University of London

Peer Review for the Committee on Climate Change

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

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KEY POINTS

- MED is an appropriate and sophisticated tool for analysis of long term economy-wide UK decarbonisation pathways.
- This novel model set-up and insightful scenario analysis - with the emphasis on transitions and uncertainty - builds on earlier EWP and Climate Change Bill modelling.
- This is a highly competent analysis, with a well written report, and a balanced and generally correct interpretation of runs.
- The model updates and scenario assumptions raise a number of key issues:
  - Welfare (producer plus consumer surplus) is the valid measure of overall economic impact. Use of energy system costs is potentially misleading in the size and relative ordering of scenario costs due to the interplay between system costs changes and the shrinking size of the energy system.
  - In the implementation of MED, long-run ESD elasticities and the variation or 'floor' level of demand responses needs to be re-examined and/or explained.
  - The model implementation of global CO_2 prices is correct although the derivation of this assumption is highly uncertain.
  - Global CO_2 prices act as a back-stop mechanism to limit marginal CO_2 prices with significant welfare gains, especially as CO_2 constraints tighten further.
  - The choice of a 3.5% social discount rate needs further justification as it is critical in the timing of decarbonisation as well as the technology selection. Core examples of this are the uptake of future transport technologies and building sectors conservation and efficiency options.
  - The further assumption of 10% hurdle rates only in the electricity sector is likely to be viewed as controversial.
  - The extension of specific biomass chains (e.g., boiler pellets) are limited by domestic resources and conservative assumptions on international bio-energy imports.
  - Higher fossil fuel assumptions spur lower reference case energy use and make overall CO_2 targets significantly less expensive.
  - Electricity sector build rate constraints for nuclear, CCS and wind may still be optimistic.
  - The use of social discount rate, removal of hurdle rates and in some cases minimum bounds for existing policy measures lead to optimistic uptakes of buildings conservation options.
  - Interacting factors that limit the use of distributed generation are higher costs in the reference case, and in the CO_2 constrained cases; resource constraints (bio-energy), CO_2 emissions (natural gas) and peak capacity constraints (solar).
  - Perhaps counter-intuitively, the cumulative constraint gives more early action that later action due to a combination of very expensive later period mitigation and a 3.5% discount rate that gives weight to these later costs in the overall objective function

- Suggestions for a follow-up set of runs (in order of importance) are:
  - Hurdle rates to mimic downstream non-cost barriers or risk
  - Further 2 stage model with CCS retrofit and all energy system investments included
  - Alternate international CO_2 pricing (beyond with or without international permits), including supply curve vs. single price approaches
  - Alternate demand elasticities
  - Alternate demand variation on 'floor' levels
  - Alternate treatment of intermittency using a peak constraint (capacity credit) approach
  - Enhanced bio-energy imports
  - Electricity build rate constraints at 1-2GW per annum for all technology classes.
  - Cumulative constraint fixed to reference case emissions in 2005-2010, and at a constant (e.g., -80%) level from 2055-2070
- Of runs already identified by CCC for follow-up runs, the following are deemed **not** necessary
  - New reference case, as long-run fossil fuel price projections are highly uncertain and are already using BERR 2008 projection
  - Additional electricity technology sensitivities - adequately covered in earlier runs

1. INTRODUCTION

a. Background to MED Modelling project

The Committee on Climate Change (CCC) was set up under the Climate Change Bill[1], as an independent statutory body to provide independent, expert advice on how the UK can best achieve its climate change goals. Its main duties will be to advise Government on:

- the level of the long-term target for UK emissions reductions by 2050
- the level of the carbon budgets (caps covering five year periods) consistent with the UK's 2020 and 2050 targets and its international obligations;
- the extent to which carbon budgets should be met by domestic emissions reductions versus emissions purchased overseas;
- the respective contributions towards meeting the budgets of those sectors of the economy covered by trading schemes (e.g. EU ETS, Carbon Reduction Commitment); and,
- the contribution towards meet the budget of those sectors not covered by trading schemes (e.g. transport, households).
- whether and how international aviation and shipping should be included in the targets
- whether non-CO_2 gases should be included in the targets

[1] Introduced in draft form to Parliament in March 2007

As part of its analytical component, CCC has commissioned AEA Energy and Environment to investigate the costs, technological pathways and sectoral trade-off in long-term (to 2050) carbon reduction scenarios. This analysis was carried out with the UK MARKAL Elastic Demand (MED) energy systems model.

b. Background and use of the MED model

MARKAL is a widely applied bottom-up, dynamic, linear programming (LP) optimisation model. It has been continually supported by the International Energy Agency (IEA), and has been heavily used for policy[2] and academic[3] research on a range of energy issues including long-term decarbonisation pathways.

