Research Councils UK Energy Programme Strategy Fellowship

Energy Strategy Fellowship Report 2:

Summary of Workshop on

Energy Strategies and Energy Research Needs

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Research Councils Energy Programme

The Research Councils UK (RCUK) Energy Programme aims to position the UK to meet its energy and environmental targets and policy goals through world-class research and training. The Energy Programme is investing more than £625 million in research and skills to pioneer a low carbon future. This builds on an investment of £839 million over the period 2004-11.

Led by the Engineering and Physical Sciences Research Council (EPSRC), the Energy Programme brings together the work of EPSRC and that of the Biotechnology and Biological Sciences Research Council (BBSRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC), and the Science and Technology Facilities Council (STFC).

In 2010, the EPSRC organised a Review of Energy on behalf of Research Councils UK in conjunction with the learned societies. The aim of the review, which was carried out by a panel of international experts, was by o to provide an independent assessment of the quality and impact of the UK programme. The Review Panel concluded that interesting, leading edge and world class research was being conducted in almost all areas while suggesting mechanisms for strengthening impact in terms of economic benefit, industry development and quality of life.

Energy Strategy Fellowship

The RCUK Energy Strategy Fellowship was established by EPSRC on behalf of Research Councils UK in April 2012 in response to the international Review Panel's recommendation that a fully integrated "roadmap" for UK research targets should be completed and maintained. The position is held by Jim Skea, Professor of Sustainable Energy in the Centre for Environmental Policy at Imperial College London. The main initial task is to synthesise an *Energy Research Prospectus* to explore research, skills and training needs across the energy landscape. Professor Skea leads a small team at Imperial College London tasked with developing the *Prospectus*.

The *Prospectus* will contribute to the evidence base upon which the RCUK Energy Programme can plan forward activities alongside Government, RD&D funding bodies, the private sector and other stakeholders. The tool will highlight links along the innovation chain from basic science through to commercialisation. The tool will be flexible and adaptable and will take explicit account of uncertainties so that it can remain robust against emerging evidence about research achievements and policy priorities.

One of the main inputs to the Prospectus is a series of four high-level strategic workshops and six in-depth expert workshops taking place October 2012- July 2013. Following peer-review, the first version of the Prospectus will be published in November 2013 and will then be reviewed and updated on an annual cycle during the lifetime of the Fellowship, which ends in 2017.

This document reports views expressed at a strategic workshop held in October 2012. These views do not necessarily represent a consensus of workshop participants nor will they necessarily be endorsed in the final version of the Energy Research and Training Prospectus.

Contents

Executive Summary

This report describes the discussions and outputs of the workshop Energy Strategies and Energy Research Needs held at Imperial College London on 24 October 2012. This workshop focused on the role that different technologies and approaches (e.g. behaviour change) might make across a range of different energy futures. The workshop engaged a wide range of stakeholders from government, business and the third sector, as well as academic experts from a range of disciplines.

1. The first plenary session of the workshop included four scene-setting presentations covering: an overview of the workshop and wider process by Jim Skea, RCUK Energy Strategy Fellow; a review of recent energy scenarios and projections by Aidan Rhodes, member of the RCUK Energy Strategy Fellowship team; the Committee on Climate Change perspective by Adrian Gault, Chief Economist of the Committee on Climate Change; and a utility company perspective by Andy Boston, E.ON.

2. Session 2, the first facilitated session, looked at the range of technologies likely to play a part in the future energy system of the UK. This section covered five major aspects of the UK energy system: electricity supply; heating; vehicle transportation; energy demand; and disruptive technologies and scenarios. The exercise distinguished between participants' 'preferred' outcomes (those that they wanted to see happen) and 'expected' outcomes (what they though was realistic).

3. A general conclusion was that while the preferred outcomes were broadly in line with the UK's energy policy goals, notably the decarbonisation targets, the expected outcomes fell short of these aspirations in relation to the deployment of low carbon supply-side technologies, electric technologies (heat pumps, battery-electric vehicles) and energy efficiency.

4. Session 3, the second facilitated session was structured to stimulate discussion around which areas of the UK's energy research and development (R&D) portfolio the workshop participants considered to be strongest, specifically in terms of the UK's scientific and industrial capabilities. Furthermore, the session was designed to provide insight into how relevant the workshop participants believed these capabilities were likely to be in terms of the UK's future energy system.

