Annex E: Energy – supplementary material

E.1 MODEL FORMULATION

For these three variables, energy demand is calculated using elasticities as follows:

$$Q = Q_0 \, [N_N / N_0]^{E_N} [P_N / P_0]^{E_P} [Y_N / Y_0]^{E_{GDP}}$$

Where:

Q: Scenario sectoral demand

Q_0: Sectoral demand from the reference case

N_0, P_0, Y_0: Reference case population, energy price and GDP

N_N, P_N, Y_N: Population, energy price and GDP from chosen scenario

E_N, E_P, E_{GDP}: Long-run population, price and income elasticities

E.2 KEY ASSUMPTIONS

Industrial gas usage, Ig is then calculated as below:

$$I_g = T_g - R_g - P_{og} * T_g$$

Where:

T_g: Total gas demand in ENERGY 2050 scenario

R_g: Residential gas demand

P_{og}: Percentage of other gas users. It is set at a constant percentage of 16.16% of total use through 2050. This is based on historical average of other gas users in 1998–2009 (Min: 15.4%, Max: 17.7%) in the 'Digest of Energy Statistics' (DECC, 2010a).

E.3 PREVIOUS QUANTIFIED ASSESSMENTS

Previous quantified assessment for future transitions of UK energy systems are available in the form of energy future scenarios. The term 'scenario' here differs from 'ITRC scenario' which is a combination of projections of key energy demand drivers. Rather, these are a quantified assessment of energy system transitions using scenario analysis. Scenario analysis is a useful technique where human systems are involved as in the case of an energy system. Given the inherent complexity of the human system, predicting medium- to long-term forecasts of the energy system becomes highly constrained. This becomes more complex when other long-term, complex and uncertain problems such as climate change are considered (Mander *et al*., 2008). Thus, these scenarios help to explore the alternative futures and broad assessment of possibility space.

In our review, we limited our assessment to the scenarios that are (a) quantitative, (b) cover the whole energy system and (c) developed within last 5 years. That left us with four influential scenarios which are briefly described below.

1 Tyndall Decarbonisation Scenarios

Five scenarios were developed using a backcasting method to achieve a 60% reduction in GHG emissions by 2050 – this 60% reduction was government target at the time the scenario was developed. The backcasting method was developed with an active participatory iterative approach (Mander *et al*., 2008). Critical factors and policies, outlined by stakeholders at each end-point period, determined the level of changes in technologies, values, behaviours, infrastructure, or other physical or social variables, necessary to bring about an pre-determined end-point up to 2050 (Anderson *et al*., 2008).

2 Royal Academy of Engineering (RAE) Scenario

RAE published four scenarios for the UK's possible energy demand in 2050 (RAE, 2010). RAE scenarios build upon the approach and four scenarios used by the Royal Commission on Environmental Pollution report published in 2000. Similar to Tyndall scenarios, the RAE scenarios achieve the new government target of 80% GHG reduction by 2050. However, it focuses on the principal components and the most salient issues to illustrate the challenges in the four transition pathways. Their goal is to achieve pre-set demand reductions in the future in heat (low and high grade), electrical appliances and through transport electrification. In supply side full deployment of renewable technologies to their potential is assumed and the rest is supplied by nuclear, CCS and fossil fuels (after exhausting CCS and nuclear). Cost is not explicitly considered in determining transitions and cost incurred is not calculated. Supply and demand is balanced by adjusting the levels of supply and an iterative process produces the final energy system.

3 DECC 2050 Pathway Analysis

This analysis is an interactive framework with an accompanying tool to explore a range of pathways to help policymakers, industry and the public to understand choices for the UK's energy future (DECC, 2010b). Users can choose one of four different sets of future trajectories pre-set inside the underlying model for each demand and supply sectors in the economy. The model combines these trajectories and looks for 'successful' pathways that deliver a secure energy system, 80% emission reduction by 2050 while ensuring supply meets demand. Focus is on low carbon energy supply (with their physical and technical limits considered) and decarbonisation – fossil fuels needed to fill supply gap are assumed to be from domestic production or international market.

All trajectories assume 0.5% and 2.5% per year growth in population and GDP respectively. To simplify the model, interactions between the sectors are not explicitly set out. However, users may define interactions through the levels to some degree (e.g. selecting high levels of solar thermal with solar PV). Possible drivers and constraints affecting the sectors are considered. Since users select which trajectory they want the sectors to transition to, cost is not an explicit consideration to arrive at the 'successful' pathways.

