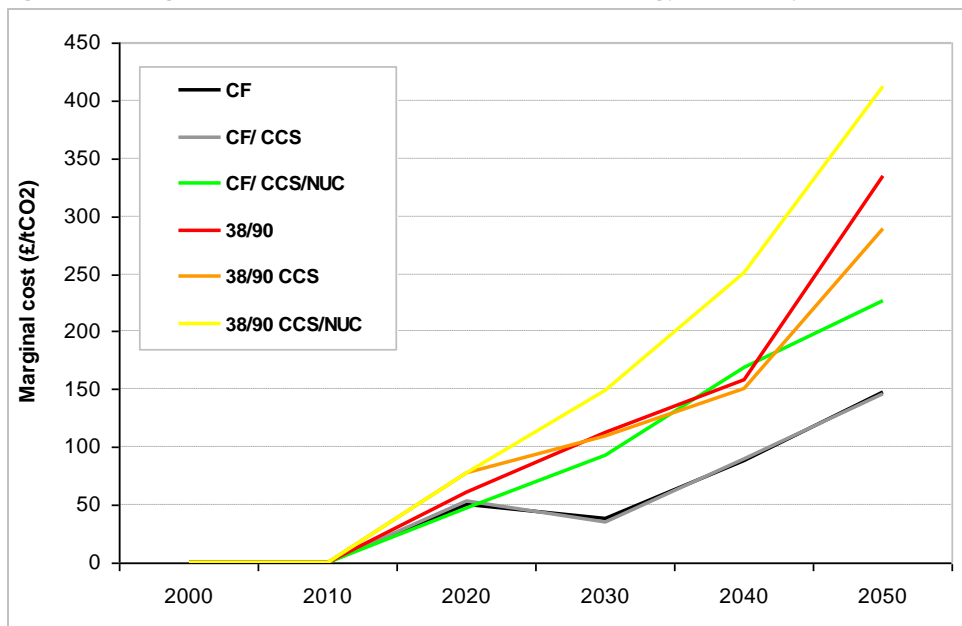
* CF denotes 33/80; CCS and NUC indicate the absence of that technology option

It is also important to note the increasing importance of demand response across all sectors under the no nuclear / CCS case, which increases significantly as mitigation options become more costly.

Impacts of technology restrictions on system costs

The impact of generation technology restrictions on marginal costs of abatement is shown in Figure 6.4. Under the 33/80 (CF) case, the impact of not allowing CCS has no observable impact on costs, primarily because of the very close cost differential between nuclear and CCS. Under the 38/90 case, marginal costs are actually lower post-2040. Additionally restricting the availability of nuclear has a major impact, as mitigation options have to be considered across other sectors due to the lower contribution from electricity generation sector. Under the very stringent 38/90 with no nuclear / no CCS, marginal costs rise to over £400 /tCO₂.

Figure 6.4 Marginal costs (£/tCO₂) of low carbon technology sensitivity runs



* CF denotes 33/80; CCS and NUC indicate the absence of that technology option

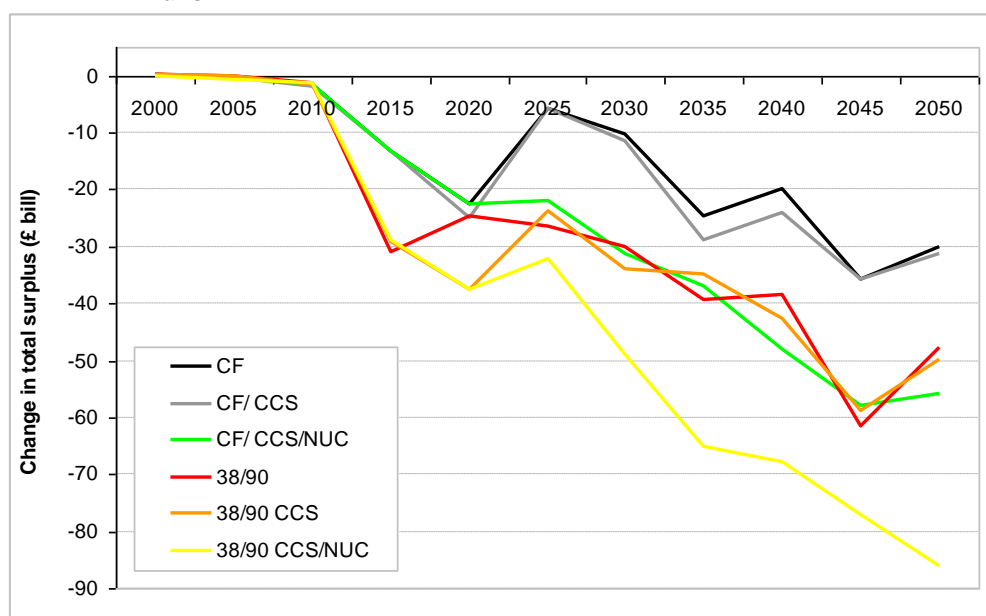
Losses in discounted economic surplus are shown in Table 6.1 below. Much greater losses are observed in the no CCS / nuclear cases. The availability of credits (in those sensitivities undertaken) reduces overall losses as would be expected.

