Carbon reduction scenarios for 2050: an explorative analysis of public preferences

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ABSTRACT

This paper presents an analysis of public preferences for a low carbon future UK and compares them with three future scenarios proposed by the UK government based on data from 10,983 self-selected participants who engaged in the UK Department of Energy and Climate Change 'My2050' on-line simulation. Participants expressed a stronger preference for demand-side options than for supply-side ones. They also chose fuel switching (to electricity) and technical energy efficiency measures above more behaviour focused options. Renewable energy options (wind, solar, marine and hydro) were preferred to other low carbon supply options (nuclear power, carbon capture and storage), with offshore wind power more popular than onshore. Nuclear power was the least popular generation option. Acceptability of the government's three proposed scenarios was tested by

comparing these scenarios with the research findings. Greatest support was suggested for the two scenarios emphasising business greenness, home energy efficiency, electrification of home heating and travel behaviour. The lowest level of support was demonstrated for the scenario based on significant growth in nuclear power with minimal increases in energy efficiency. Despite issues regarding the representivity of the sampled respondents, the work demonstrates the possibility of using outputs from the tool to assess publically preferred pathways.
Keywords: ‘Public engagement’, ‘Energy scenarios’, ‘2050 Calculator’, ‘Climate policy’

1. Introduction

The Climate Change Act provides a legally binding requirement for the United Kingdom (UK) to reduce greenhouse gas emissions by eighty percent by 2050 (HM Government, 2008a). The government has published three preferred scenarios to achieve this target within the national Carbon Plan (DECC, 2011a). Alongside this, the Department of Energy and Climate Change (DECC) has developed public engagement tools to promote understanding of the challenges in developing carbon reduction scenarios, and encourage debate about energy futures (DECC, 2011b). Any significant effort to move towards decarbonisation of the energy supply, or reduction in energy demand or fuel switching by the public, will require significant public support due to the scale of change required (Whitmarsh *et al.*, 2011).

One of DECC's public participation tools, the 'My2050' online simulation (DECC, 2011c), attracted over 10,000 responses between its launch in early March and the end of June 2011 (the first four months after it was launched). This paper reports on an analysis undertaken of this first tranche of responses. This is an exploratory study that has been carried out in order to test the possibilities for summarising data generated by the simulation, and to highlight where, for various reasons, caution will need to be taken in future use of the tool, or interpretation of its outputs.

Policy analysts have considerable interest in understanding to what extent the options being pursued by DECC's three scenarios align with public preferences, and would welcome information about where options clash with public acceptance or willingness to act[i]. This research investigated the outcomes of the first wave of public engagement using the 'My2050' web-tool developed by DECC, by scrutinising the data for preference patterns and comparing these with DECC's proposed scenarios as set out in the Carbon Plan (DECC, 2011a). The comparison with DECC's three preferred scenarios can provide some indications about how feasible each of these scenarios might be if implemented, if the self-selected respondents are sufficiently representative of the wider population. In addition to questioning the representivity of respondents, the paper also discusses whether self-reporting in this format can be reliably considered to represent actual support for policy implementation, particularly where there is a lack of clarity over who would be required to make the necessary changes. As planning for long-term carbon reduction grows as a policy area, recommendations for improvements to the 'My2050' simulation are sought to ensure public engagement aligns with good practice[ii]. There is also growing interest in adapting the UK's 2050 carbon reduction public participation tools in other countries, including China[iii] . However, this type of approach would require much more rigorous evaluation and re-design to become more that a very limited test of opinion. Within the paper we also draw attention to some issues regarding the design and layout of the tool that might inadvertently skew participants' responses and, considering the current popularity of 'behavioural sciences' within UK government (Chatterton and Wilson, 2013), might merit significant further testing.

2. Background to DECC's 2050 calculator and online simulation

Following the IPCC and Stern reports, in 2008 the UK became the first country to pass legislation for long-term greenhouse gas emissions reductions (HM Government, 2008a). The Climate Change Act 2008 requires an eighty percent reduction in greenhouse gas emissions by 2050 (against a 1990 baseline for carbon dioxide, nitrous oxide and methane, and a 1995 baseline for other greenhouse gases). This target was determined as a result of recommendations by the Committee on Climate Change (2008), however some scientists argue that even this is not ambitious enough to mitigate serious impacts (Hansen *et al.,* 2008).

There is a growing body of literature emerging from business, industry, academia and the NGO sector setting out road maps and exploring options for how to achieve the targets in the Climate Change Act (Centre for

Alternative Technology, 2010; Ekins, *et al.* 2011; Jamasb and Pollitt, 2011; Nicholson, 2011; Skea *et al.*, 2011; Williams *et al.,* 2012; WWF, IPPR and RSPB, 2007). Systematic assessments for long-term policy analysis are challenging due to the complexity of planning across timeframes where many factors remain unknown (Lempert *et al.*, 2003). Most scenario studies examine the impact of different policy measures on technological uptake , although emerging research highlights the significant role institutional and behavioural change will also have to play in achieving a low carbon energy future. This suggests that scenario building would be strengthened if it integrates qualitative and quantitative methods (Söderholm *et al.,* 2011). Policy decisions will need to be made in the near future about preferred low carbon scenarios for energy and transport supply and demand options, particularly for infrastructure investment, if the targets in the Climate Change Act are to be achieved (Skea *et al.*, 2011).

Prior to becoming Chief Scientific Adviser at DECC, MacKay published several possible scenarios with associated emissions reduction calculations (MacKay, 2009). DECC subsequently published six illustrative ‘pathways’ outlining possible whole energy system change scenarios (HM Government, 2010). DECC has encouraged public engagement and debate by developing tools which enable the creation of new scenarios, facilitated by online and offline versions of a ‘2050 Pathways Calculator’ (DECC, 2010), a simplified web-based simulation called ‘My2050’ (DECC, 2011c) designed for wider public engagement (and which has provided the data in this study), an online debate initiated by a panel of experts, and a toolkit to enable local community participation (DECC, 2011d).

Fulfilling legal requirements for the Climate Change Act, DECC subsequently published The Carbon Plan (DECC, 2011a), which described three possible scenarios for achieving the 2050 carbon reduction targets, and illustrated them using the DECC calculator. These scenarios show possible pathways, but they are not yet actual policy choices or recommendations by DECC, since the political decision-making process to select a preferred pathway is ongoing. At the same time, DECC also published a detailed spreadsheet setting out cost ranges, land use implications and other technical data associated with choices available in the 2050 calculator (DECC, 2011b).

Public participation in development of carbon reduction policies offers the possibility of more effective policy decision-making (Castell, 2010), although the challenges in adapting the political system to enable greater democratic involvement in responding to climate change should not be underestimated (Lidskog and Elander, 2010). Public acceptance of new technologies will influence their uptake and speed of adoption, while public preparedness to adapt behaviour or comply with new legislation will test the viability of low carbon policy measures (Spence and Pidgeon, 2009). The implementation of low carbon technology changes (such as the proposed shift towards low emission vehicles) and societal change towards lower carbon behaviours (such as the increased use of public transport and car-sharing) will only be realised if they are socially acceptable (Christmas *et al.,* 2009), yet research to understand the likelihood of extensive behaviour change towards low carbon demand-side policy options is still in its infancy (Darnton, 2008). Given the scale of societal change that is predicted to be required to reduce emissions, an understanding of public preferences for different low carbon energy and transport policies is essential (Spence *et al.*, 2012). More recent work is indicating that increased public participation is crucial as public preferences are potentially based on complex, and far from transparent, sets of underlying values (Parkhill *et al.*, 2013). The 'My2050' simulation is proving to be a useful tool in aiding public engagement, by providing a clear focus for discussion around a hugely complex set of issues.

This paper introduces and describes the 'My2050' tool before going on to examine an initial set of results collected over the first four months of its availability. The study evaluates the representativeness of the self-selected sample of participants, explores patterns in the data by looking at most popular choices (across the whole sample and within sub-groups), and finally attempts to compare these to the three existing DECC scenarios published in the Carbon Plan.

3. Methodology

This research explored whether there were consistent patterns within people's responses to the 'My2050' simulator that could be seen as demonstrating any clear public preferences for how significant carbon reduction can be achieved by 2050. It also tested to what extent these voluntary responses aligned with the options currently being explored by government. The research reported here involved a quasi-experimental evaluation, with a quantitative research strategy. Wider research also involved undertaking semi-structured interviews with six experts from academia and policy development (with backgrounds in the physical sciences, psychology, politics and social research). These informed the interpretation of preliminary findings, but are not analysed in this paper.