4 UKERC Energy 2050 Pathways

UKERC's ground-breaking ENERGY 2050 analysis produced 32 variants of scenarios of varying levels of targets of decarbonisation, resilience, lifestyle change, technology acceleration and global uncertainties (Skea *et al*., 2010). The analysis involved two optimisation models namely, MARKAL-MED, a UK variant of the widely used MARKAL model for demand estimation, and WASP (Wien Automatic System Planning) model by International Atomic Energy Agency for electricity generation capacity estimation. MARKAL-MED is a technology rich model with detailed technology representation of UK energy system. Using detailed characterisation of technology performance and costs, elasticity of energy services demand to price, availability and cost of energy supply and baseline energy services demand, MARKAL-MED maximises welfare to arrive at the optimal energy system for the given constraint (e.g. GHG reduction goal, resiliency level etc.). Depending on the scenario, policy interventions are systematically introduced to the model. Then, for each scenario WASP produces national level generation capacity using a sophisticated set of reliability indicators.

Selected quantitative assessment

Based on the review, we selected UKERC Energy 2050 Pathways for this Fast Track Analysis (FTA) for following reasons:

1. It is based on widely used peer-reviewed models, uses both detailed engineering and essential econometric approach to depict the complex interaction within the energy system and incorporates possible future policy interventions – we believe this enables it to best mimic the future dynamics of the UK energy system.
2. It produces detailed outputs on demand, supply, generation mix, emissions, installed capacities etc. by sector and fuel.
3. All input data, assumptions, methodology and results are transparent and freely available. Since, the purpose of the FTA was to understand the uncertainty space of demand and explore possible supply options, ENERGY 2050 provides essential information and valuable insight on possible transition pathways of the UK energy system in order to design the Energy CDAM for robust analysis.
4. Since a wide range of futures were modelled, it is more likely that defined transition strategies in FTA are represented closely in one or more of them.

Despite its strength, MARKAL is criticised for being highly data intensive and assuming a perfect energy market – this tends to overestimate deployment of nominally cost-effective energy-efficiency technologies without proper constraints. However, we consider it the best available representation of the complex UK energy system for a confident FTA.

It should be noted that there is no spatial representation of the pattern of energy supply and use in any of the above scenarios which the Energy CDAM in later phases of ITRC aims to achieve.

E.4 TRANSMISSION – BACKGROUND INFORMATION

There is an interconnection of high-voltage transmission system in England and Wales to France, but this is rather limited (2 GW) in the context of the total market. In April 2011, BritNed, a 1000 MW 250+ km high voltage DC bi-directional interconnector between the Isle of Grain in Kent and Maasvlakte near Rotterdam became operational. A 500 MW DC interconnection with the Republic of Ireland for mainly peak-time export is planned to be commissioned in 2011. The Channel Tunnel interconnector (GB-France) is a 500 MW DC link expected to be completed by 2015.

Increasing focus on the embedded generation and high growth in the sector has implications for the robustness of the transmission network. One effect from embedded generation will be a reduction in flow across the interface between transmission and distribution networks, thus delaying (not eliminating) the reinforcements of parts of the network. Embedded generation may also increase electricity exports from distribution networks to transmission system and reduction of power flow in the opposite direction. However, NETS (2011) states that such changes are not likely to pose major difficulties. Since system reinforcements are a function of size and geographical location (volume and direction of power flows), opening and closure of large generation (plants), levels of demand (where it exceeds generation) and location of both will be of more importance. Thus, with increasing wind generation (both offshore and onshore), the resulting north-south and east-south power flow increase will be a major factor for the reinforcements and expansion of the present system which presently has very little spare capacity. To tackle these challenges, new projects are considering the latest technologies around HVDC, energy storage, land and submarine cables etc. (ENSG, 2009).

Intermittent/variable generation coming from wind as well as solar, wave and even some CHPs also have implications on the transmission system. For example, although analysis shows that there would not be a technical ceiling on the amount of wind generation due to their intermittent nature, increasing their level on the system may increase the costs of balancing and managing the system frequency (NETS, 2011).

A critical role for low carbon electricity is a robust assumption. Key technologies will therefore be the low carbon electricity generating technologies with high potential contributions to UK supply by mid-century. These are nuclear fission, wind energy (onshore and offshore) and fossil fuels with carbon capture and storage (CCS). The mix is very uncertain (as well as controversial) and has major implications for transmission infrastructure. Major uncertainties include how much of each of these resources will be developed, the continuing role of gas and the future fuel demand and mix in transport.

The role of biomass, and the vectors through which it is used (solid, liquid and gaseous) is an important sensitivity. Some other renewables also need to be considered, especially marine and solar. The latter is a possible component of more decentralised generation scenarios which are radically different from existing networks. CO_2 disposal infrastructure needs to be considered in scenarios with CCS.

The key technologies for energy demand fall into two broad categories. Firstly, those with the potential to reduce demand; there are a large number of these and they tend to be grouped, at the sectoral level (buildings, transport, industry) in the energy futures literature. And secondly those implied by transitions to low carbon vectors (primarily electricity). Given the supply assumptions, high levels of electrification will need to be considered. This implies widespread use of electric vehicles and heat pumps, both of which have significant implications for power networks, and supply/demand balancing.

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