The MARKAL energy model framework been heavily utilised in the UK including assessment of the impacts of long-term decarbonisation scenarios as supporting analysis to the Energy White Paper 2007 and the Climate Change Bill. A major part of this process - supported by the UK Energy Research Centre (UKERC) research programme - has been methodological improvements. These have included the technological scope of the entire energy-economic system, stakeholder reviewed data updates and extensions to first a general equilibrium version (UK M-M), to enhanced spatial and temporal versions, and finally to a flexible and partial equilibrium optimization of both energy supply and demand via the UK MED model. Section 2 highlights the methodology updates for the 2008 version. A comprehensive description of the model, its use in the UK and insights is discussed in a range of peer reviewed publications.[4]

MED is a powerful and highly relevant tool to examine long term UK decarbonisation pathways. Its coverage allows the explicit elucidation of trade-offs between energy pathways, sector contributions, and supply vs. demand measures. Its assumptions of competitive markets, and economic optimisation facilitates a structured comparison between possible evolutions of the energy system and the resultant economic impacts. In addition the transparency of its data and assumptions enhance its credibility. Like all models, the breadth of MED entail inevitable simplifications, and CCC has correctly identified the need to do systematic sensitivity analysis. These sensitivity runs build upon earlier EWP and CCC work and add real value in exploring alternate emission pathways, the role of international credits, possible relaxation of perfect foresight assumptions over the model horizon, and investigation of substitution opportunities via restrictions on key technologies.

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[2] IEA, (2008), Energy technology perspectives 2008: Scenarios and strategies to 2050, International Energy Agency, Paris.
[3] Smekens K., (2004), Response from a MARKAL technology model to the EMF scenario assumptions, Energy Economics, 26, 655-674.
[4] Strachan N., Kannan R., (2008), Hybrid modelling of long-term carbon reduction scenarios for the UK, Energy Economics, doi:10.1016/j.eneco.2008.04.009
Strachan N., Kannan R., Pye S., (2007), Final report for DTI-DEFRA on scenarios and sensitivities using the UK MARKAL and MARKAL-Macro energy system models, http://www.ukerc.ac.uk

c. Scope of the peer review

CCC's scope of work for this peer review requested an in-depth review of the first set of MED runs, recommendations for a follow up set of runs, and a subsequent evaluation of these follow-up runs. The review was to focus on the initial report conclusions drawn from the analysis, picking out strengths, weaknesses, new insights and alternate interpretations.

This peer review is primarily based on the final draft report on the CCC analysis produced by AEA[5], supplemented by detailed analysis of the MED model version[6], together with the model output spreadsheet and supporting assumptions documents (notably on DEFRA's GLOCAF model of international carbon trading).

Section 2 detail key review findings on the MED methodology, the impact of key assumptions and further issues deemed of particular interest to CCC. Section 3 covers the report findings (by page number) in more detail, while section 4 presents suggestions for follow-up runs.

2. METHODOLOGY, ASSUMPTIONS AND CCC KEY ISSUES

As a detailed energy systems model, MED is an appropriate and powerful modelling environment for undertaking systematic scenario analysis of long-term decarbonisation pathways. The development of MED facilitates the dual optimisation of energy supply and demand. Furthermore a range of model updates add significant functionality, and have been peer reviewed by sectoral experts via the UKERC Energy 2050 process[7]. These include a wide range of input data assumptions, improved sectoral tracking of CO_2 and SO_2 emissions, implementation of updated existing policy mechanisms, updated treatment of biomass resources and bio-energy chains (notably direct use in the industrial, service and residential sectors), and a mechanism to treat intermittency electricity generation in an energy systems approach.

The implementation of this modelling exercise was found to be highly competent. Furthermore the report itself is well-written and provides a balanced discussion of the core findings, together with the modelling trade-offs and the possible uncertainties in the findings. Its is a highly relevant and useful publication for the CCC and other policymakers.