5. The results of the exercise are reported according to seven broad areas: energy efficiency; fossil fuels; renewable energy; nuclear; hydrogen and fuel cells; power and storage; and other cross-cutting technologies and research. In some areas, there is strong correlation between scientific and industrial capabilities on the one hand and relevance to the UK's energy future on the other. For example, the UK is consistently strong in relation to oil and gas and energy system analysis. On the other hand, there are consistent weaknesses in relation to geothermal power and solar heating and cooling. Furthermore, in other areas such as energy efficiency, nuclear fission and hydrogen/fuel cells, there is no clear correlation. In some areas, such as bioenergy and energy storage there is currently no clear international lead and the UK could have a potential role.

6. In the final wrap-up session, it was noted that there had been a strong divergence among participants in terms of the assessment of UK scientific strengths. The degree of disaggregation of technologies might affect the assessment of capability. For example, the UK may be strong at carbon storage but less so at carbon capture. The "technocratic" focus of the workshop was discussed. For example, PV is not just a technology, it has the potential to give households a stake in energy supply. The next workshop in the series would address alternative, non-technological ways of framing energy research issues

1. Introduction

This report describes the discussions and outputs of the workshop *Energy Strategies and Energy Research Needs* held at Imperial College London on 24 October 2012. The workshop was the first in a series of three "strategic" workshops held under the auspices of the RCUK Energy Strategy Fellowship established earlier in 2012. One of the key aims of the Fellowship is to develop an *Energy Research Prospectus* which will help the Research Councils to plan their portfolio of research and training in the energy field.

The first workshop focused on the role that different technologies and approaches (e.g. behaviour change) might make across a range of energy futures. It was informed by a systematic review of energy scenarios and projections at the UK, European and global levels conducted by the Energy Strategy Fellowship team. The central purpose of the workshop was to identify, at a high level, the research and training needs associated with a range of possible futures. The workshop engaged with a wide range of stakeholders from government, business and the third sector as well as academic experts from a range of disciplines. The workshop agenda is included as Annex A and the list of participants at Annex B.

This report describes each of the main components of the workshop. Section 2 briefly summarises four introductory presentations and, in anonymised form, the discussion that followed. Section 3 describes the conduct of and outputs from a facilitated session addressing the range of UK energy futures. Section 4 describes a second facilitated session which took the outputs of the previous session and considered the priorities that might be attached to different areas of energy research within a broad portfolio, taking account of their relevance to UK energy futures, the UK's industrial capabilities and the UK's scientific and technical strengths. Section 5 briefly summarises the wrap-up discussions.

2. Plenary Session 1: Energy Strategy and Energy Research Needs

Overview of the workshop and wider process, Jim Skea, Energy Strategy Fellow

Jim Skea's introductory presentation first described the process which had led to establishment of the Energy Strategy Fellowship and the current series of workshops. The origin lay in the International Review of Energy conducted for the Research Councils in 2010. This had recommended the establishment of a "roadmap" for energy research and training activities. Under the Fellowship, the "roadmap" had been re-named the *Energy Research Prospectus,* the first version of which would be produced in autumn 2013. The presentation then went on to describe the workplan, the consultations conducted in summer 2012, the planned series of strategic and expert workshops and plans for updating the prospectus beyond 2013. Jim then summarised the workshop agenda and made some observations about different styles of energy research, noting a distinction between "use-inspired" research and "discovery/grand challenge" research which was more blue-skies in character.

In discussion, it was noted that energy storage could take forms other than electrochemical. There was some discussion about the policy impact of the work. Jim noted that the primary audience for the work was the Research Councils and expectations about wider impact were being managed down. Nevertheless there was an aspiration to make the work useful more widely. It was noted that some of the biggest challenges lay at the interface between Technology Readiness Levels (TRLs) and between different funding agencies. There was a specific comment that the work Ofgem supported was across the widest range of TRLs (2-9) and not just the high TRLs as reported in DECC's Science and Innovation Strategy.

Review of energy scenarios and projections, Aidan Rhodes, Research Fellow

Aidan Rhodes then presented findings from the review of energy scenarios and projections conducted by the Fellowship team. The introductory slides covered the range of scenarios covered (UK and international, public sector and private), the metrics used to compare scenarios and the difficulties of comparison. The presentation focused mainly on UK comparisons looking at the wide range of projections for UK primary energy, electricity demand, electricity generation mix, heat demand and supply, and transport energy. Uptake of electric vehicles was particularly varied across scenarios. Finally, the presentation compared global International Energy Agency (IEA) and Exxon projections to 2040, noting that the Exxon forecasts were broadly compatible with IEA's "4 degrees" world.