Table 6.1 Discounted loss in economic surplus (£2000 billion) for technology sensitivities

Case	Description	Loss in economic surplus (£ billion)
CF	Standard 33/80 case	123.6
CF/ CCS	33/80 no CCS	141.1
CF/ CCS/NUC	33/80 no CCS / nuclear	220.3
38/90	Standard 38/90 case	241.1
38/90 CCS	38/90 no CCS	248.6
38/90 CCS/NUC	38/90 no CCS / nuclear	370.5

The annual undiscounted losses in economic surplus are shown in Figure 6.5.

Figure 6.5 Reduction in economic surplus (£ billion) associated with low carbon technology sensitivity runs



* CF denotes 33/80; CCS and NUC indicate the absence of that technology option

6.2 Alternative trajectories

The following model runs were undertaken (all using central fossil fuel prices) to explore the impact of using different trajectories:

- 38/80 (38/80)
- 38/80, with credits (38/80 CR)
- 33/85 (33/85)
- 33/90 (33/90)
- 33/90, REN 32 (33/90 R32)
- 38/85 (38/85)
- 26/90 (26/90)

In this section, most comparisons are against the standard 33/80 (CF) case.

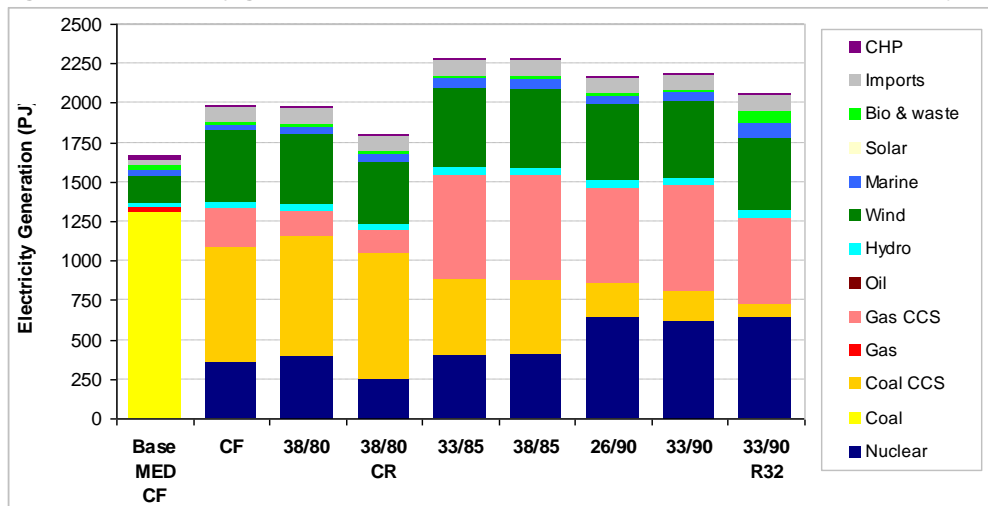
Electricity generation sector

The changes in generation profile associated with different trajectories are shown in Figure 6.6. As constraints tighten in 2050, the proportion of low carbon generation increases. Moving to an 85%

reduction (compared to 80%) results in much higher uptake of gas CCS than coal CCS by 2050. Nuclear and wind generation levels are also slightly higher, with a net increase in overall generation levels.

Under a 90% constraint, there is an increase in nuclear generation, further reducing the role of coal CCS. In the case with a higher renewable constraint, levels of gas and coal CCS are both lower due to higher installed capacity of marine and biomass by this period. The role of CCS generation is limited by the residual emissions that are not stored under assumptions of 90% capture efficiency.

Figure 6.6 Electricity generation (PJ) in 2050 under different emission reduction trajectories

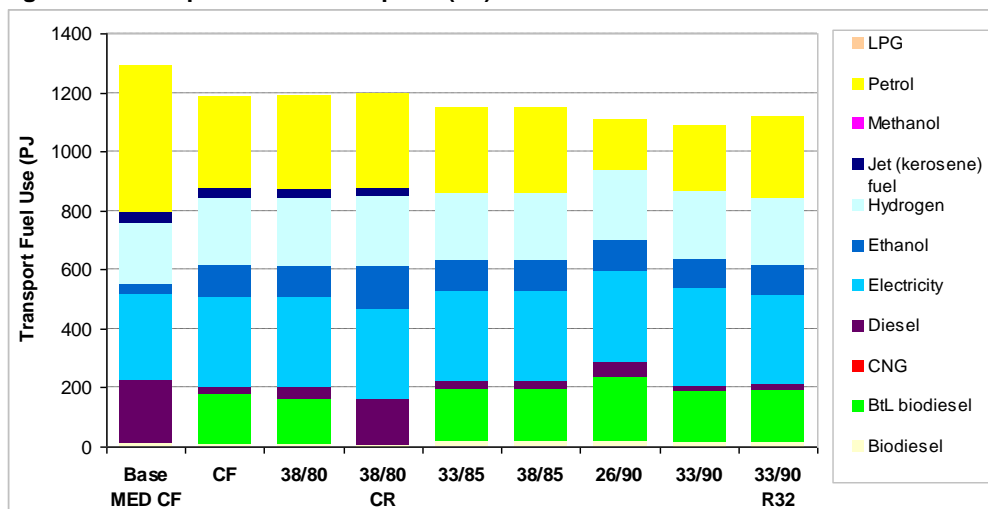


In one case where credits are available (38/80 CR), this allows for an increase in generation from coal CCS, reducing levels of nuclear investment / generation.