In addition to the construction and use of MED and the other modelling updates, a range of assumptions were built into this scenario exercise. These add significant value by focusing on

[5] AEA Energy and Environment, MARKAL-MED model runs of long term carbon reduction targets in the UK, draft final report to Committee on Climate Change, July 2008
[6] Model version: UKERC MED 3-17 (25April08) - AEA update 19th June
[7] See www.ukerc.ac.uk/Downloads/PDF/U/UKERCEnergy2050/0709UKERCEnergy2050flyer.pdf

transitions and key uncertainties and build upon earlier modelling work (e.g. resource and technology sensitivity for the EWP), However some interpretation of these combined updates and scenario assumptions, along with suggestions for improvements are relevant and are discussed in turn below:

MED supply-demand optimization

The MED elastic demand variant extends the standard MARKAL optimization of minimizing (discounted) energy systems costs ,to include the key micro-economic feedback of changes in individual energy service demand (ESD) changes. Thus the model now optimises (maximises) the combination of producer and consumer surplus. This represents a valid measure of societal welfare. Furthermore this optimization occurs in a stepwise fashion making the model computationally easy to both calibrate and solve for alternate scenarios, although it is stressed the combination of the demand response can be highly non linear.

In the standard model, when total energy systems costs are minimized, this is equivalent to maximizing producer surplus (assuming that all prices are passed through to consumers in the long-term). In the MED model, as prices rise in a policy case (i.e., economy wide CO_2 constraints), the resultant demand response via reduced ESDs is a critical response. However as a CO_2 constraint tightens there will be two impacts - the costs of energy supply will rise and the size of the overall energy systems will shrink. These two conflicting impacts make presentation of energy system costs changes confusing and potentially open to misinterpretation. The best metric is total welfare (combined producer and consumer surplus). Under price rises there may be some transfer of consumer to producer surplus[8] (provided producers pass through costs) but the combined surplus will always fall.

Another key interpretation is the role of ESD changes. The model uses (discounted) reference prices, and from this basis calculates any change in marginal costs - if these rise then demand will fall (and vice versa). The change in marginal costs will depend on the availability of fuel and technology substitution and or conservation and efficiency options. Based on these changing marginal costs, the ESD will change based on the individual (long-run) elasticities, and will fall in steps to a predefined 'floor' for demand changes (or 'ceiling' if prices are falling). However aggregated ESD elasticities are problematic to define due to lack of data on energy service demands (as opposed to energy demands), the reliance of data from other countries and uncertainty in long term changes in consumer responses (due to public opinion etc). Hence this appears a key sensitivity. Further the variation or 'floor' of demand changes is currently set to 50% and this should be re-examined for feasibility and wider economic impacts, especially in very highly constrained runs. For example, in agricultural and industrial ESDs with limited technological substitution opportunities, or in residential and transport demands with essential requirements of energy use and mobility, the meaning and

[8] Under price falls (e.g. further technological change), consumers would be expected to benefit over producers under competitive conditions.

practicality of either no response through to a potentially large demand response needs to be examined. This is potentially another area for sensitivity analysis.

Treatment of intermittency

In an energy systems model with limited temporal resolution there are essentially two ways to better account for intermittency The first option is to impose grid balancing costs on increasing level of intermittent generation beyond a predefined threshold (-25% of total generation in this case). This is the approach used here; it is a valid mechanism and one that adds considerable realism to these results.

The second option is to utilise the peaking constraint (capacity credit) in the model with a declining contribution to peak demands for successive tranches of intermittency generation (which already have a limited guaranteed contribution to peak requirements). This approach, in conjunction with increased T&D costs based on a spatial assessment of intermittent on- and off-shore wind, wave and tidal barrage technologies is used the UKERC Energy 2050 MED runs. It would be an interesting sensitivity in these cases, notably in the renewable electricity sensitivity run. Further complementary modelling of intermittency could conceivably use a detailed power sector model (e.g., WASP) or combined gas and electricity model (e.g., CGEN).

2-Stage optimisation

The approach taken here is satisfactory to illustrate possible non-optimal investments. However the approach needs to consider all embedded investments, not just in the electricity sector. For example, although many transport technology have short lifetimes, this is not the case for air, bus or rail technologies, nor for investments in 2030 itself. More importantly demand-side conservation (which is heavily taken up in the near term), can have long lifetimes as can key heating and cooling service sector technologies. In addition investments in infrastructures, refining and other upstream technologies needs to be considered.

The lack of CCS retrofits is an issue in the current approach. A technical fix is possible (see section 3d).