3.1 Data generation

The 'My2050' online simulation was developed by DECC (through a contract with digital democracy company Delib) and launched on 3 March 2011 with a BBC Radio 4 feature (DECC, 2011e). 'My2050' invited self-selected respondents to choose one of four settings, representing increasing effort levels, for fourteen different 'sliders' representing seven supply and seven demand-side energy issues (see Figure 1). The aim of the simulation was to achieve at least an eighty percent reduction in carbon emissions by selecting one of four settings for all fourteen sliders for 2050. The four settings for all supply sliders are described in Table 1 and for all demand sliders in Table 2.

Figure 1: Screenshot of 'my2050' simulation showing layout of 'sliders'

Progress is illustrated by an online 'thermometer', which starts at one hundred percent and needs to reach twenty percent before choices could be submitted, although respondents could exceed this target. Each choice influences the overall carbon reduction achieved, although reduction figures vary depending on the inter-relationship of settings selected for sliders. Each choice also influences an overall 'Energy Security Indicator', which shows how balanced the overall choices are in terms of consequent supply and demand for electricity and 'fuel'. This consists of a graphical illustration showing whether demand was exceeding supply or vice versa, or whether the choices made result in a 'balanced world' in which supply exceeds demand "but not by a wasteful amount". In total there are over 250 million possible combinations of sliders[iv]. The simulation creators have not calculated the number of scenarios that could legitimately be selected to achieve the target, but it is anticipated to be considerable.

After submitting choices, respondents were asked for information on their age, the UK region where they live, type of location (urban or rural), how happy they would be to live in the ‘world’ they had created, and how concerned, if at all, they were about climate change. A comment box was also provided for free text on the question ‘Why did you choose your My2050 world?’. It is worth noting that over 90% of respondents indicated that they were happy with their world.

The simulation was developed as a simplified tool to enable public engagement in long-term carbon reduction strategies[v], and was based on a more complex calculator and technical analysis regarding future energy scenarios (DECC, 2010). All assumptions, descriptions and calculations underpinning the simulation derived from this more extensive body of work. These assumptions limit the flexibility offered by the simulation, providing constraints on the number of options available, the settings provided for each option, and the resulting preferences a participant can express. For example, participants were unable to select ‘no biofuel production’ as a setting, since this was not available in the simulation. These limitations need to be considered when interpreting any findings from this research.

Table 1 – Possible settings for supply sliders

Supply	Setting 1	Setting 2	Setting 3	Setting 4
Biofuel production	We use bioenergy crops grown in the UK covering an area half the size of Wales	We use bioenergy crops grown in the UK covering an area half the size of Wales and an area half the size of Wales overseas	We use bioenergy crops covering an area the size of Wales in the UK and another area the size of Wales overseas	We use bioenergy crops covering an area twice the size of Wales and the same again overseas
Oil, gas and coal power	Fossil fuel supplies increase by more than 25% in 2050 from today, many of which will be imported	Fossil fuel supplies in 2050 fall by 25% of those supplied today	Half as much fossil fuel supplies as today in 2050	Fossil fuel supplies in 2050 are only 10% of those supplied today
Nuclear power	No nuclear power in 2050	Four times as much nuclear power as today in 2050, comparable to building 13 large nuclear power stations	Nine times as much nuclear power as today in 2050, comparable to building 30 large nuclear power stations	Thirteen times as much nuclear power as today in 2050, comparable to building 50 large nuclear power stations
Clean coal and gas power	No clean coal and gas stations beyond UK demonstration programme. Carbon capture and storage does not work at scale.	Around 30 gas and coal stations store their carbon - equivalent to today's gas and coal stations.	Around 45 gas and coal stations filter and store their carbon. Coal and gas industry produces over 50% more power than today.	Around 70 gas and coal stations filter and store their carbon underground. Coal and gas industry over double the size of today.
Wind turbines on land	No onshore wind turbines in 2050.	8,000 onshore wind turbines built by 2050. In 2010 we had 3,000.	13,000 onshore wind turbines built by 2050.	20,000 onshore wind turbines built by 2050.
Wind turbines on sea	No offshore wind turbines in 2050.	10,000 offshore wind turbines built by 2050. In 2010 we had 436.	17,000 offshore wind turbines built by 2050.	40,000 offshore wind turbines built by 2050, including some floating turbines.
Solar, marine and hydro power	No solar, hydro, geo-thermal or marine energy sources used in 2050.	$4m^2$ of solar panels per person; 8,000 wave machines; small tidal, geothermal and hydroelectric schemes.	$6m^2$ of solar panels per person; 16,000 wave machines; major tidal, geothermal and hydroelectric schemes.	$10m^2$ of solar panels per person; 27,000 wave machines; highly ambitious tidal, geothermal and hydroelectric schemes.
All text taken directly from 'My2050' (DECC, 2011c)				

Table 2 – Possible settings for demand sliders

Demand	Setting 1	Setting 2	Setting 3	Setting 4
Manufacturing growth	UK manufacturing grows strongly, more than doubling in size. International shipping growth triples today's demand.	Manufacturing stays roughly same size as today. International shipping grows with over 150% growth in demand.	Manufacturing stays roughly same size as today. International shipping growth slowed with greater use of IT and services.	Manufacturing declines, becoming about a third smaller by 2050. Less demand for shipping traded goods.
Business greenness	Incremental action to improve energy efficiency.	Some energy efficiency measures. Higher electricity demand overall by industry.	Good improvements in energy efficiency. Some emissions from heavy industry are filtered and stored underground.	Stellar improvements in energy efficiency. Half of emissions from heavy industry are filtered and stored underground.
Home efficiency	5% of homes have additional insulation.	A quarter of homes have additional insulation.	Three quarters of homes have additional insulation.	Almost all homes have additional insulation.
Home temperature	Increases from today's 17.5°C to 20°C - following trend from past decades.	Increases from today's 17.5°C to 18°C.	Decreases from today's 17.5°C to 17°C - breaking international trend from past decades.	Decreases from today's 17.5°C to 16°C - time to put jumpers on!
Heating fuel	Proportion of heat supplied by electricity is small - the same as today.	20% of domestic heat supplied by electricity.	About half of domestic heat supplied by electricity.	About 90% of domestic heat supplied by electricity.
How we travel	We continue to use cars as we do today.	We use public transport instead of cars for a fifth of our journeys.	We use public transport instead of cars for a quarter of our journeys.	We share our journeys more, and don't use our cars for two-fifths of our journeys.
Transport fuel	Most cars are like those you see today - but more efficient.	3 out of every 5 cars are powered by electricity - 60%.	4 out of every 5 cars are powered by electricity, and some use hydrogen fuel cells.	All cars are electric or run on hydrogen. All trains and most buses are electric.
All text taken directly from 'My2050' (DECC, 2011c)				

3.2 Adjustment of data

To maintain consistency with DECC's reports, settings representing increasing effort levels are presented throughout this paper on a scale of 1-4. Three sliders (*'oil, gas and coal power'*, *'manufacturing growth'* and *'home temperature'*) were presented visually in 'My2050' as descending sliders for increasing effort and carbon reduction, since these three conceptually involve reductions. All other sliders ascended for increasing effort and carbon reduction since these involve increasing different technologies, supply options or new behaviours. This was intended to ensure the simulation remained intuitive. Settings were coded consistently (whereby lowest effort = 1; highest effort = 4).

However, this obvious inconsistency in the layout of the simulation also gives lie to a range of other, much more subtle, differences regarding the descriptions of the effort levels that might lead to particular skews towards or away from certain settings. These include possible primings or particular framings of issues e.g. the use of the terms 'good' and 'stellar' in the higher options for *'business greenness'* convey a strong positive norming message, whereas the phrase 'time to put jumpers on' in *'home temperature'* conveys a much more negative message. Similarly, there are other differences such as how the different levels refer to current baselines (for instance, level 1 for *'biofuel production'*, *'oil, gas and coal power'* and *'manufacturing growth'* are all based on significant changes from the present compared to the other sliders) or existing trends (as *'home temperature'* is the only slider that clearly sets out levels in terms of current/past trends). Another factor that may skew or affect participants' final scenarios is the fact that there are inter-relationships between some of the sliders that are not immediately obvious to the user. In particular, significant carbon reduction from demand side options involving electrification are only achievable when supply side options have been chosen that significantly decarbonise the energy supply (and vice versa). Unless very careful attention is paid then users may consider particular sliders to be ineffective (and therefore set them overly high to over compensate, or low as they are deemed of no use). It may also be the case that sliders that produce the most obvious and direct reductions in carbon may trigger a bias due to a visual reward effect as the thermometer changes.