Changes in end use sector energy / technology profiles

Transport sector fuel use in 2050 does not significantly change under different reduction levels. Under 85%+ reductions, the main change is a 100% switch from kerosene to biokerosene in the domestic aviation sector. Petrol use across the car fleet is also reduced due to increase uptake of PHEVs, replacing standard hybrid models. Under a 90% constraint, PHEV diesels are taken up (using BtL), reducing the use of petrol PHEVs. Between the high / low renewable 33/90 cases, lower levels of battery electric vehicles are observed, potentially due to higher electricity prices

Figure 6.7 Transport fuel consumption (PJ) across different CO₂ emission reduction trajectories



Concerning the production of hydrogen used in the transport sector, most is produced using electrolysis under an 85% constraint; in the 90% cases, 75% of hydrogen used is imported (except in the R32 case where all hydrogen is imported) with the remainder produced by electrolysis.

Additional mitigation costs

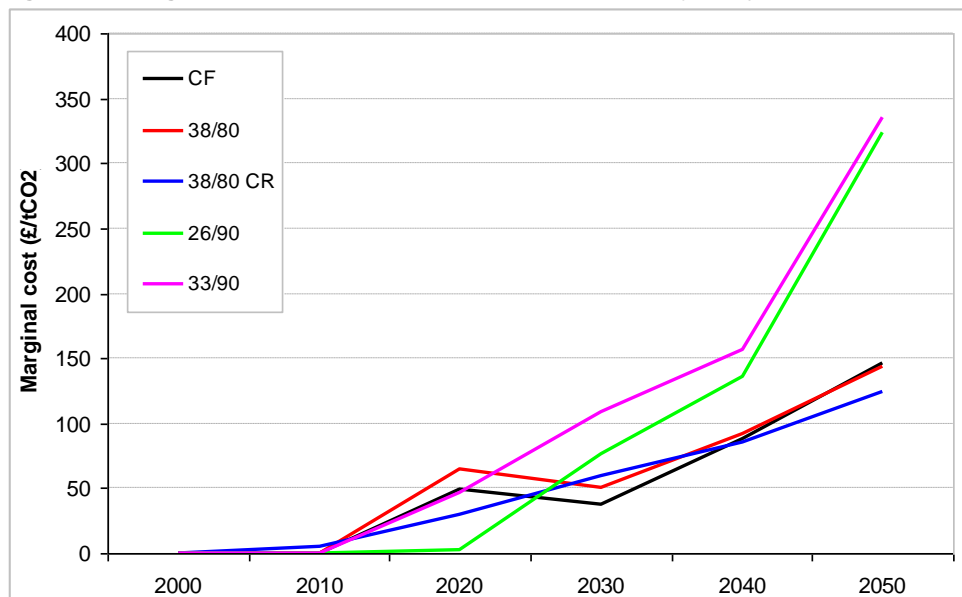
Losses in economic surplus inevitably increase as constraints become more stringent. For the different trajectory runs, the discounted losses are shown in Figure 6.8. It is worth noting that uncertainties associated with the more stringent cases increase, as the mitigation technologies used are often currently at a demonstration phase and their costs are not well known.

Figure 6.8 Discounted loss in economic surplus (£2000 billion) for selected trajectory cases

Case	Description	Loss in economic surplus (£ billion)
CF	Standard 33/80 case	123.6
38/80	38/80	160.5
38/80 CR	38/80 with credits	133.1
33/85	33/85	160.2
38/85	38/85	177.9
26/90	26/90	212.2
33/90	33/90	222.3
33/90 R32	33/90 with 32% renewable generation target	241.2

Marginal costs for selected cases are shown below. It is interesting to observe the much higher 2050 value under the 26/90 and 33/90 case relative to the 85% cases. In addition, particularly under the 26/90 case, large period on period increases are observed due to the relatively low 2020 starting point.

Figure 6.9 Marginal costs (£/tCO₂) of selected alternative trajectory cases



The role of credits, as shown by the 38/80 CR case, is to ensure a more gradual rise in the marginal costs, following the profile of the credit prices.

6.3 Two stage runs

The MARKAL model calculates the optimal solution (maximising economic surplus) over the whole model horizon. It can deliver the optimal mix of technologies to meet carbon reduction targets in 2020 with the knowledge that a more stringent level of reduction will be required in 2050.

An important aspect of this work (particularly covered in the Phase 1 analysis) was to consider what investment decisions might be made if the model’s foresight was limited to short term targets, and how this would impact on the model’s ability to meet the longer term targets. This in a sense reflects the situation where investors in energy technologies do not consider the longer term targets, perhaps due to regulatory uncertainty or policy failure, and decide, for example, to invest in new coal (non-CCS) plant post-2020. It could also reflect a lack of available low carbon technologies e.g. that may only be available post-2020, or that may be currently available but only at very high cost.

The approach taken in these model runs has been to fix investment levels in the electricity generation sector between 2000 and 2030, based on a specific 2050 target. These investment levels have then been fixed under an alternative reduction trajectory to provide insights into what happens when the model sets investment levels under a less stringent reduction trajectory.