A future process would be to use a stochastic MED approach based on probabilities of different emission constraints - with uncertainty revolved in 2030. This would generate hedging strategies, as well as the value of perfect information. Stochastic MED can also be run with non-risk neutrality assumptions.

The use of myopic SAGE is not recommended as it is currently a global model, focused on US markets, and contains a complication of market share algorithms).

International CO_2 purchases

The implementation of global carbon purchase assumptions in the MED model is correctly done. Also correct is the general view of matching more stringent global and UK reductions cases.

However the derivation of global carbon prices is highly uncertain. This is not the place to critique the GLOCAF model (which makes a good faith effort to investigate some key uncertainties in future long - term carbon pricing), but some points are relevant:

- GLOCAF correctly grapples with issues relating to targets and burden sharing, input marginal abatement cost curves (MACs), whether countries and firms are rational, and issues of supplementary and domestic action.
- MACs are the most uncertain aspect to long term global carbon trading with different models giving very different answers. The use of POLES model MACs (plus additional non-CO_2 GHGs and land-use models) give a cost range that is reasonable related to some reviews[9] but the IEA 2008 ETP study shows a variation of £125-£400/tCO_2 in 2050, and this is for just one target level and just one model.
- The global target and resultant burden sharing assumption is critical - in fact in the long term it is not clear either how many or if any credits at what price would be available[10], nor which countries would be buyers and seller. Some studies[11] show that fast growing developing countries could require to buy credits from developed countries with technology and resource advantages.
- In the long term under a well functioning market, rationality is a reasonable assumption.
- For domestic action the modelling assumes that a ceiling of 50% of required emission abatement is allowed - this appears reasonable.

Two more fundamental questions are firstly why the UK is not a seller of credits in the medium term as its marginal abatement costs are below the international market price (perhaps selling to other OECD nations?) Secondly, whether to consider a single price under a pooled market, vs. a supply curve of international credits if UK firms were sponsoring CDM and joint implementation activities. A secondary issue is why is the UK would not bank credits.

In the model scenarios the international carbon price has a pivotal role of moderating carbon prices and welfare costs, effectively acting as a backstop option. This is particularly true in the -80% and more stringent cases. In the -90% case, 19% of emission reductions in 2050 at a price of £176/tCO_2 instead of £350/tCO_2 is extremely important. Sensitivity analysis (beyond with and without international purchases) is essential.

[9] IPCC, (2007). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

[10] Strachan N., Pye S., and Hughes N., 2008, International drivers of a UK evolution to a low carbon society, Climate Policy, 8, S125-S139.

[11] Bataille C., Tu, J. and Jaccard M. (2008) Permit sellers, permit buyers: China and Canada's roles in a global low carbon society, Climate Policy, 8, S93-S107.

Discounting and hurdle rates

The choice of a 3.5% social discount rates is critical is the timing of decarbonisation as well as the technology selection. A core example of this in the reference case is the uptake of future transport technologies (hybrids, then future fuel and drive-trains) which contributes to a very low reference case energy-use. This declining reference case energy use also sees very significant building sectors conservation and efficiency changes which are ever greater under CO_2 constraint cases. The stated CCC consistency in approaching discounting is appreciated, but combined with MED's assumptions of perfectly competitive markets and rational cost-optimal behaviour leads to a reference case and near-term decarbonisation measures that are not realistic. Re-imposing hurdle rates to mimic non-cost barriers or risk are a modelling mechanism for sensitivity runs, although these would have to be defined and justified - beyond the current rationale (in the transport sector) for refuelling infrastructure uncertainty.

The further assumption of 10% hurdle rates only in the electricity sector is likely to be viewed as controversial. The rational of electricity being a competitive market vs. other energy system sectors which require regulation is one justification. However not applying similar hurdle rates to other uncertain upstream energy chains or to downstream technologies and measures will generate considerable debate.

Biomass energy chains

The extension of specific biomass chains (e.g., boiler pellets) are limited by domestic resources and conservative assumptions on international bio-energy imports resources. Bio-energy imports are now linked to oil prices, although as some are much higher than oil prices (200-400%) which needs to be further explained.