Due to the numerical categorisation of choices, data from the 'My2050' simulation were analysed using quantitative statistical methods. A simple pathways comparison method was created to enable a comparison between 'My2050' responses and DECC's proposed scenarios. Data generated by 'My2050' respondents were provided in Excel by DECC. Data cleaning involved removing international responses (n = 693), since these were not selected for analysis, and data arising from design testing and alterations (n = 130). This process left 10,983 cases for analysis. Initial data interrogation involved exploratory statistical analysis (Pallant, 2010). Descriptive statistics provided information about when respondents participated in the simulation and how long they took to complete their choices; summary information on demographics and attitudinal responses;

frequency data for setting choices; and numbers of respondents achieving different carbon reduction levels. Duplicate case analysis identified how many unique pathways[vi] had been selected. The central theme of this paper is based on an analysis of the modal values selected by participants for each of the sliders.

4. Results

4.1 Demographic data

The responses were analysed to assess whether they were representative of the UK population. The age of respondents is illustrated in Figure 2, alongside comparison data for the UK population from the 2001 census (ONS, 2001). Respondents over-represented their equivalent age group in the UK population for people between 16 and 45. In contrast, respondents under-represented their equivalent age group in the UK population for people under 16 and over 45, most notably in the 'over 65' age group.

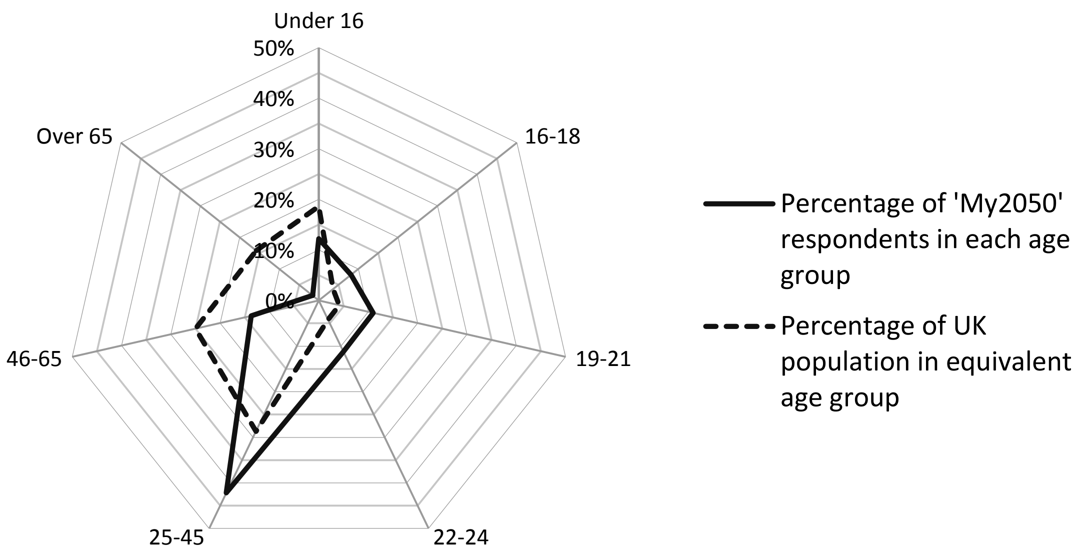

Figure 2 – Demographic comparisons: age

The region/country respondents came from is illustrated in Figure 3, alongside comparison data for the UK population from the 2001 census (ONS, 2001) for the same regions and countries. Respondents over-represented the population in the South (West and East), Greater London, and marginally in the North East.

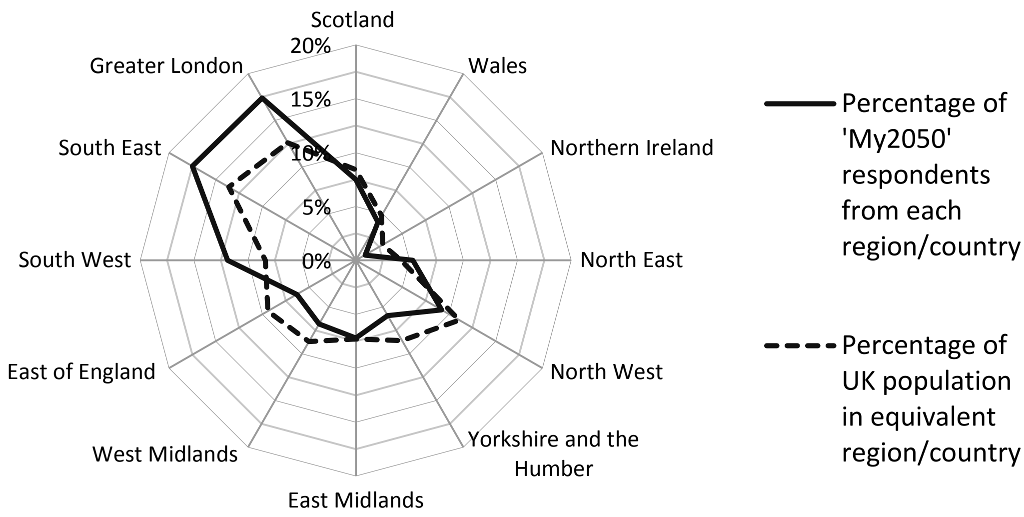

Figure 3 – Demographic comparisons: location

Respondents were asked 'Would you describe your home as being rural or urban?'. The responses of the participants closely matched the UK population from the 2001 census for these two types of location (Chi-square = 3.54, p = 0.06). The simulation did not ask participants to describe level of education attained, employment status, gender or other potentially critical variables, and therefore the extent to which this sample can be evaluated for representativeness is limited.

4.2 Attitudinal representativeness of respondents

Respondents were asked 'How concerned, if at all, are you about climate change?'. Responses are illustrated in Figure 4. 91.1% of respondents stated that they were concerned about climate change.

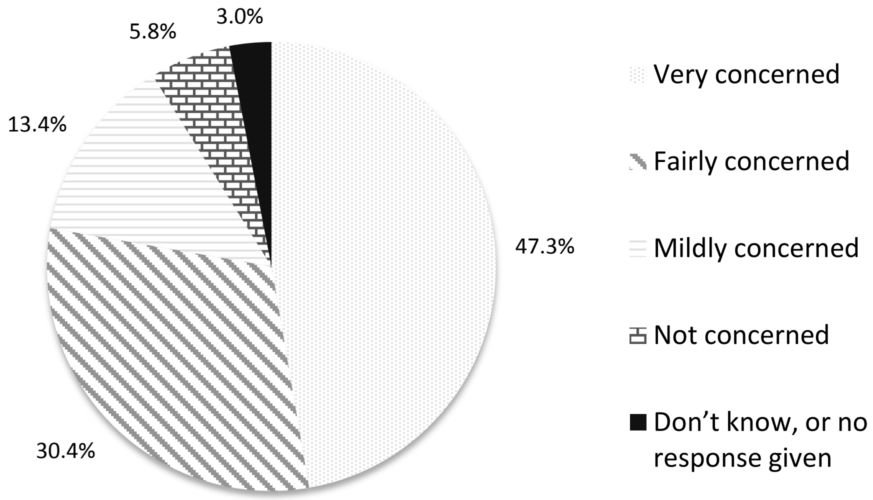

Figure 4 – Concern about climate change

Public attitude surveys investigating concern about climate change with nationally representative samples have found that approximately 70% of people are fairly or very concerned about climate change (Corner *et al.,* 2011; Department for Transport, 2011), although other research indicates lower levels of concern (European Commission, 2007; Lynn and Longhi, 2011; National Centre for Social Research, 2012). When compared with Figure 4, this demonstrates that these respondents were more concerned about climate change than the population.

4.3 Demographic data summary

Demographic and attitudinal data demonstrated that participants were younger than the UK population, with over-representation in the 16-45 age group, and also more concerned about climate change, based on limited information collected through the simulation. This poses some limitations on how generalised any findings might be, since this sample cannot be wholly regarded as a representative sample of the UK population. Since these participants were self-selecting, this sampling approach was more likely to attract participation from people already interested and engaged with the topics discussed, hence any conclusions derived from data analysis reflect the views of these participants, but cannot be assumed to match the views of the general public.

4.4 Overview of participation data

10,983 responses were submitted between 2 February[vii] and 28 June 2011. 90.7% of responses were submitted during March 2011, with 49.3% of all responses submitted on 3 March 2011, the day 'My2050' was launched. Respondents took on average just over fifteen minutes to make their choices (5% truncated mean = 15 minutes 34 seconds), although 6.4% took five minutes or less, and 3.4% took over an hour. Figure 5 illustrates how long people took to make their choices.