The following three runs have been undertaken in this analysis:

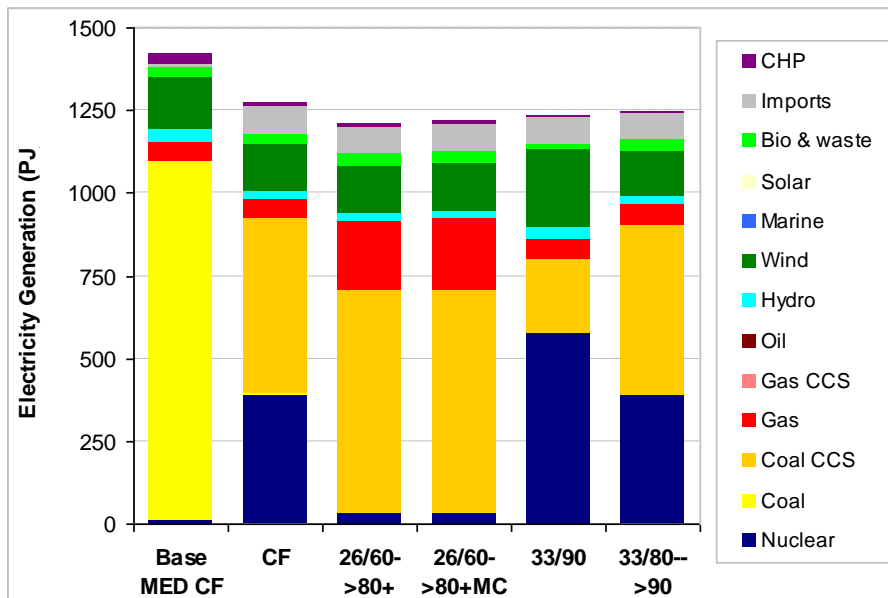
- 33/80--->90 (33/80 is the trajectory used in a run to determine fixed investment levels. The model is then run again using a 33/90 trajectory with the investment levels fixed based on the first run, and the results analysed).
- 26/60--->80+ (80+ implies the same cumulative emissions between now and 2050 as the 33-80 case, but only achieving 26% in 2020 and therefore needing to do additional abatement over the period to 2050).
- 26/60--->80+ with credits

The 33/80 --->90 run is compared against the 33/90 run. The 26/60--->80+ run is compared to 33/80 (CF).

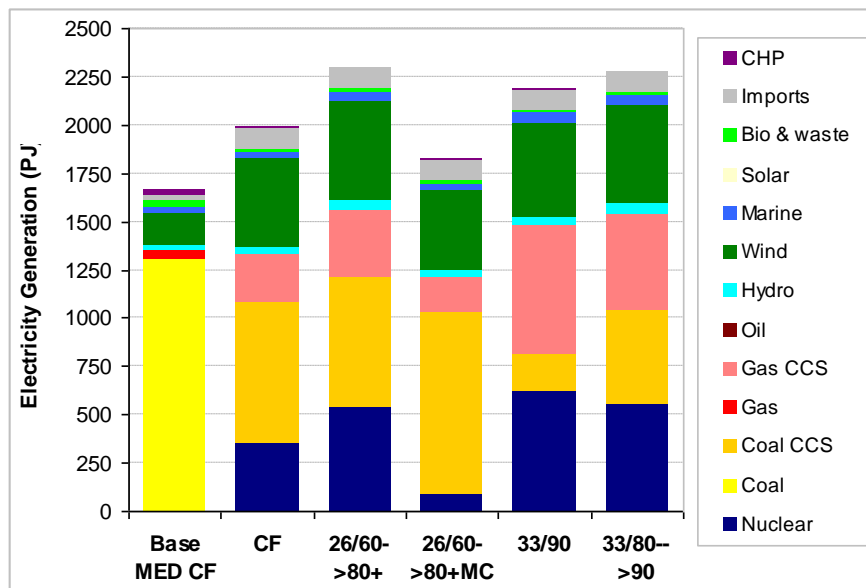
Electricity generation profile

Changes in the electricity generation sector are most crucial to consider given that this is where restrictions on technology uptake are imposed. In Figure 6.10, the profile for the 26/60→80+ cases reflects the investment under a 26/60 trajectory. Compared to the 33/80 case, we can see only very limited generation from nuclear, and significantly more gas and coal CCS generation. In 2050, generation levels are higher, as is the contribution from low carbon technologies. The availability of credits results in very low levels of nuclear generation.

Figure 6.10 Electricity generation (PJ) for two stage runs 2030



2050



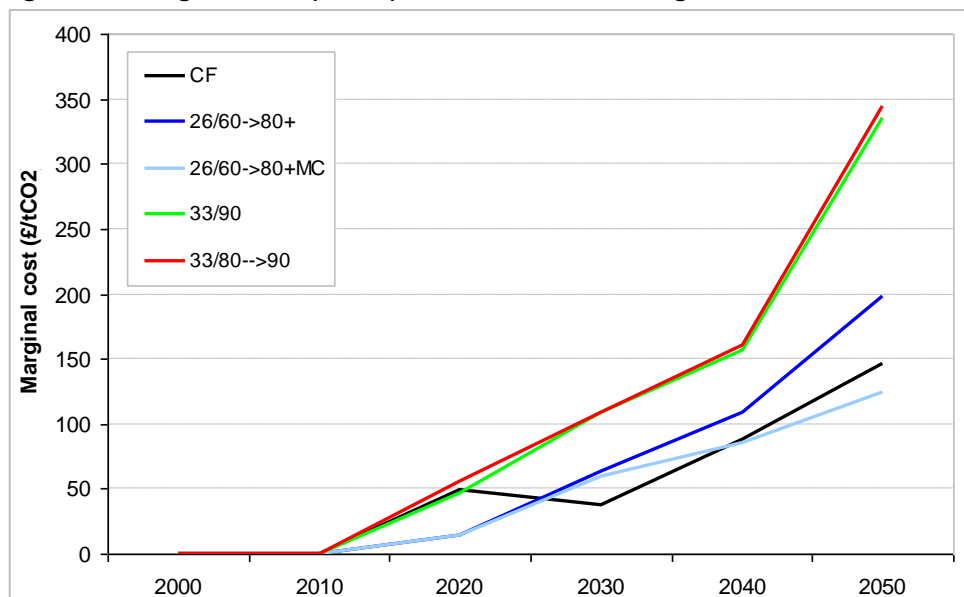
The 33/80→90 case fixes investment levels in hydrogen production and electricity generation to those observed under 33/80 run. These fixes do not appear to have a significant impact on marginal abatement costs at any period in the time horizon. This appears to be because total investment costs in these sectors in the period 2020-2030 do not seem differ much between 33/80 and 33/90 cases.