Much of the discussion focused on the reasons underlying scenario differences, though the Fellowship team cautioned that digging too deep could distract from the central purpose of the workshop. It was established that the main difference between the UKERC 2050 and DECC 2050 reference scenarios was that UKERC included the effect of a carbon price floor rising to £70/tCO_2 by 2030. The reason that heat demand does not appear to fall in spite of assumed efficiency gains is that some of the figures refer to energy services rather than final energy demand and the number of households in the UK is assumed to increase. The focus on technologies was questioned as it was suggested that other factors, such as business models, public attitudes and structures of markets would have an important effect. It was noted that technologies are easier to quantify and that the topic of this workshop drew the discussions towards technologies. The wider issues mentioned will constitute the focus of Workshop II. It was suggested that the Fellowship team should also look at an Energy Networks Association (ENA) review of scenarios and make use of the Energy Technology Institute's (ETI's) ESME model and analysis. The difference in rigour between "pathways" and "scenarios" was also stressed.

Committee on Climate Change Perspective, Adrian Gault, Chief Economist, Committee on Climate Change

Adrian Gault presented the logic and analysis underlying the Committee on Climate Change's 4th carbon budget recommendation. This had been based on an indicative 2030 target which took account of the 2050 target, feasible pathways through the 2020s, and the feasibility of continuing emission reductions beyond 2030. The importance and feasibility of decarbonising electricity and of increasing the role of electricity was noted. The analytical tools included high-level cost-optimisation modelling using MARKAL, but the primary tools underpinning the recent recommendations on international aviation and shipping had been bottom-up models. Going forward, work would focus on advice to Government on the 2014 review of the 4th carbon budget.

A question was asked about the role of demand reduction in meeting the targets vis-a-vis the more ambitious efficiency targets in Germany. Adrian noted that the CCC still anticipated a very substantial contribution from energy efficiency gains.

A utility company perspective, Andy Boston, E.ON

Andy Boston started by identifying who within E.ON was interested in futures over what timescales. This ranged from trading (2-3 years out), corporate headquarters (mid-2030s) and RD&D (as far as 2050 for some topics). The techniques included modelling, business games and scenarios. E.ON particularly likes the probabilistic nature of the ESME model. Other points were that granularity matters, a lot of options remain on the table pending more clarity and different technology options could win out under different future scenarios. The presentation also referred to the energy "trilemma" (environment-cost-security) and the three way interplay between industry, government and society.

A variety of questions was posed concerning the risk of institutional bias, whether the UK mattered on a global scale and the relationship between quantitative and qualitative scenarios. On the latter point it was noted that accountants hate probability distributions while innovation people like the narrative of qualitative scenarios. A final point concerned industry's role in lobbying government in order to influence the climate for investment decisions.

3. Session 2: UK Energy Futures

Introduction

This facilitated session looked at the range of technologies likely to play a part in the future energy system of the UK. Workshop attendees were split into five self-selected groups. Around the walls of the meeting room were five 'stations', each representing a sector of the UK energy system. These were:

- *Electricity Supply*
- *Heating*
- *Vehicle Transportation*
- *Energy Demand*
- *Disruptive Technologies and Scenarios*

For the *Electricity Supply*, *Heating* and *Vehicle Transportation* stations, several common technologies were selected and represented by a basic thermometer image, with delineations from 0-100% market share for individual technologies. Attendees were given a set of blue and red sticky dots, and asked to place these on the thermometers. The blue dots represented what attendees 'wanted' the technologymix to be in 2050, in an idealised world where there were no barriers to deployment. The red dots represented the technology mix attendees 'expected' to occur, given their knowledge of barriers, policy directions, technology limitations and other factors. This exercise was designed to illustrate the uncertainty and diversity in the UK's future energy mix, identifying the technologies most popular with a broad spectrum of experts and their views of the likelihood of these technologies being deployed in high proportions.

For the *Energy Demand* station, the attendees were asked to place their red and blue dots on a piece of paper containing a horizontal line in the middle representing the UK's current total final energy demand. As before, they were asked to place dots where they 'wanted' UK energy demand to be by 2050, and to estimate where they 'expected' it to be based on their knowledge of the area and interpretation of current trends. This was a more free-form scenario than the others – attendees were asked to explain their choices via post-it notes attached to the paper.