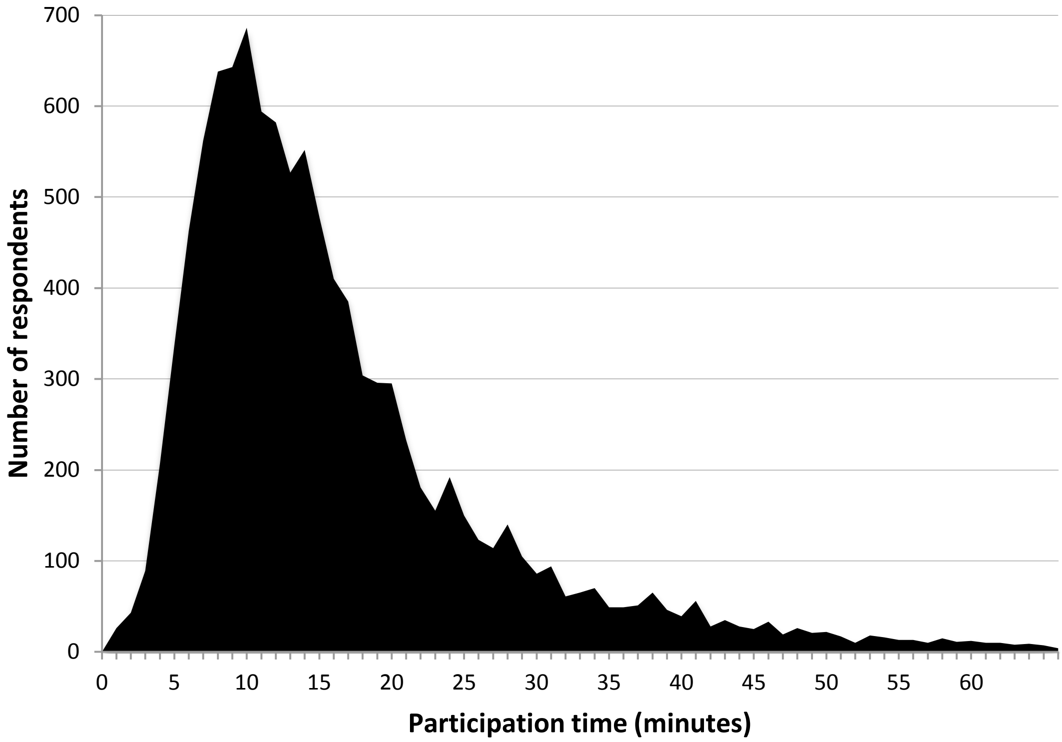

Figure 5 – Total participation time

Respondents were unable to submit choices until at least eighty percent carbon reduction had been achieved, and 27.5% of respondents submitted when their choices hit this 80% carbon reduction target. The remaining 72.5% of respondents achieved greater reductions, as illustrated in Figure 6. A substantial number of respondents (17.4%) achieved carbon reduction levels of ninety-five percent or more, suggesting that participants were highly engaged with the issues involved, to such an extent that they went well beyond the required target. This aligns with the high level of climate change concern illustrated above. 'My2050' did not allow respondents to exceed ninety-nine percent carbon reduction.

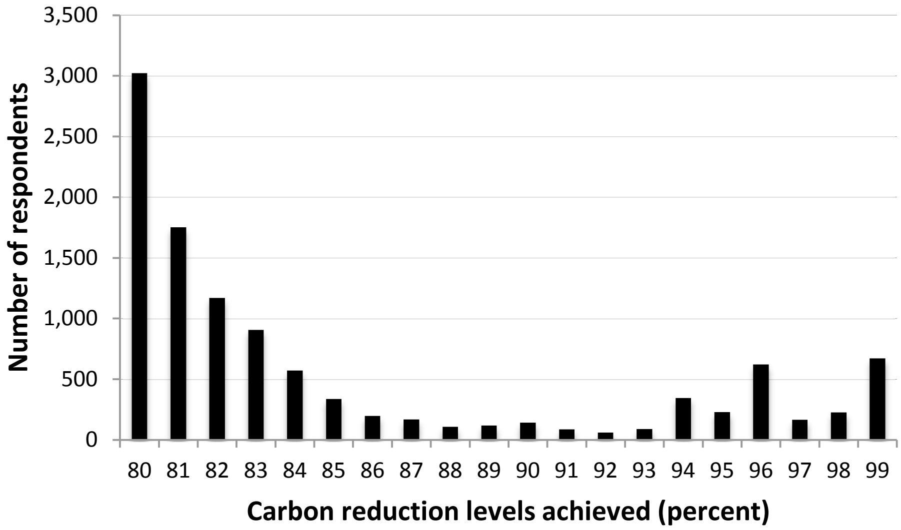

Figure 6 – Levels of carbon reduction achieved

4.5 Popular setting choices

Duplicate case analysis for pathways (represented by slider setting choices) showed that 85.4% (n = 9,377) of all pathways created were unique. The remaining 14.6% (n = 1,606) of pathways were duplicates, consisting of 452 different pathways, demonstrating a very high variability in pathway preferences. Of these duplicate pathways, the most common was selected by only 1.1% (n = 122) of participants and only 229 pathways were chosen by more than two respondents. The high level of variability in responses was not anticipated by the simulation creators within this initial sample of ≈10,000 responses.

Rather than judging the comparative popularity of entire pathways, a 'preferred pathway' has been generated using the most frequently selected setting for each of the individual sliders. Table 3 shows this pathway, which can be represented as S2322233 / D2443333[viii], along with the relative strength of the most popular setting and the relevant description of the effort level. This pathway exceeded the required target and achieved an 84% carbon reduction. This pathway was not balanced on the Energy Security Indicator, as supply exceeded demand by a wasteful amount. Testing of this scenario found that one minor alteration to this pathway (reducing *'wind turbines on sea'* by one setting) achieves balanced energy security without altering the level of carbon reduction, and therefore the extent to which this is an unbalanced pathway is assumed to be small.

Table 3 – Most popular slider settings from sample (n = 10,983)

Slider	Setting	Chosen By	Description
Supply			
Biofuel production	2	3,497 (31.8%)	We use bioenergy crops grown in the UK covering an area half the size of Wales and an area half the size of Wales overseas.
Oil, gas and coal power	3	7,748 (70.5%)	Half as much fossil fuel supplies as today in 2050.
Nuclear power	2	4,077 (37.1%)	Four times as much nuclear power as today in 2050, comparable to building 13 large nuclear power stations.
Clean coal and gas power	2	3,825 (34.8%)	Around 30 gas and coal stations store their carbon - equivalent to today's gas and coal stations.
Wind turbines on land	2	3,784 (34.5%)	8,000 onshore wind turbines built by 2050.
Wind turbines on sea	3	4,491 (40.9%)	17,000 offshore wind turbines built by 2050.
Solar, marine and hydro power	3	4,013 (36.5%)	6m^2 of solar panels per person; 16,000 wave machines; major tidal, geothermal and hydroelectric schemes.
Demand			
Manufacturing growth	2	3,921 (35.7%)	Manufacturing stays roughly same size as today. International shipping grows with over 150% growth in demand.
Business greenness	4	5,713 (52.0%)	Stellar improvements in energy efficiency. Half of emissions from heavy industry are filtered and stored underground.
Home efficiency	4	5,441 (49.5%)	Almost all homes have additional insulation.
Home temperature	3	4,521 (41.2%)	Decreases from today's 17.5°C to 17°C - breaking international trend from past decades.
Heating fuel	3	5,209 (47.4%)	About half of domestic heat supplied by electricity.
How we travel	3	4,612 (42.0%)	We use public transport instead of cars for a quarter of our journeys.
Transport fuel	3	4,494 (40.9%)	4 out of every 5 cars are powered by electricity, and some use hydrogen fuel cells.

Figures 7 and 8 show the frequency of selection for each setting on the supply and demand slider options (with descriptions of settings in Table 1 and Table 2). It is worth noting that, while high setting choices always represented higher levels of effort, for three sliders this equated to a reduction in the relevant activity (*'oil, gas and coal power', 'manufacturing growth'* and *'home temperature'*), while for all other sliders this equated to an increase in activity (e.g. more cars or domestic heating being powered by electricity). Higher levels of effort tended to be selected for demand sliders than for supply sliders.