Technology choice however does differ. Under a 33/80 run, much higher levels of coal CCS can be observed. This capacity is used and as a result, gas CCS and nuclear generation is lower (by 2050). This however does not markedly change the contribution to abatement by this sector.

Impacts on system costs

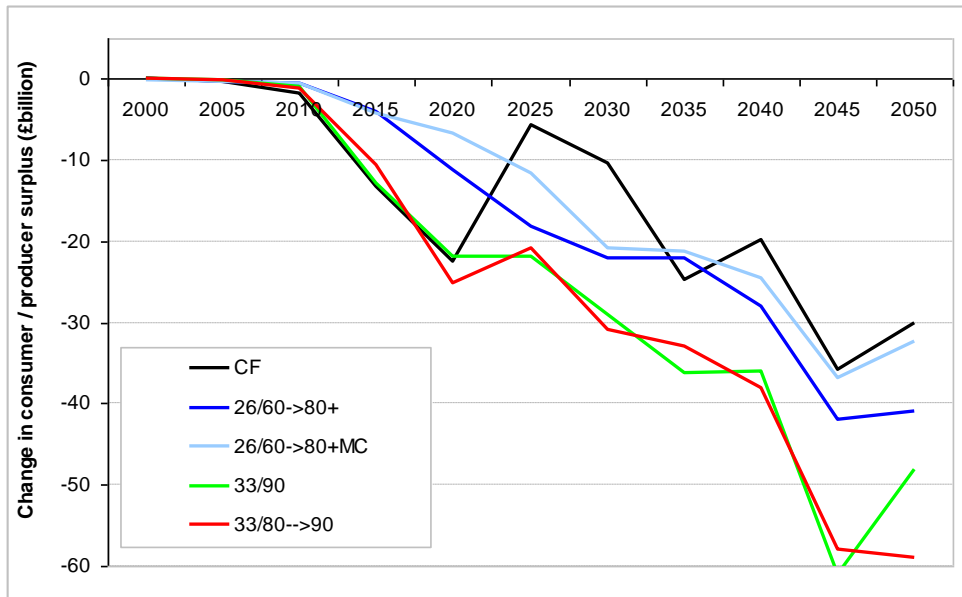
Marginal costs for these two stage runs are shown in Figure 6.11. As would be expected, 2030 costs are higher for the 26/60→80+ case due to the additional investment required in the generation sector. Post-2030, the availability of credits ensures that system marginal costs are significantly reduced. Differences in costs are not observed in the 33/80→90 case due to the similar levels of investment across the periods.

Figure 6.11 Marginal costs (£/tCO₂) associated with two stage runs



The losses in annual economic surplus for the two stage runs are shown in Figure 6.12. For the 33/80 equivalent cases, losses are lower in earlier periods due to the less stringent near term targets. Post 2025, they are however larger. The trends for the 33/90 cases show limited differences in losses.

Figure 6.12 Reduction in economic surplus (£ billion) associated with 2-stage runs



Discounted system economic surplus losses are shown in Table 6.2 below.

Table 6.2 Discounted loss in economic surplus (£2000 billion) for selected trajectory cases

Case	Description	Loss in economic surplus (£ billion)
CF	Standard 33/80 case	123.6
26/60->80+	26/80* with investment levels set based on 33/80	148.9
26/60->80+MC	26/80* with investment levels set based on 33/80, with credits	137.1
33/90	33/90	222.3
33/80-->90	33/90 with investment levels set based on 33/80	226.9

* Run has same cumulative emissions between now and 2050 as the 33-80 case, but only achieving 26% in 2020 and therefore needing to do additional abatement over the period to 2050

6.4 Additional sensitivity runs

Two additional sensitivity runs have been undertaken that include:

- 33/80 at a 3.5% discount rate (33/80 3.5%), to explore how the removal of technology specific discount rates impacts on overall costs
- Targets from 33/80 trajectory only applied in periods from 2040 onwards. This provides insights into how the system responds when the first targets to meet are in 2040 (NB. The system has perfect foresight to know that this target is approaching).