The *Disruptive Technologies and Scenarios* was a freeform exercise where attendees were asked to write and rank which technologies and scenarios they felt had the potential to disrupt the commonly-accepted views of the UK's energy future. Attendees were asked to place an emphasis on so-called ‘smart’ technologies, a catch-all term relating to the inclusion of ICT and data services into the energy system.

Following the exercise, which lasted roughly twenty-five minutes with five minutes spent at each station, there was a wrap-up session where interesting points were raised and feedback on the exercise was given.

Results

Electricity Supply

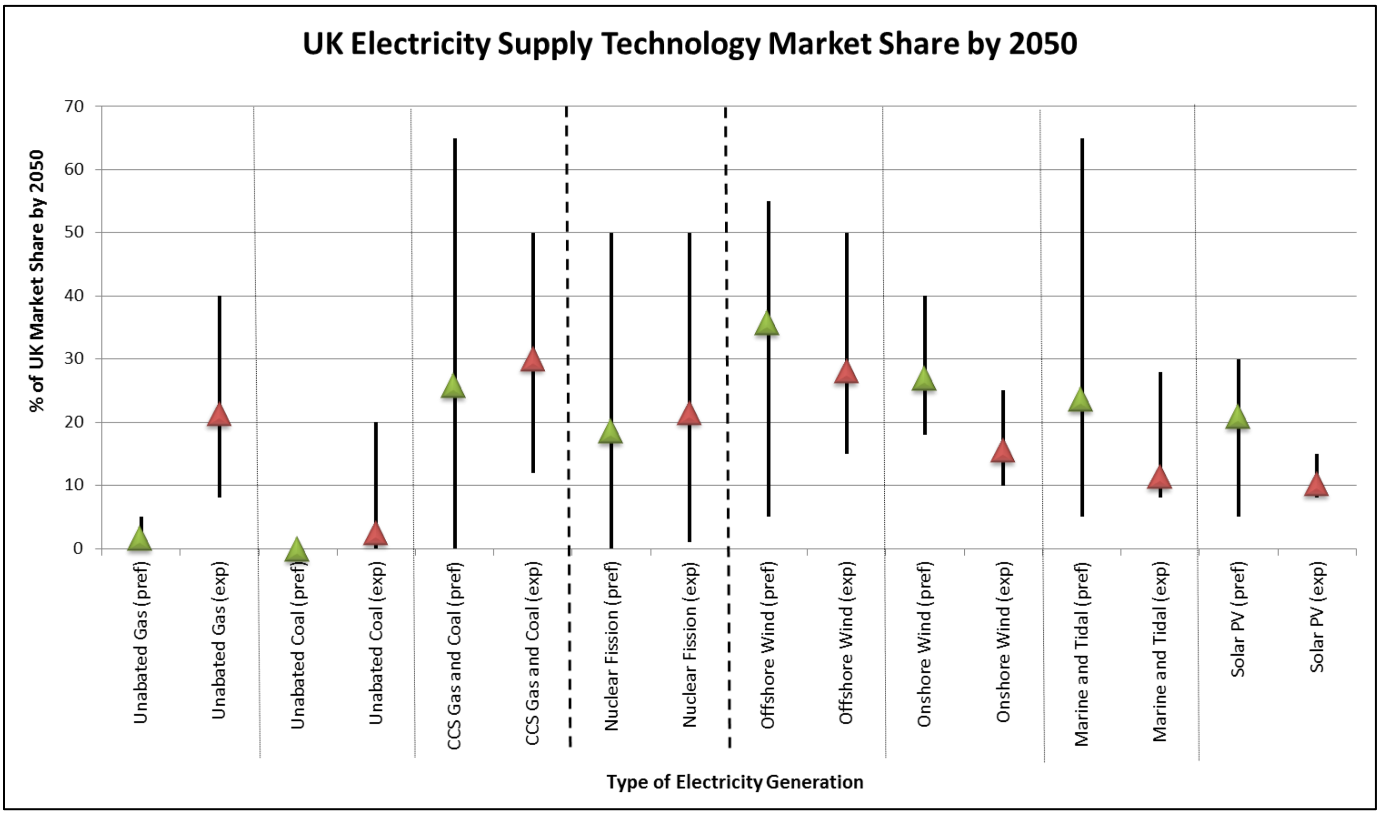

Figure 1: Preferred (green) and expected (red) ranges and mean average values for electricity supply technologies