The results for the *'oil, gas and coal power'* slider in Figure 7 clearly stand out as having a different pattern to the other supply sliders, with an extreme preference for setting 3, "Half as much fossil fuel supplies as today in 2050". This was the only slider invented specifically for 'My2050' and not derived from DECC's full 2050 calculator nor referenced in DECC's 2050 scenarios. This slider also differs from the others through the fact that it represents external constraints to our fossil fuel supplies, rather than being an indication of positive effort. As with the three 'reduction sliders' discussed above, this raises significant issues around whether a greater degree of consistency is required in the layout and design of tools such as this, both in terms of straight forward analysis and interpretation of results, but also with regard to the different framings a question can be given depending on the direction of the slider. For example, in this case, the reversal of the slider in this instance might trigger loss aversion (Kahneman, 1991) in contrast to the positive focus conveyed by the other sliders. Later on, we discuss issues of whether the effort will be borne by the respondent or by others, but there is a wide range of other unspoken or tacit issues that might skew participants' selections. These include cost, technological readiness, familiarity with measures, and the degree to which they would require a change in patterns of everyday life. The work presented here focuses on how participants responded, rather that hypothesising why they did so. However, if standalone results from the simulation were to be given significant credence (in the absence of additional qualitative data), a detailed exploration of these factors would be advisable.

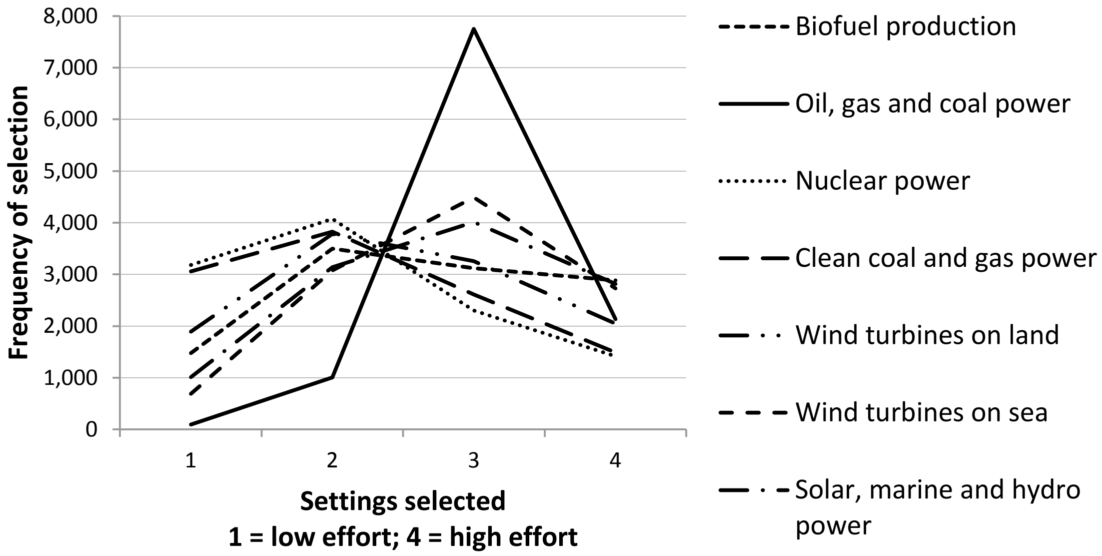

Figure 7 – Frequency of setting choices: supply

Figure 7 shows that effort for *'nuclear power'* and *'clean coal and gas power'* was least popular, while renewable energy technologies and biofuels followed similar choice patterns to each other, with higher effort preferred for offshore than onshore wind power.

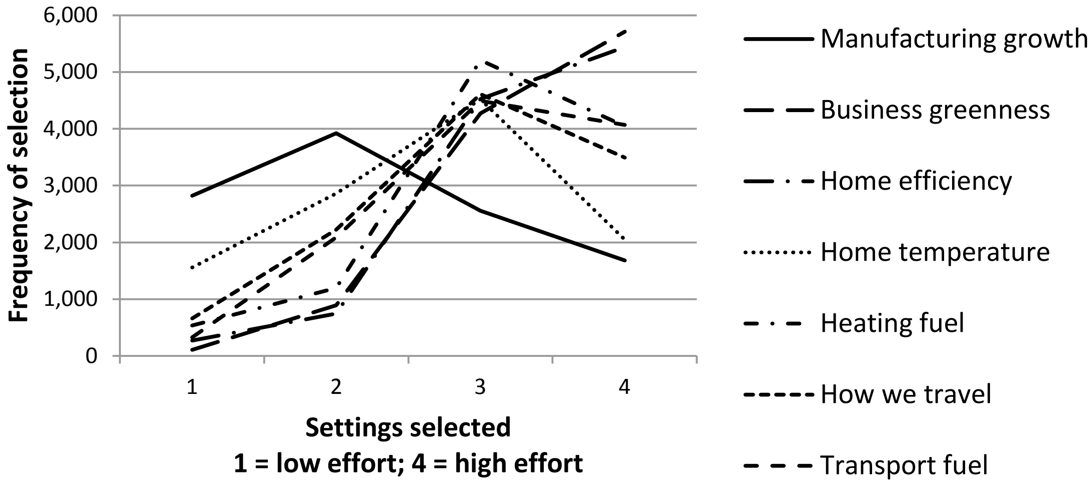

Figure 8 – Frequency of setting choices: demand

Figure 8 illustrates that high effort for energy efficiency (‘*business greenness’* and *‘home efficiency’)* was very popular. High effort towards home and transport electrification (*‘heating fuel’* and *‘transport fuel’*) was also popular, while high effort for the sliders potentially representing the greatest need for individual behaviour change (*‘how we travel’* and *‘home temperature’*) was less popular. *‘Manufacturing growth*’ choices showed the least preference for change, comparable with the trajectory for *‘nuclear power’* and *‘clean coal and gas power’*. It is notable that the pattern for *‘manufacturing growth*’ appears somewhat different to the other sliders. As with the *‘oil, gas and coal power’* slider described above in the context of Figure 7, this slider can be seen as representing the effects of external constraints that we may have to live with, rather than the result of proactive policy choices.

Figure 9 shows the variance for each slider, giving an indication of the homogeneity of opinion for each issue. *‘Manufacturing growth’, ‘biofuel production’, ‘nuclear power’, ‘clean coal and gas power’ and ‘wind turbines* *on land'* come out as the issues where preference is most varied (var ≥ 0.9). *'Home temperature'* and *'solar, marine and hydro'* also vary strongly (var ≥ 0.85).

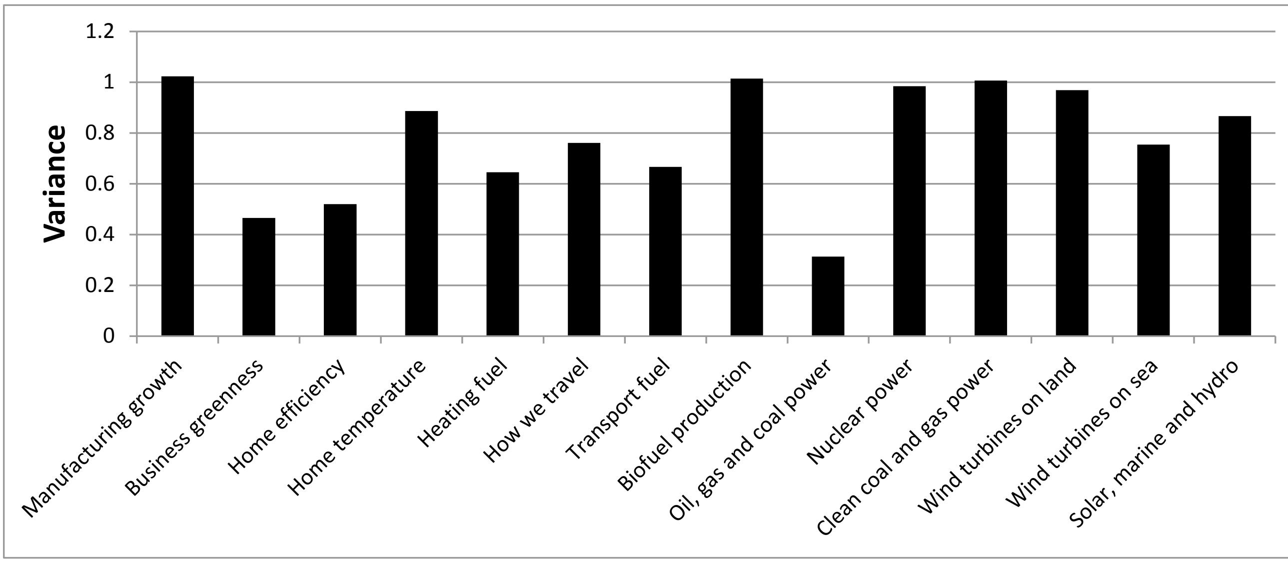

Figure 9: Variance of slider settings

To understand respondents' overall preferences when comparing across different energy issues, frequency-weighted means were calculated from all setting responses for each slider. This enabled a preference ranking for effort across all sliders as illustrated in Figure 10. This shows the greater preference for demand-side options, in particular for extensive energy efficiency improvements, and home and transport electrification. It is also of note that there are apparent differences in expressed preference with regard to where the burden of action lies. That changing *'heating fuel'* and *'transport fuel'* were more popular than changing *'home temperature'* and *'how we travel'* suggests a tendency for participants to support wider change across society, rather than actions that they might more closely relate to on a personal level.

