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Integrated Scenarios to Achieve a 60% Carbon Reduction for the UK by 2050

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Note: This paper addresses the Conference question: 'What technological options are there for achieving stabilisation of greenhouse gases at different stabilisation concentrations in the atmosphere, taking into account costs and uncertainties?'

Summary

The Energy Report of the Royal Commission on Environmental Pollution recommended that the UK should cut carbon emissions by 2050 by 60% (from a 1997 level), in order to contribute to a global emissions trajectory that would stabilise atmospheric concentrations of greenhouse gases at 550ppm. This paper will present eight scenarios for the UK energy system (supply and demand), which will describe a wide range of ways in which this target might be met. Decomposition analysis is used to quantify and differentiate the scenarios in terms of energy demand and economic activity, with energy demand divided into fourteen different sectors, and energy supply being distinguished by the four main decarbonisation options: nuclear, renewables, CHP and carbon sequestration. The paper discusses the various implications of these eight scenarios for the UK population, and the global contexts in which these scenarios might come about.

Quantification of the Scenarios

Each of the scenario endpoints in 2050 has carbon emissions from the UK that are 60% below the level in 1990. The scenarios show that it is possible to envisage that such a level of carbon reduction can be achieved in a variety of different ways.

In order adequately to characterise the scenarios, the common level of carbon emissions in each of the endpoints needs to be related to a number of fundamental parameters, including energy demand (primary and final, where primary energy demand equals final energy demand plus the energy lost in conversion [from, for example, fossil fuels to electricity]), economic growth (which has historically been an important influence of energy demand) and, for households, both population (POP) and the number of households (HH), which are important influences on household energy demand.

Eight scenarios have been created, two of each showing low, medium-low, medium-high and high energy demand. The demand side of the energy system has been divided into 15 sectors: the household sector; six business sectors (energy intensive industry, non-intensive industry, public sector, commercial sector, agriculture, construction); seven transport sectors (road – passenger and freight, air – domestic and international, rail, water freight – domestic and international); and the energy industries (a balancing miscellaneous sector in data sources has been omitted, and space is provided for the addition of a new sector for flexibility). Some sectors have been further disaggregated. The supply side, which has been matched to the demand envisaged by each of the scenarios, includes fossil fuels, a number of low- or no-carbon energy sources (nuclear, renewables, CHP), the possibility of carbon dioxide storage, and hydrogen (generated from a range of different energy sources). The different supply options have been feasibly matched to the demand sectors. Aggregate energy demand is derived by summing across the demand sectors. Total carbon emissions are derived from the carbon emission coefficients of the supply sources which are envisaged to meet the demand. The various contributions by different factors (e.g. economic activity, energy demand) to carbon emissions are identified and analysed by means of decomposition analysis.

Decomposition Analysis

Decomposition analysis in relation to scenario analysis of energy use and carbon emissions was discussed by the Intergovernmental Panel on Climate Change (IPCC) in its scenarios report IPCC 2000 (p.105), which followed Kaya (1990) in identifying four ‘driving forces’ for carbon emissions (CO2): population (POP), Gross Domestic Product (GDP) per head, the energy (E) intensity of GDP and the carbon intensity of energy. Such an approach proceeds from the identity:

$$CO2 \equiv CO2/E \times E/GDP \times GDP/POP \times POP \quad (1)$$

More recently, in acknowledgement that the demand related to energy is more for the *energy services* (ES, for example, heat, light, power, mobility) that energy delivers than for energy itself, Ekins and Barker (2001, p.343) split the E/GDP ratio into two ratios: E/ES and ES/GDP, where E/ES indicates the technical efficiency with which energy services are delivered by energy use, and ES/GDP indicates the demand for energy services by economic activity. Ekins and Barker (2001, p.343) also distinguished between the production side of the economy, where the relevant measure of economic activity for each sector is its gross value added (GVA) and its consumption side, where the relevant measure for households is consumer expenditure (CE). The economic activity that creates demand for transport is both domestic production and consumption (GDP), and the demand for imports, and is therefore symbolised by GDPI.

A further point to note is that although energy services are what energy users are interested in, they are very varied and, in many cases, difficult to measure (for example, the energy service delivered by a TV might be described as ‘press-button entertainment’, but even if one could derive a unit to measure this [e.g. viewing hours], it is not clear how to divide the energy service between the TV itself and the stand-by facility). Moreover, the demand sectors each demand a huge variety of energy services. In the decomposition analysis that follows, therefore, the energy service term is suppressed (with the exception of transport) in favour of the simple energy intensity, energy per unit of economic activity (E/GDP in equation (1), though the unit of economic activity differs for different sectors, as discussed above). The exception has been made for transport, because the proximate units of energy service, or mobility (MOB) in this case (passenger-kilometres for passengers, tonne-kilometres for freight), are both well understood and officially measured.