Fossil fuel updates

Based on BERR's 2008 energy modelling these are implemented correctly in MED in terms of supply curves and refined oils. Prices are close to UKERC Energy 2050 averaged approach using UK and international estimates. These prices are significantly higher than the EWP analysis and will spur lower reference case energy use and cheapen overall CO_2 targets (e.g., in EWP M-M runs, marginal prices fell from £105/tCO_2 to £79/tCO_2 under a move to higher fossil fuel prices.
It is a matter of debate as to whether forecasts of very long term fossil fuel prices should be driven by short-term supply and demand responses - for example, unconventional oil is likely to be competitive at $70-80/barrel, while global decarbonisation pathways and reduced demand could also lower prices.

Build rates

These may still be over-optimistic as in annual terms the model can build 30 or 50 GW of any technology category in any 10 year period. This is probably greater than a 'dash for gas mark 2'. Build rate constraints are still triggered - for nuclear in 2020, for CCS in 2020-2030, and for wind in 2050.

IDC
The addition of interest during construction appears reasonable. More detail would be useful on why coal and gas IDC is 11.3% (same construction time?), wind is at 8.9%, and nuclear is at 22.2%.

Conservation constraints
The use of social discount rate, removal of hurdle rates and in some cases minimum bounds for existing policy measures lead to optimistic uptakes of buildings conservation options. Conservation technologies in the residential sector has a minimum level of 120PJ in both the reference and CO_2 cases, with CO_2 case upper bounds of 149PJ in 2030 or 221PJ in 2050. The service sector additionally has 63PJ in reference case but adopts up to 200PJ by 2050 in the 33/80 constraint case. Conversely industry is limited to only 10PJ of technical conservation due to lack of data.

Report write up
In general this is excellent, however it would be useful to have additional detail on the non-electric and transport sectors - i.e. expand p.33-34. The value of an extended write up would be to describe the interacting factors that limit the use of distributed generation - higher costs in the reference case, and in the CO_2 constrained cases; resource constraints (bio-energy), CO_2 emissions (natural gas) and peak capacity constraints (solar). Other model insights would include the role of night heat storage technology constraints on base-load generation options, and the trade-off between technology/conservation (residential and service) vs. energy service demand reduction (industry) in various end-use sectors.

Stringent constrained cases -
Under -90% and -95% CO_2 scenarios, the role of backstop international carbon prices (if available) becomes even more critical. For domestic reduction scenarios, model characteristics (including industrial natural gas fuel share, limited biomass resources, and the 10% minimum share of diesel cars in rural/island locations) are important. Furthermore the model relies on uncertain assumptions, notably the availability and price of hydrogen imports, and this reflects the extreme difficulty of any model representing a very low CO_2 constrained energy system in the long-term.

3. DETAILED MODEL REPORT FINDINGS AND INTERPRETATION

Additional comments are given below by report chapter

a. Core trajectory runs

Note these scenario constraints are run against 1990 levels. As year 2000 = 547.8 $MtCO_2$ vs. 1990 = 592.4$MtCO_2$, this represents easier equivalent targets.

p.6, Fig 2.1 and p.7, Fig 2.3 - illustrate the impact of the very low energy (and CO_2) base case. Is this realistic? - what's policies are enabled the constraints and assumptions (not the EU-ETS). ESDs not changed, MED not activated in reference case, hence its purely resources pricing, new technology data and especially lower discounting and hurdle rates
p.6, Fig 2.2. - useful to see 2000 case for comparison (especially decline in transport oil use)
p.8, Fig 2.5. - rising CO_2 emissions are driven by conventional coal in power sector - misleading to think of growing energy economy
p.13 - high constraint cases heavily impacted by international carbon price
p.13 -M-M costs could be a useful comparison: -60% case range from £61/tCO_2 to £169/tCO_2, or look at UKERC Energy 2050 MED: -60% case = £85/tCO_2, -80% = £169/tCO_2
p.14, Fig 2.8 and fig 2.9 - example of underestimation of costs looking at supply instead of welfare. Also will have a temporal component on demand changes vs. conservation and technological change
p.14 - welfare costs are not to be used as a percentage of GDP but for illustrative purposes, a 2% growth rate = £T2.8 in 2050 - hence 33/80 = -£B30 = 1.07% GDP (UKERC MED = -£B37 - 1.32% GDP)
p.15 - discussion of MED prices - don't include distributional impacts on key groups costs (old, rural, industrial sectors). nor competitiveness and trade (both put costs up), but also does not account for renewable sector economic contribution or revenue recycling (costs down)
p.17 - is this a weighted average for aggregated sectors? - e.g., cars vs. 2 wheelers. Suggest remove agriculture and place into industry
p.18 - Box 1 care in stating that the electricity system reserve fraction is 30% - this account for the reserve PLUS the instantaneous (hourly) peak - the industry definition of a reserve fraction is hence a good deal lower but we are consistent with this
p.19, Fig 2.12 - The EU-ETS is NOT enabled - hence reference case coal is not paying this charge - if it did this would impact the coal gas take-up in the reference case (and the coal vs. nuclear trade-off)
p19, Fig 2.13 - gas plant is acting as a flexible balancing mechanism for wind. Also note that electricity imports have both a generation and capacity bound - reasonable to assume the UK will not take very substantial percentages of power from out-with the UK but could use this as a balancing mechanism (as does Denmark). Hence the former constraint is lower than the latter. Also import capacity appear to be missing (14GW) from this graph
p.20 - adding IDC seems to a useful proxy for issues related to timing of a build
p.21 - as the CO_2 constraint tightens, the use of gas CCS is more likely to be system balancing than the remaining emissions. At £140/tCO_2 this equates to 2.5p/kWhr for gas or 0.25p/kWh gas CCS. Accounting for coal's higher CO_2 content and its lower efficiency may raise this to 0.5p/kWhr for coal CCS but this small difference is probably not worth switching unless the coal-gas differential is already very small. Instead the enhanced use of wind need balancing plants and at some point if you are building gas plant you may as well build some of this as gas CCS and hence use it.
p.22 - what does short term commodity prices (steel etc) say about commodity prices in 2030-2050?
p.22 - the electricity sector NEVER fully decarbonises - even in the -95% case there is some gas CCS