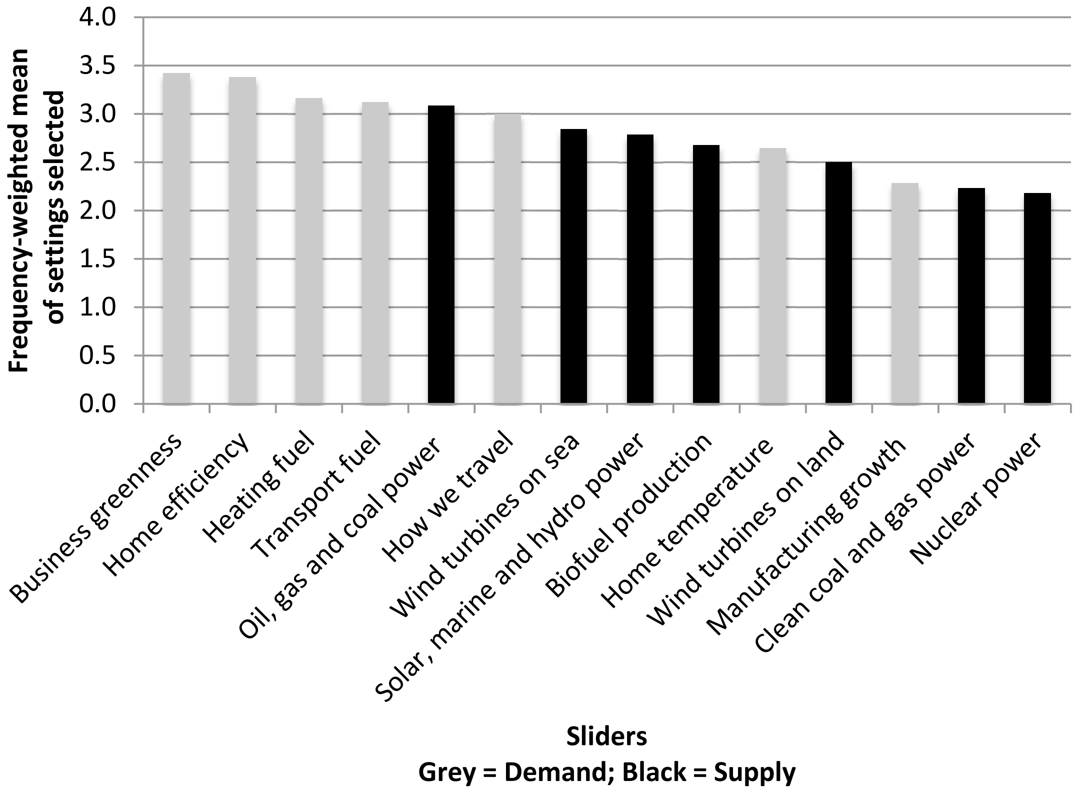

Figure 10 – Preference ranking for effort: all sliders

4.6 Popular pathway summary

Initial examination of the data has illustrated that, while 85.4% of responses were unique, a preferred pathway can be constructed from modal settings for each option, as illustrated in Table 3. For each slider, the modal choice was significantly different to the second most popular choice[ix]. In this constructed preferred pathway, higher effort for demand-side options was chosen when compared with supply options. When considering the second most popular response for each option, this was always found to be adjacent to the most popular setting choice (e.g. if the modal selection was 3, then the second most popular choice was always 2 or 4 rather than 1). This suggests that there is some homogeneity in responses, even where there was greater variation in the selections.

4.7 Pathway patterns for sub-groups of respondents

Sub-groups within the sample were analysed to explore underlying trends. Sub-groups were analysed where respondents:

- belonged to different demographic groups (age, region, and type of location)
- took five minutes or less to make their choices
- took over one hour to make their choices
- achieved ninety-five percent or more carbon reduction
- were not concerned about climate change.

This sub-group analysis revealed that participants under 18 and over 65 chose greater effort levels for most sliders. Responses from people taking over an hour to make their choices were very similar to responses from the whole sample. All other sub-groups demonstrated a greater preference for more extreme effort levels (both high and low). In some sub-groups the second most popular setting was not adjacent to the most popular setting, suggesting choices for some sliders should be considered heterogeneous[x] and that opinion was considerably more divided over them.

Scrutiny of sub-groups suggested that the modal data resulting from analysis of the whole sample does not reflect the diversity of views that can be illustrated through more detailed analysis of defined sub-samples. Further research could extract greater granularity for preferences through closer examination of sub-group responses, preferably by integrating quantitative analysis with qualitative research approaches. In this instance, there was insufficient information on the nature of the sub-groups and their representivity to merit significant analysis.

4.8 Summary of preference patterns

When looking at the sample as a whole, significant patterns in preferences for long-term carbon reduction scenarios in the 'My2050' responses have been identified. The strongest and most important findings were as follows:

- 85.4% of respondents selected unique pathways for the fourteen sliders. Despite very few respondents selecting identical pathways, modal analysis based on the sliders can be used to demonstrate a pattern in preferences.
- Higher effort settings were generally selected for the demand than for the supply sliders. The highest level of effort was selected for energy efficiency improvements (for home, workplaces and industry), closely followed by a preference for high levels of electrification of home heating and transport. Renewable energy technologies were more popular than non-renewable technologies (with greater development of offshore wind power preferred to onshore wind power). By comparison, carbon capture and storage and nuclear power were selected for lower levels of effort.
- The most popular setting for each of the fourteen sliders is illustrated in Table 3. All sliders demonstrated one setting that was significantly more popular than the others, and when choices are ranked for each slider, the second most popular setting was always

adjacent to the most popular setting when considering all responses, suggesting that none of the sliders were heterogeneous across the whole sample. No supply sliders were selected most frequently for the highest level of effort. No sliders were selected most frequently for the lowest level of effort, although four supply sliders and one demand slider were selected most frequently for the second lowest level of effort: *'biofuel production'*, *'nuclear power'*, *'clean coal and gas power'*, *'wind turbines on land'*, and *'manufacturing growth'*. However, these also showed the greatest variance in selected settings.

- The greatest demographic difference was demonstrated by respondents aged under 18 or over 65 – these sub-groups generally selected higher settings than the whole sample. Sub-groups were also analysed by time taken (five minutes or less and more than an hour), carbon reduction achieved, and low concern about climate change. With the exception of respondents taking over an hour to make their choices, all sub-groups demonstrated several different preferences when compared to the whole sample.

5. Comparison with DECC Scenarios

DECC's three preferred scenarios are entitled *'Higher CCS, more bioenergy'*, *'Higher renewables, more energy efficiency'* and *'Higher nuclear, less energy efficiency'* in the Carbon Plan. Since they are all illustrated in DECC's 2050 pathways calculator (DECC, 2010), and this calculator is the basis for the online simulation (with matching options and setting levels), it was possible to translate these from DECC's pathways calculator into equivalent 'My2050' pathways, as illustrated in Table 4. In making these comparisons, the simulation slider for *'oil, gas and coal power'* had to be left out as there was no equivalent within the DECC scenarios. It should also be noted that the titles of the scenarios are somewhat misleading as they do not fully reflect the relevant levels of effort. For example, although one scenario is described as *'Higher CCS, more bioenergy'*, this scenario actually has less effort selected for biofuel production than the *'Higher nuclear, less energy efficiency'* scenario.

Table 4 – DECC scenarios

Slider	Higher CCS, more bioenergy	Higher renewables, more energy efficiency	Higher nuclear, less energy efficiency
Supply			
Biofuel production	3	2	4
Nuclear power	2	2	3
Clean coal and gas power	2	2	1
Wind turbines on land	2	3	2
Wind turbines on sea	2	2	1
Solar, marine and hydro power	1	2	1
Demand			
Manufacturing growth	2	2	2
Business greenness	4	4	1
Home efficiency	3	4	3
Home temperature	3	4	2
Heating fuel	3	4	3
How we travel	3	4	2
Transport fuel	2	4	3

5.1 Pathway comparisons

DECC's three scenarios were compared with the pathway based on the modal setting for each slider overall. The degree of alignment between each of the three DECC scenarios and the modal pathway was calculated by comparing whether slider choices from the preferred modal pathway coincided with the levels of effort in the DECC scenarios (and if not, how big the mismatch was), such that a higher number of slider matches produces a higher percentage[xi].