These considerations and refinements in relation to the ratios in equation (1) have led to the following decomposition analyses in the sectors being used for the scenarios in this project:

For the household sector:

$$CO2 \equiv CO2/E \times E/CE \times CE/POP \times POP/HH \times HH \quad (2)$$

For the business sectors:

$$CO2 \equiv CO2/E \times E/GVA \times GVA \quad (3)$$

For the transport sectors:

$$CO2 \equiv CO2/E \times E/MOB \times MOB/GDPI \times GDPI \quad (4)$$

In the spreadsheet tables that quantify the scenarios, the energy demand for each sector (E) has been divided into Electricity and Other Energy, because of the differences in terms of supplying these different kinds of energy.

Decomposition analysis is useful in seeing how CO2 emissions *change* with changes in the ratios. For example, if in equation (3) each of the three ratios increases by 1% per annum (p.a.), then CO2 emissions will change by (1.01*1.01*1.01 – 1)% p.a. In the quantification of the scenarios, the ratios for each scenario have been adjusted to produce the 60% reduction in CO2 emissions that is the common endpoint in all the scenarios. The various ratios can also be related to aspects of the economy or energy system that are important for decarbonisation to occur. For example, CO2/E is the carbon intensity of energy supply; E/ES indicates the energy intensity of energy services (and its inverse gives the technical efficiency with which energy delivers energy services); ES/ACT gives the intensity of economic activity's demand for energy services (or E/ACT gives the energy intensity of economic activity). Many of these ratios are included in standard indicator sets that seek to show how the environmental impact of the economy is changing over time.

Long-term Trends, 1970-2002

The scenarios are compared with, and calibrated against, the average annual percentage changes in various variables and decomposition ratios in the UK over the period 1970-2002. Clearly these ratios have been subject to many changes over this 32-year period. However, in 2002 final energy demand was 169.5 Mtoe, and application of the same average long-term trends as existed over 1970-2002 would lead to energy demand in 2050 of 330.1 Mtoe. For the Household sector, the energy demand was 47.8Mtoe, which increases under the average trends of the last 32 years by 0.8% p.a. to 69.9 Mtoe in 2050, because of increasing consumer expenditure per head (CE/POP; 2.6% p.a.), partially offset by decreasing energy intensity of consumer expenditure (E/CE; -1.9% p.a.). For Non-intensive Industry the long-term trends have been very different: a 0.2% p.a. increase in economic activity has been accompanied by a 1.0% p.a. reduction in energy intensity, leading to an overall 0.8% p.a. reduction in energy demand, such that if continued to 2050 the sector's energy use would fall from19.2 Mtoe in 2002 to 13.3 Mtoe in 2050.

Finally the transport sectors' decomposition can be illustrated in respect of private (passenger) Road Transport and Air International. For private Road Transport, the relevant economic activity (ACT) increased by 2.8% p.a. Mobility (MOB, passenger kms.) increased by 2.4% p.a., so that MOB/ACT (the demand for mobility per unit of economic activity) fell by 0.4% p.a. In addition, the energy intensity of mobility fell by 0.4% p.a., so that overall the energy intensity of economic activity in respect of private road transport fell by 0.8% p.a. The resulting compound change in energy demand of 2.0% p.a. would, if sustained, mean that the energy demand of private road transport would increase from 26.6 Mtoe in 2002 to 67.6 Mtoe in 2050.

The corresponding increase for Air International is even more dramatic. The same 2.8% p.a. increase in economic activity is here augmented by an 8.9% p.a. increase in mobility, leading to a 5.9% p.a. increase in the mobility intensity of economic activity for this transport mode, which was only partially offset by a 3.9% p.a. reduction in the energy intensity of mobility, so that the energy intensity of economic activity for Air International increased by 1.8% p.a. The resulting compound change in energy demand of 4.7% p.a. would, if sustained, increase the energy demand of Air International from 9.4 Mtoe in 2002 to 85.3 Mtoe in 2050.

Eight Scenarios for 2050

The eight endpoints presented all achieve a 60% reduction in carbon dioxide emissions through differing combinations of demand reduction, achieved through efficiency improvements and changing consumption behaviour, and low carbon energy supply. For the first time sectors which have previously been omitted from UK energy scenarios, such as international aviation and international marine, have been included. In essence, the scenarios highlight that a small number of sectors, namely aviation, international shipping, households and road transport, contribute the greatest proportion of emissions in 2050. Back-casting is used to articulate the trajectories from the present day, setting out policy steps, technology, social, cultural and political milestones as well as necessary infrastructure developments required to achieve a particular combination of energy demand and supply by

2050. The influence of external events such as climate change impacts, oil price and global conflict is also considered.

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