p.22 - footnote 12 is incorrect - the spatial hydrogen modelling showed higher levels of hydrogen due to better matching of supply and demand points
p.22 - decentralised technologies are stuck between two cases - in the reference case there are too expensive, in the CO_2 constrained cased they are either resource constrained (biomass), do not contribute to peak demand in late winter days (solar) or are too carbon intensive (gas)
p.24 - electricity LGV vehicle limit in market share is actually 10%
p.25 - H_2 production and use is dominated by 2050 constraint level- this makes sense as only later post-2030 vintages are competitive. H_2 production changes as the CO_2 constraint tightens, moving to zero carbon small scale electrolysis and then imported hydrogen - the latter is especially uncertain in its costs and availability
p.27 - under very stringent constraints (-90%) air travel switches to bio-kerosene - this is an unusual and interesting finding. Other modelling exercises runs have switched air to H_2 but it is the hardest sector to decarbonise - suggest one priority use of limited biomass resources?
p.32 - two wheelers could conceivably use a hydrogen diffusion constraint similar to this employed for electric 2 wheelers, but this is a very small demand sector
p.33 - minimum natural gas share in the various industrial sub-sectors influences the decarbonisation patterns in the overall economy. The enabling of bio-methane (which is exclusively used in industry) is limited by resource constraints - e.g. in the 33/80 case there is 749PJ of industrial natural gas but only 39PJ of bio-methane in 2050 (90% case is 377PJ and 53PJ respectively)
p.33, Table 2.4 - final section (changes relative to reference) should have negative values. The small impact in the transport sector show the role of changes in the reference case. The predominance of final energy reduction in the service and especially the residential sector reflect the strong role of conservation and efficiency improvements under a low discount rate. The industrial and agriculture sectors require energy service demand reductions due to the paucity of technical opportunities to decarbonise.
p.34 - 30% limits on night storage heating in both the service and residential sectors are triggered - this may have a large impact of the possible use of base-load electricity plants. 2020 heat pump vintages have a 10 year lifetime, but this should be 20 years
In Annex 1 - the CM-GCH-E description is incorrect

b. Cumulative emissions targets

It is striking that a cumulative constraint gives more early action that later action - under any positive discount rate one would expect the opposite to occur. However in this case the discount rate of 3.5% still places some model attention on later periods, where reductions are very expensive (with no moderating international carbon pricing. Hence the model does more action early to mitigate against these long-term later costs. This is not the same as having more cost effective measures in the near-term. Another defining reason may be that in most constraint cases the 2010 target is not binding (due to the sharp optimal reductions already happening in the base case.