Removing technology specific discount rates

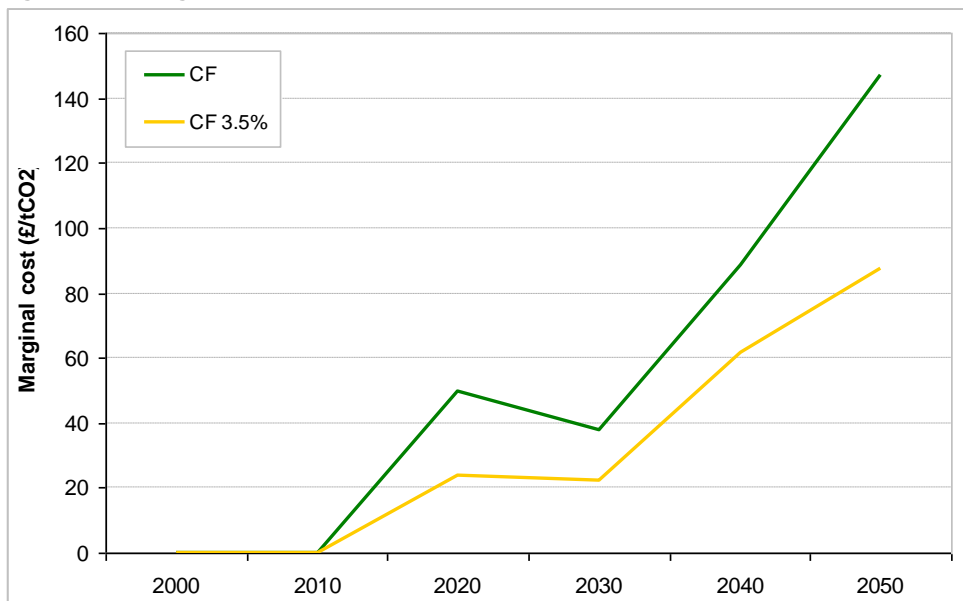
In this sensitivity run, all capital investment is discounted at the same value as the global discount rate – 3.5%. This in effect reduces the cost of capital (making larger scale projects relatively more attractive), as most technology specific discount rates in other runs are set at around 10%.

This removal of technology specific discount rates suggest that some of the barriers to investment in specific technologies are removed under the 33/80 low carbon scenario, and that optimal decisions are made for society as a whole, rather than for the individual investor.

As would be expected, the loss in discounted economic surplus is lower under the 3.5% DR case. Losses (on a year 2000 basis) are at £68.3 billion, compared to £123.6 billion under the standard case. Note that the 3.5% case has not been compared to an equivalent baseline, as the assumption is that these specific discount rates are no longer considered in the move to a low carbon economy.

Marginal costs, however, can be considered independently of the baseline. As shown in Figure 6.13, marginal costs are significantly lower in 2020 and later periods. The gap between the trend lines reflects to some extent the importance of capital intensive projects within the range of mitigation options.

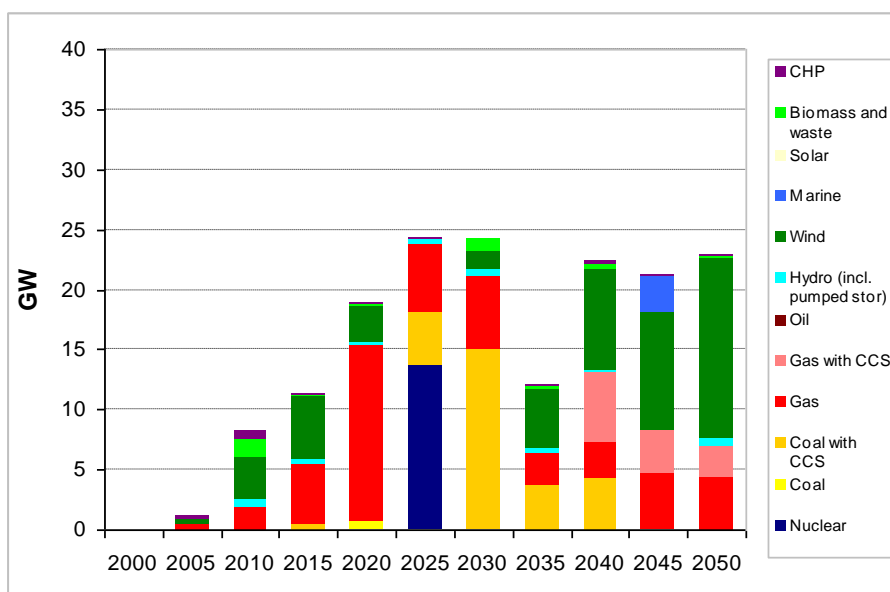
Figure 6.13 Marginal costs (£/tCO₂) of the 3.5% DR case vs. standard 33/80 case



