BENEFITS OF INCORPORATING NON-ENERGY AND NON-CO_2 PROCESSES INTO ENERGY SYSTEMS MODELS

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Overview

Energy systems models identify cost-optimal decarbonisation pathways across all sectors of an economy. While most of these models contain highly-detailed, bottom-up representations of the energy system, they tend to poorly represent or omit non-energy processes that produce greenhouse gas (GHG) emissions. For example, the UK MARKAL model, which has underpinned UK decarbonisation policy for the last 10 years, does not represent greenhouse gases other than CO_2 and does not represent processes outside of the energy system (Kannan et al. 2007). While the global ETSAP-TIAM Integrated Assessment Model (Loulou and Labriet 2008) does represent some methane and nitrous oxide emissions from agriculture, land use, land use change and forestry (ALULUCF), it does not include mitigation options to reduce these in the future, and many other non-CO_2 GHG sources are not considered. In a policy environment driven by climate policy, not considering non-energy emission reductions could lead to sub-optimal outcomes for the energy system.

The potential for cutting CO_2 emissions from the energy system is better understood than the potential for cutting non-CO_2 emissions, which occur from numerous processes across the economy including agriculture, business (mainly refrigeration) and waste management, leading governments to assume that many non-CO_2 emissions are unavoidable and that the burden of meeting emissions targets should fall mainly on the energy system. For example, although the UK Climate Change Act 2008 requires the UK government to reduce GHG emissions in 2050 by 80% relative to 1990 levels (HM Parliament 2008), decarbonisation pathway assessments using UK MARKAL have used 90% and 95% targets to recognise the uncertainties in the contribution of non-CO_2 GHGs and the emissions from ALULUCF change (Usher and Strachan 2010; Hawkes et al. 2011).

The UKTM-UCL energy systems model has a comprehensive representation of the UK energy system. It has been expanded to include non-CO_2 GHGs, including those from outside the energy system, and to incorporate a range of costed mitigation options for these emissions. While energy service demands have been fixed in previous versions of the model, we introduce demand elasticities in this version to represent behaviour change in response to price signals. This has been viewed as a key improvement in other energy systems models. In this study, we assess the benefits of representing all GHGs in the model against the CO_2-only approach adopted by most models and we compare the differences in the results with those from simulating elastic demands.

Methods

UKTM-UCL is built using TIMES, which is a widely-applied partial equilibrium, bottom-up, dynamic, linear programming optimisation model (Loulou et al. 2004). TIMES models are used to identify the energy system that meets energy service demands with the lowest discounted capital, operating and resource cost, subject to constraints such as GHG emission targets and government policies. In the standard version of the model, demands are fixed and the objective function minimises the total system cost over the entire model horizon. In the elastic demand version, the model instead maximises welfare (defined as the sum of producer and consumer surplus) so that energy service demands and the energy supply reach equilibrium. Demands may increase or decrease by up to 25% in response to price signals, using elasticities from the literature for each of the 50 demands. Non-energy emissions originate across the economy and mitigation processes are implemented on a case-by-case basis. For example, we use marginal abatement cost curves to implement a range of internally-consistent ALULUCF processes (Moran et al. 2008) and waste processes (Hogg et al. 2008), while industrial process emissions from each industrial sub-sector are accounted for and mitigated individually. A fuller description of the model is available on the UKTM website (Dodds et al. 2014).

Our base scenario constrains UKTM to reduce only CO_2 emissions by 90% in 2050 relative to 1990, with stepped reductions required from 2020 to 2050 to achieve this target (denoted "CO2 90%"), following the approach of previous studies. We compare this scenario to one in which total GHG emissions must be reduced by 80% in 2050; the model identifies the optimal reduction of each GHG in order to meet this target. We examine the impact of introducing demand elasticities on both of these scenarios.

Results

The share of emission reductions in the two scenarios are shown in Figure 1. Total non-CO_2 emissions were 102 $MtCO_2e$ in 2010 and the CO_2 90% scenario assumes that these would reduce only by only 5% in the period to 2050. In fact, in the GHG 80% scenario, non-GHG emissions reduce by 45% relative to 1990, with cost-effective mitigation options available in several sectors. This substantially reduces the need for CO_2 emissions in the energy sector, with an 82% reduction required rather than the 90% assumed in previous UK MARKAL studies. Since the marginal cost of emitting CO_2, which is applied to all commodities in the model, is very high in the energy sector in 2050 for an emissions reduction of 90% (£257/tCO_2), this represents a substantial reduction in the total energy system cost relative to the CO_2 90% scenario. The savings are most economically applied in the transport sector and by reducing the need for “negative emissions” from expensive biomass-fuelled electricity and hydrogen plants using carbon capture and storage.

The cost of decarbonising the energy system in the CO_2 90% scenario over the period to 2060[1] is £233bn in net present cost terms (assuming a discount rate of 3.5% based on social time preference), compared to the same scenario with no emissions constraint. Table 1 shows that using a GHG rather than a CO_2 target reduces this cost by 29%, while lower demands in response to higher prices only reduce the total cost by 7%. Implementing all GHGs, including those outside of the energy system, clearly has a much greater impact on the results than implementing elastic demands and considering only the energy system.

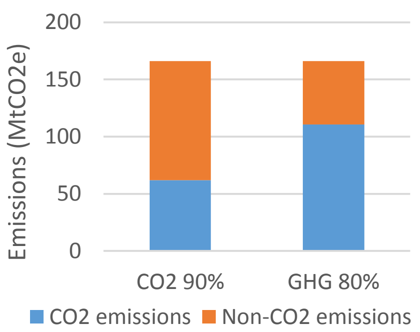

Figure 1. Emissions of CO_2 and non-CO_2 GHGs in 2050 for scenarios with a 90% reduction in CO_2 emissions and an 80% reduction in total GHG emissions.

	CO_2 90%	GHG 80%
Fixed demand		–29%
Elastic demand	–7%	–35%

Table 1. Change in the total cost of decarbonisation relative to the CO2 90% case from simulating all GHGs and elastic demands.

Conclusions

Previous assumptions about the potential for cutting UK non-CO_2 emissions seem unnecessarily pessimistic. Our results suggest that the energy system emission reductions that are required in 2050 should be lower than previously assumed as cheaper non-energy mitigation measures are available. Behavioural responses to price rises are included in many models but have a much lower impact on overall costs than including all GHGs, which are not included in most models. This demonstrates that assessments of decarbonisation pathways for the UK energy system should take account of non-energy mitigation options and we recommend that energy systems models of other countries should similarly consider adding these options.

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[1] The model scenarios are run to 2060 to ensure that the 2050 target remains achievable beyond 2050.