An alternate case to run would be to change the constraint to be fixed to reference case emissions in 2005-2010 and at a constant (e.g., -80%) level from 2055-2070. This would focus on the period of the long-term CCC budgeting, rather than the very near and very long-term - this is the cumulative constraint procedure in the UKERC Energy 2050 modelling. It is worth noting that CO_2 reductions in 2010 vs. 2050 are not entirely equivalent depending on the timing of cumulative emission concentrations and resulting damage levels.

c. International carbon credits

See section 2, plus the below individual comments.

p.42, Figure 4.2 - this would be improved if it was welfare rather than annual systems costs. For example the 33/80 case gives an annual system reduction of £B30.1 to £B28.8 but a welfare reduction gives £B49.5 to £B40.8 - i.e. a much bigger impact of international carbon purchasing
p.43 - as expected when international carbon credits are removed, the most expensive domestic reduction are avoided - this can be seen in the expansion of low but non-zero carbon electricity generation, and higher carbon intensity of transport hydrogen.

d. Short- vs. long-term investment decisions

See section 2, plus the below individual comments.

A technical fix for a CCS retrofit option would involve a new technology set with CCS only available 20 years after it was invested in, with investment timing controlled. The technology would have an initial capital cost increment to signify capture readiness and a fixed O&M cost upon commencement of the CCS option to complete the CCS upgrade. This technology would not be invested in under a conventional constrained run as this would be a less mature and more expensive technology than later CCS options.

Hydrogen investments are not part of this 2-stage optimisation approach as they are only competitive post 2030.
p.52 - the forcing in 15GW of coal scenario is of less interest as this optimising model will simply let this paid-off technology to exist and contribute to the capacity constraint but not generate due to the high variable costs of CO_2 permits to operate the plant.

e. Limits on Low carbon technologies

The runs on no CCS and no CCS, nuclear are reflective of earlier EWP model runs
p.57 - , easy substitution between coal CCS and nuclear leads to small system and cost impacts, a switch to higher costs expanded renewable is more expensive

p.60 - the constraints on hydrogen production is an interesting constraint and illustrates a key uncertainty of whether this energy pathway will materialise. The switch to biomass and ESD reductions in other sectors is an direct response.
p.61 - this is a good example of misleading use of annual system costs which give the hydrogen restriction case with lower supply costs, while it has higher welfare losses due to an increased demand reduction.

f. Renewable energy targets

The current new treatment of intermittency makes this sensitivity case tractable (as opposed to the earlier EWP version). The most interesting trade-off is the use of limited biomass resources of electricity vs. transport of direct industrial use. Transport now decarbonizes less and utilizes more hydrogen from small scale electrolysis (with electricity partly from renewable generation). It is worth noting that 40% electricity generation from renewables does not necessarily equate to near- or long-term targets in terms of final energy. Renewables in the 33/80 case are 4.6% of final energy in 2020 and grow to 19.2% by 2050. the renewable-40 case gives 10.4% of renewable final energy in 2020 and only grows at the same pace to 24.8% in 2050.

A suggested sensitivity would be using the alternate intermittency treatment based on transmission costs and contribution to capacity credits (peak constraints).

4. SUGGESTIONS FOR ONGOING WORK

CCC are further intending to commission some follow-up runs to this first project, which are likely to include:

- use of an updated baseline to reflect the latest runs of the BERR Energy Model
- sensitivities on fossil fuel prices
- sensitivities on discount rate and hurdle rates
- sensitivities on technology costs and constraints
- more '2-stage' runs (looking at lock-in and impacts of short-term choices on long-term outcomes and costs)

From this peer review, suggestions for a follow-up set of runs (in order of importance) are:

- Hurdle rates to mimic downstream non-cost barriers or risk
- Further 2 stage model with CCS retrofit and all energy system investments included
    - A possible extension is to a full stochastic MED
- Alternate international CO_2 pricing (beyond with or without international permits), including supply curve vs. single price approaches
    - An possible extension is the UK selling to other OECD nations
- Alternate demand elasticities
- Alternate demand variation or 'floor' levels

- Alternate treatment of intermittency using a peak constraint (capacity credit) approach, including the renewable-40% case
- Enhanced bio-energy imports
- Electricity build rate constraints at 1-2GW per annum for all technology classes
- Cumulative constraint fixed to reference case emissions in 2005-2010, and at a constant (e.g., -80%) level from 2055-2070.

Of runs already identified by CCC for follow-up runs, the following are deemed **not** necessary

- Not new reference case, and long-run fossil fuel price projections are highly uncertain and are already using BERR 2008 projection
- Not additional electricity technology sensitivities - adequately covered in earlier runs