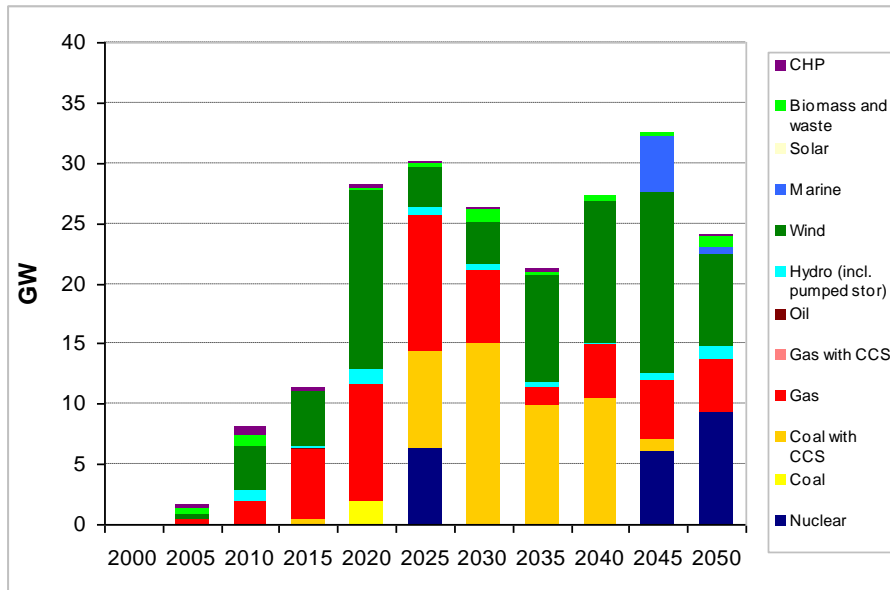
With lower cost of capital, large scale electricity generation is more favoured, with increasingly higher levels post 2020. In 2050, much higher levels of coal CCS can be observed, plus increased nuclear generation. The differences in the levels of investment are illustrated in Figure 6.14 below.

Figure 6.14 Electricity generation sector investment profile (GW) under 3.5% technology discount rate and the 33/80 case

33/80

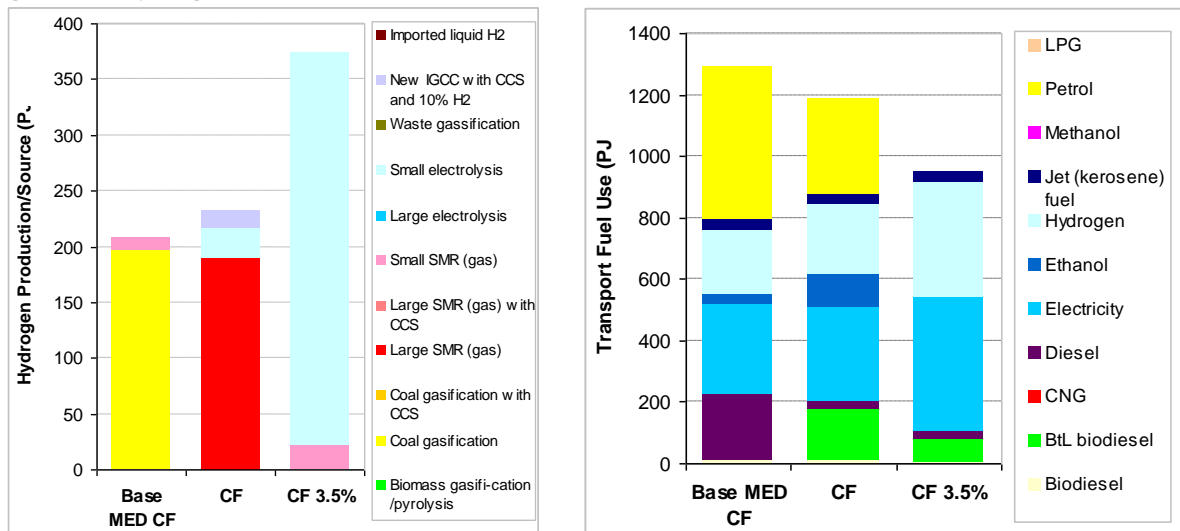


33/80 (3.5% DR)



Electricity appears to make a similar abatement contribution; however, transports contribution increases markedly by 2050 due to lower fossil fuel use, and increased levels of electricity / hydrogen use. Hydrogen usage increases by about 70%, and is primarily produced through electrolysis.

Figure 6.15 Hydrogen production and transport sector fuel consumption in 2050 (PJ)

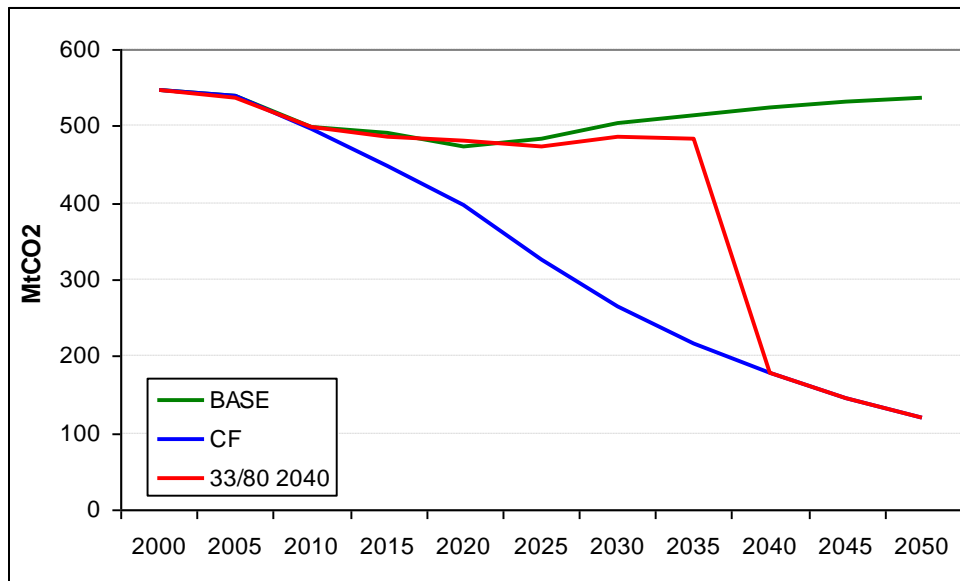


Lower demand response in industry / residential sectors can also be observed. This results in increased demand for coal in industry / gas in residential sector in 2050. The increase in emissions in these sectors is offset by lower emissions in the transport sector.