	Average ‘preferred’	Average ‘expected’
Unabated Gas	2%	21%
Unabated Coal	0%	3%
CCS Gas and Coal	26%	30%
Nuclear Fission	19%	22%
Offshore Wind	36%	28%
Onshore Wind	27%	16%
Marine + Tidal	24%	11%
Solar PV	21%	10%

Unabated gas and coal were universally viewed as unpopular options, with the ‘preferred’ dots clustered tightly and ranging from 0% to below 10%. The ‘expected’ values for gas were considerably higher and ranged in a loser cluster from less than 10% to 40%, suggesting that many attendees expected gas to still play a major role in our energy system by 2050, either as backup or base-load plant. Unabated coal was almost universally expected to disappear by 2050, with no attendee 'preferring' it, and only a couple 'expecting' that it will have a share of the market by 2050.

CCS technology and nuclear fission attracted very mixed views, with the 'preferred' and 'expected' points for both technologies scattered over a wide range from 0% to 50%. On average, people expected higher proportions for both technologies than they wanted. The averages for nuclear were somewhat lower than for CCS, at around 20% of the system compared to CCS's 25-30%. It was pointed out in comments that biomass-fuelled CCS creates negative emissions, which are important in several recent scenarios in meeting the 80% emissions reduction CO_2 target. Safety, public perception and risk concerns were raised in relation to nuclear fission, including the concerns private investors have with taking on the attendant risk of a nuclear power plant.

Offshore wind was the technology which attracted the highest average 'preferred' percentage ', at roughly 36%. Attendees' expectations put this technology at around 28% penetration, still higher than any other technology except CCS. Onshore wind was rated almost twice as highly under 'preferred' (27%) than 'expected' (16%), showing both an enthusiasm among attendees for this technology and considerable uncertainty that these ambitions could be realised. The greater local and political opposition to onshore wind farms as opposed to offshore was cited by some attendees as a major reason for their pessimism towards onshore wind.

Marine and tidal showed some of the greatest divergence in views, with the 'preferred range being 5-65%, and the 'expected' range 10-30%. The average figure for expected deployment was very much biased towards the bottom of the range (11%), showing significant pessimism over the expected deployment of this technology. Solar PV likewise showed substantial pessimism, with the expected deployment (10%) being less than half the desired penetration (21%). Concerns were raised about the economic viability of solar PV in the UK, given our high northern latitude.

Overall, the idealised 'preferred' scenario involved a clear preference for an electricity system based heavily on renewable technologies, with offshore and onshore wind, marine and tidal and solar PV scoring highly. Other low-carbon technologies such as CCS and nuclear power were less popular, with attendees preferring them to make up a significantly smaller portion of the electricity system than they expected. Unabated gas and coal were universally unpopular. Of note are the large spreads in responses seen for CCS, nuclear and wave and tidal – showing a wide range of views for these technologies among attendees.

Attendees 'expected' a more diverse electricity generation portfolio, with significant quantities of unabated gas on the networks, as well as higher proportions of CCS and nuclear power. Onshore wind, marine technologies and solar PV drop by more than half from the preferred scenario, and a significant drop in offshore wind can also be seen. These predictions were also more tightly clustered than the preferred scenario, with only nuclear approaching the ranges seen for the 'preferred' scenario, suggesting a higher level of agreement for these 'expected' proportions of generation technologies.