- 'Higher CCS, more bioenergy' = 89.7% match
- 'Higher renewables, more energy efficiency' = 84.6% match
- 'Higher nuclear, less energy efficiency' = 66.7% match

To test the relative acceptability of each of the different energy issues, the range of settings for each slider in DECC's scenarios was compared with the modal pathway. This enabled an issue-specific comparison as set out in Table 5. This showed that the most popular preferences for eleven of the thirteen sliders fall within the range of options proposed by DECC through their three published scenarios. However, for two sliders (*'wind turbines on sea'* and *'solar, marine and hydro power'*), a greater level of effort was selected more frequently than is currently proposed in DECC's scenarios.

Table 5 – Range of effort settings: a comparison

Alignment	Supply / demand option	Setting range: DECC's three scenarios	Modal setting: 'My2050' respondents'
Exact match	Manufacturing growth	2	2
'My2050' respondents' modal choice is within the range for DECC's three scenarios	**Modal choice at the lower end of the DECC range**		
	Wind turbines on land	2-3	2
	Biofuel production	2-4	2
	Nuclear power	2-3	2
	Heating fuel	3-4	3
	Modal choice in the middle of the DECC range		
	Home temperature	2-4	3
	How we travel	2-4	3
	Transport fuel	2-4	3
	Modal choice at the higher end of the DECC range		
	Home efficiency	3-4	4
	Business greenness	1-4	4
	Clean coal and gas power	1-2	2
'My2050' respondents' modal choice is for higher effort than DECC's three scenarios	Wind turbines on sea	1-2	3
	Solar, marine and hydro power	1-2	3

An illustration of the alignment between modal choices in this sample and the range of effort proposed through DECC's three scenarios is provided in Figure 11.

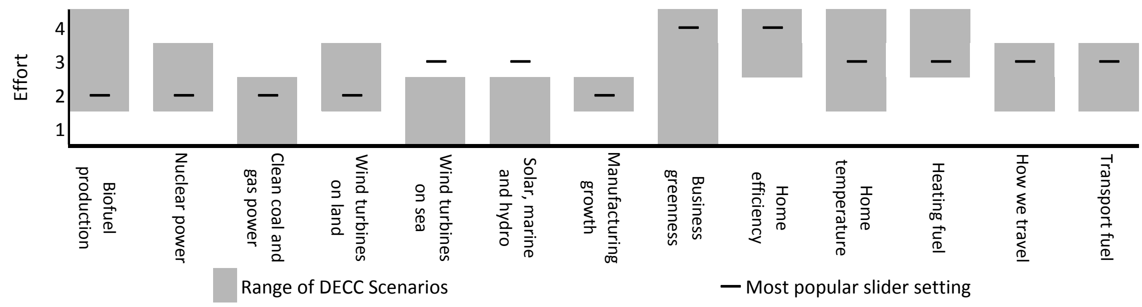

Figure 11 – Comparison of modal data with DECC scenarios

6. Discussion

This research demonstrates that, despite there being a huge number of submitted pathways, and therefore no clear single preferred 2050 scenario, it is possible to analyse submitted responses to construct a popular, or preferred, pathway. Within this paper, a basic analysis has been presented based on a single pathway based on modal slider settings. Variations in modal pathways can be demonstrated by comparing responses from different sub-groups, and this provides a simple method of establishing both the difference in main preference and its relative strength. Cluster analysis may also provide a useful tool for identifying preferred pathways, and was explored within the research but proved too complex to present within this paper. Nearly all patterns demonstrated a preference for higher effort for demand-side options compared to supply.

However, the extent to which these preferences can be generalised from this research is questionable, since 'My2050' respondents were not representative of the general population, as illustrated through demographic comparisons. Respondents were younger than the UK population, with over-representation in the 16-45 age group. In particular the analysis showed that respondents were more concerned about climate change than the general public. Since these participants were self-selecting, this sampling approach was more likely to attract participation from people already interested and engaged with the topics discussed. Caution is required when extrapolating findings from this sample, since respondents were not sufficiently representative to enable observations to be made about wider public opinion. A weighted analysis would improve reliability, although insufficient demographic data were collected to translate this sample into a more representative sample. Alternatively, a re-sampling with nationally representative participants would increase confidence in reliability. Other researchers are currently considering such sampling to secure more reliable results[xii] .

Modal preferences have been compared with DECC's proposed scenarios to test acceptability of these scenarios. Comparing DECC's three proposed scenarios with the most frequently selected settings across all issues in the 'My2050' sample, DECC's *'Higher CCS, more bioenergy'* scenario showed the strongest alignment, closely followed by the scenario called *'Higher renewables, more energy efficiency'*, whilst the weakest alignment was demonstrated by *'Higher nuclear, less energy efficiency'*. The most popular settings selected by the 'My2050' sample was similar to the range of settings across all of DECC's scenarios, with the exception of solar, marine and hydro-power, and offshore wind power. In these instances, the most popular choice for this sample was for greater effort than any of the DECC scenarios are proposing.

This research drew out several identifiable patterns in preferences for long-term carbon reduction scenarios. The main one of these is that greater effort for demand-side options was favoured over supply-side changes, and this is in agreement with earlier findings from the data (Ipsos MORI, 2011). However, elements of the simulation design (such as the inability to choose options other than the four presented for each slider) and the absence of accompanying cost implications may have influenced or constrained choices to the extent that they would not represent specific views of respondents. This preference for demand-side measures presents an unusual picture, since this will require society-wide behaviour change. Many analysts and decision-makers regard this as a more difficult policy option (Jamasb and Pollitt, 2011) in part due to the embryonic nature of the evidence base (Jackson, 2005). Consideration of simulation design suggests that many demand-side options were ambiguous as to whose 'effort' may be required to bring about the changes selected (possibly suggesting that people want others to change their lifestyle in order that they may carry on as they are). Demand-side options may, therefore, have been interpreted as easier options due to this ambiguity. For example, over ninety percent of respondents expect three quarters or more homes to have additional insulation by 2050, but if homeowners are required to meet the costs of installing such insulation to a high standard, this expectation may have been considerably lower. We highlight the higher preference (shown in the weighted means analysis) given to fuel switching for home and transport over and above their more behavioural counterparts of '*home temperature'* and *'how we travel'* .

The high level of support demonstrated in the results for energy efficiency measures is echoed in other research (Defra, 2011; Parkhill *et al.,* 2013). The high level of support found in this research for the electrification of home heating and transport is not matched by results from early pilot schemes designed to encourage the uptake of heat pumps and electric cars[xiii] (Energy Saving Trust 2010). The demonstration of preferences for renewable energy over nuclear power reinforces findings from previous multivariate evaluation (Stagl, 2006), while 'reluctant acceptance' for nuclear power as a solution to climate change remains an unstable and conditional public opinion (Pidgeon *et al.*, 2008; Parkhill *et al.,* 2013), which is reflected in the nuclear option being selected for the lowest level of effort by respondents in this sample. The preference for greater levels of offshore over onshore wind power found in this research has been illustrated previously (Jones and Eiser, 2010). However, the absence of cost implications for this preference, as well as the relatively early stage of development for the offshore wind industry compared to the more mature and arguably more controversial onshore wind industry, may have influenced responses. The high preference demonstrated for travel behaviour change in this research reinforces existing findings (Goodwin and Lyons, 2010), although preferences were selected in the absence of information about how obstacles to mode shift might actually be overcome and therefore remain purely aspirational.

Analysis of sub-groups demonstrated greater variation in choices than was demonstrated when considering the whole sample, suggesting there are pockets of extreme opinion contained within the responses. This could reflect participation from different lobby groups and industry representatives with a vested interest in influencing policy, as even though DECC makes no claims that the results from people's participation in the 'My2050' simulation will directly inform policy, they clearly state that the results will "feed into the debate" around the 2050 emissions reduction target (DECC, 2011c). Alternatively, it may just represent the 'context free' use of the simulation where any range of options could be tested with no consequence. Any plans for future development and promotion of the 'My2050' simulation could clarify whether and how responses will be used to shape future policy, in line with public participation good practice (HM Government, 2008b). A greater level of sub-group analysis may demonstrate the tendency for individuals to fall into different segments. Analysis of these responses could inform the design of targeted public engagement with sub-populations most relevant to different policy objectives, although a greater breadth of demographic data would need to be collected to enable a sophisticated segmentation analysis. As with proposed use of the simulation with nationally representative samples, future exercises could be conducted testing particular subsets (based either on socio-economic or attitudinal characteristics).