CO₂ constraints in 2040-2050 only

In this sensitivity, annual constraints between 2000 and 2035 are not imposed, only introducing targets (based on the 33/80 trajectory) between 2040 and 2050. This sensitivity was to investigate model behaviour with respect to technology choices in the constrained periods compared to the case in which annual targets are implemented much earlier.

The difference in emissions across the model time horizon is shown in Figure 6.16.

Figure 6.16 CO₂ emissions (MtCO₂) under different target trajectories and base case

The loss in discounted economic surplus is lower under the 2040-2050 constrained case due to the system being less constrained, and having a much lower cumulative target across the time horizon. Losses (on a year 2000 basis) are at £92.7 billion, compared to £123.6 billion under the standard case. Marginal costs are only incurred in 2040 (the first year of constraints). They are at a slightly higher level than observed in the 33/80 case, reflecting the limited impact of late action on period specific marginal costs.

In terms of mitigation between 2040-2050, sector contribution does not differ significantly. Investment profiles, however, do change. Most low carbon investment occurs in the 2040 period reflecting the lack of modelling of construction lead in time / potential increased costs of such rapid expansion.

Across other sectors, the technology profile similar to the baseline pre-2035 and similar to the 33/80 run post-2035.

The results need to be considered carefully, as they are unlikely to represent real policy choices in target setting terms nor does the model behaviour reflect how market players might behave. The model has perfect foresight and understands that the targets will be incurred in later periods. Post 2040, choices in technology investments may be made that help ensure additional costs are kept low. Additionally, the model can select technologies fairly quickly, with limited consideration of lead in time or experience of previous implementation.

Annexes

Annex 1. List of Phase 2 model runs

Annex 1. List of Phase 2 model runs

MRKL model name	Description	Report model name
BM-AEA-C	Base MED - with new transport constraints (central fossil prices)	Base MED CF
BM-AEAHH	Base MED - with new transport constraints (high high fossil prices)	Base MED HHF
BM-INTAV	Base MED - with new transport constraints + Int Aviation (central fossil prices)	Base MED IAV
BS-AEA-C	Base standard - with new transport constraints (central fossil prices)	Base S CF
BS-AEAHH	Base Standard - with new transport constraints (high high fossil prices)	Base HHF
BS-INTAV	Base standard - with new transport constraints + Int Aviation (central fossil prices)	Base IAV
CM-S1A-1	(33/80) Central fossil prices, without credits (with new transport constraints)	CF
CM-S2A-1	(33/80) Central fossil prices, with credits and REN32	CF/C/R32
CM-S2A-2	(33/80) Central fossil prices, without credits and REN32	CF/R32
CM-S2A-3	(33/80) Central fossil prices, with credits	CF/C
CM-S2B-1	(33/80) High-high fossil prices, with credits and REN32	HF/C/R32
CM-S2B-2	(33/80) High-high fossil prices, without credits and REN32	HF/R32
CM-S2B-3	(33/80) High-high fossil prices and with credits	HF/C
CM-S2B-4	(33/80) High-high fossil prices and without credits	HF
CM-S2C-1	(33/80) Central fossil prices, without credits, REN32 and No CCS	CF/R32/CCS
CM-S2C-2	(33/80) Central fossil prices, without credits, REN32 and No CCS/Nuclear	CF/R32/CCS/NUC
CM-S2C-3	(33/80) Central fossil prices, without credits and No CCS	CF/CCS
CM-S2C-4	(33/80) Central fossil prices, without credits and No CCS/Nuclear	CF/CCS/NUC
CM-3A-1	CO2_8 (33/90), central fossil prices, without credits and REN32	33/90 R32
CM-3A-2	CO2_8 (33/90), central fossil prices, without credits	33/90
CM-3B-1	CO2_5 (38/90), high high fossil prices, without credits	38/90 HHF
CM-3C-MY	33/80--->90	33/80-->90
CM-3D-1	CO2_9 (38/80)	38/80
CM-3D-2	CO2_10 (33/85)	33/85
CM-3D-3	CO2_11 (38/85)	38/85
CM-3D-4	CO2_12 (26/90)	26/90
CM-3D-5	CO2_9 (38/80) with credits	38/80 CR
CM-3E-DR	33/80 3.5% discount rate	33/80 3.5%
CM-3F-CU	33/80 with target only in 2040-50	33/80 2040
CM-3G-1	CO2_4 (33/80), central fossil prices, with credits, REN32 and No CCS	33/80 CR CCS R32
CM-3G-2	CO2_4 (33/80), central fossil prices, with credits and No CCS	33/80 CR CCS
CM-3H-1A	26/60--->80+	26/60->80+
CM-3H-2A	26/60--->80+ with GLCF_MA	26/60->80+MC
CM-INTAV	33/80 with international aviation	CF AVINT
CM-INT2	33/80 with international aviation	CF AVINT-KER
CM-NNB38	38/90 with no new nuclear or CCS build	38/90 CCS/NUC
CM-CCS38	38/90 with no new CCS build	38/90 CCS
CM-AEAET	(38/90) Central fossil prices, without credits (with transport constraints)	38/90



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