There is a danger that over-interpreting meaning from the preferences selected may lead to erroneous conclusions due the constrained nature of the simulation. For example, the simulation required the respondents to achieve an eighty percent reduction in carbon emissions before submitting choices, and the respondents had to select one of four defined options for every slider, even if none of the options actually reflected the respondents' preferred opinions. As briefly discussed, there are a large number of aspects of the simulation that may provide particular framings or priming that may also lead to skewed results. These considerations add weight to the argument that scenario building should focus on integrated qualitative and quantitative methods (Söderholm *et al.,* 2011), and that deliberative public engagement is a more appropriate approach when there are complex policy issues that require trade-offs and public buy-in for successful implementation (National Consumer Council, 2008). Placing such an approach within an overarching public engagement strategy would be required to accommodate the diversity and extent of the UK population.

Since DECC published their three carbon reduction scenarios in December 2011 (DECC, 2011a), they have not documented any comparison of them with public opinion. This research has demonstrated that, by comparing preference pathways identified through modal analysis of the submitted pathways, the DECC scenario currently named *'Higher CCS, more bioenergy'* is likely to be considered the most popular with this sample of over 10,000 self-selected respondents. However the extent to which this tests 'public acceptability' is limited, for the reasons set out above. Given that the competition for the first UK demonstration for carbon capture and storage was cancelled in October 2011 due to budgetary issues (National Audit Office, 2012), and the implementation requirements of carbon capture and storage at a commercial scale remain largely unknown, it is reasonable to question how viable this scenario might be for this particular policy area.

When comparing preferences in this sample with the range of options selected across all three of DECC's carbon reduction scenarios, this sample demonstrated particular caution around support for high levels of effort in seven policy areas in particular: biofuel production, nuclear power, onshore wind power, home temperature, travel behaviour change, and home and transport electrification. However, the most ambitious goals for these policy areas only occur in the two less popular DECC scenarios, providing further evidence of the greater acceptability of the *'Higher CCS, more bioenergy'* scenario.

In the absence of pre-existing approaches, the method used in this research to compare preference patterns in this sample with the three government scenarios was based on the assumption that differences between each and every setting in 'My2050' should be equally weighted. The same assumption was made for each supply and demand slider, which are all treated as directly comparable in their measures of 'effort'. Assumptions are also made about high alignment indicating strong acceptability, such that an exact match between respondents' preferences and DECC scenarios (as was illustrated for *'manufacturing growth'* for instance) translates directly into public acceptability. Such simplifications however hide many qualitative factors that require closer scrutiny. For instance, social science literature shows the range of public opinion about different energy supply options (Pidgeon *et al.*, 2008; Corner *et al.,* 2011; Upham and Roberts, 2011; YouGov, 2011), ranging from largely agnostic to frequently polarised, with extensive networks of organised lobby groups both for and against some supply options (e.g. Stop New Nuclear, 2012 and Country Guardian, 2012). Additionally, high levels of public support for a technology, as frequently reported for onshore wind power for instance (Renewable UK, 2012), do not always translate to swift implementation of the same technology (Barclay, 2012). This suggests that public opinion is but one of many influences in a complex web of socio-political and economic considerations in implementing policy change (Whitmarsh *et al.*, 2011). Such complexities need to be accounted for when testing public acceptability of government options in order to avoid over-simplification.

7. Conclusions and policy implications

The 'My2050' simulation was developed to enable DECC to 'engage in an open and transparent debate around the choices and trade-offs the United Kingdom faces to reach the 2050 emissions reduction target'[v]. Assessing, and trying to quantify, public opinion on such issues, while not a stated aim of this simulation, may be a useful contribution to such a debate. If interactive simulations such as 'My2050' are to play a significant role in future assessments of public opinion, then more sophisticated analytical models will be required to try and determine the public acceptability of government proposals before any definitive conclusions can be reached. It would be essential for this to incorporate qualitative as well as quantitative data in order to verify that interpretations of the expressed preferences were correct, and/or to explore misunderstandings or uncertainties as to the meanings and implications of the sliders and their settings. It would also be helpful to test aspects of the design of the tool, particularly the phrasing of the effort descriptions, for any untoward priming or framing effects.

The use of the web-tool as a means to assess the alignment of public opinion with DECC's three scenarios was compromised by its simplification of options (as the scenarios are illustrated through the DECC pathways calculator with over forty different issues to manipulate, while the simulation contains only fourteen options). Future research could separate the initial stage of calculating alignment between pathways from subsequent assumptions about acceptability of different government scenarios. This latter stage could then utilise a mixed-methods approach to capture the qualitative factors that also influence policy acceptability. It is clear, however, that this simulation-based approach does have the opportunity both to reflect significant variation in opinion (as indicated by the vast majority of responses being unique), and to identify patterns within these variations. However, in the way that the web-tool was deployed in this instance, the validity of the responses is somewhat questionable. Where better attempts can be made to identify the motivations for and context of participation, and where better socio-demographic data and more detailed qualitative feedback can be gathered, we conclude that this type of method has a significant and valuable part to play both in education around climate and energy issues, and also in assessing public opinions.

Acknowledgements

This work was carried out as part of an MSc in Environmental Consultancy at the University of the West of England, Bristol. The authors would like to thank Jan Kiso, Tom Counsell and the rest of the 2050 team at the Department of Energy and Climate Change for the provision of data and support in undertaking the project as well as the (anonymous) panel of experts who participated in the interviews that complemented this research. We are also very grateful for the helpful comments from the paper reviewers, and to Paul White and Deirdre Toher at UWE for their statistical advice.

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[i] Kiso, J. (2011) Department of Energy and Climate Change. Personal communication, 11 April.
[ii] Counsell, T. (2011) Department of Energy and Climate Change. Personal communication, 23 March.
[iii] Kiso, J. (2012) Department of Energy and Climate Change. Personal communication, 27 January, and see http://2050pathway-en.chinaenergyoutlook.org.
[iv] 4^{14} = 268,435,456 possible combinations.
[v] The home page for the simulation states: 'This web presence is a visualisation as well as simplification of the 2050 Pathways Analysis in order to further share its findings. The Department of Energy and Climate Change is keen to engage in an open and transparent debate around the choices and trade-offs the United Kingdom faces to reach the 2050 emissions reduction target. The data you are entering on this site will feed into this debate.'
[vi] The word 'pathway' is used here to describe carbon reduction scenarios represented by a combination of settings selected for all fourteen supply and demand sliders in 'My2050'.
[vii] Nineteen cases pre-dated the launch date of 3 March 2011 – two from February and the remainder from 1 and 2 March 2011. These were retained for analysis since they were not coded as 'test' cases.
[viii] S = supply and D = demand. Each subsequent number corresponds to the setting selected for each supply and demand slider (where choices range from 1 – 4 as described in Table 1 and Table 2).
[ix] A Chi-square test was run for each slider comparing the frequency of the most popular two selections to an 'expected' set of two values equal to the first slider. For all sliders $p \leq 0.05$.
[x] The word heterogeneous was selected to convey the caution necessary in drawing conclusions from the data for these sliders.
[xi] Pathways comparison method calculations were as follows:
13 sliders are compared for each DECC scenario. If the DECC scenario setting for the first slider was 1 and the modal setting was 1, that is regarded as full alignment. If the DECC scenario setting for the first slider was 1 and the modal setting was 2, that is regarded as 1 mismatch. If the DECC scenario setting for the first slider was 1 and the modal setting was 3, that is regarded as 2 mismatches. If the DECC scenario setting for the first slider was 1 and the modal setting was 4, that is regarded as 3 mismatches. Therefore for each slider,

there are a possible maximum of 3 mismatches. As there are 13 sliders (as the '*oil, gas and coal'* slider is not represented in the DECC scenarios), then there is a possible maximum of 13 x 3 mismatches (39).
6 mismatches = 33/39 alignment (84.6%)
7 mismatches = 32/39 alignment (82.1%)
14 mismatches = 25/39 alignment (64.1%)

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[xiii] Vaughan, A. (2011) Electric car UK sales sputter out. *The Guardian* [online]. 21 October. Available from: http://www.guardian.co.uk/environment/2011/oct/21/electric-car-uk-sales-sputter [Accessed 17 March 2012].