Heating

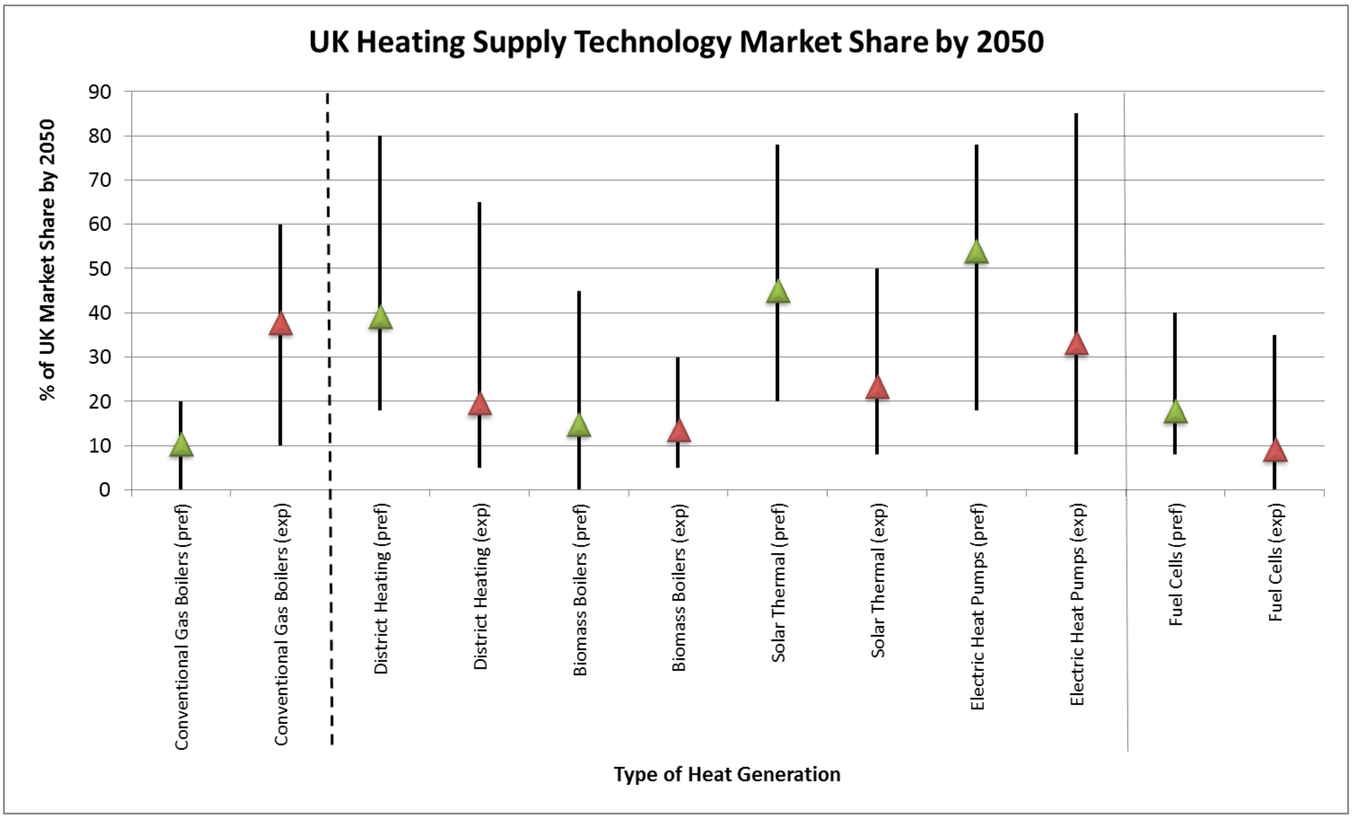

Figure 2: Preferred (green) and expected (red) ranges and mean average values for heat supply technologies

	Average 'preferred'	*Average 'expected'*
Conventional Gas Boilers	11%	***38%***
District Heating	39%	20%
Biomass Boilers	***15%***	14%
Solar Thermal	42%	24%
Electric Heat Pumps	54%	33%
Fuel Cells	***18%***	9%

Overall, considerably more uncertainty can be seen in the attendees' responses to heating supply technologies than the electricity supply sector, perhaps reflecting the greater policy uncertainty in this area. Very large ranges can be seen in the 'preferred' graph for these technologies, with values for district heating, solar thermal and electric heat pumps ranging from 20-80%. This is partly due to the inherent difficulty of assessing heat technology penetrations – unlike electricity, which is generated and (mostly) fed into a centralised network, most heating technologies generate heat at point of use. This necessarily puts constraints on numbers – biomass boilers will be constrained by the supply of available biomass, solar thermal installations will be constrained by available good-quality roof space, and district heating is constrained by geography and population density. Even with these difficult-to-measure constraints, some conclusions can be drawn from the data.

The three technologies attendees 'preferred' to see most were district heating (39%), solar thermal (42%) and electric heat pumps (54%). Electric heat pumps play a major part in the vast majority of future low-carbon scenarios, and it is unsurprising to see them account here for a large share of heat generation. Attendees 'expected' a smaller but still significant share for heat pumps (33%), but this value had one of the greatest ranges in the whole exercise, from less than 10% to greater than 80%. Comments focused on the need for heat pumps to be competently sited and installed, noting that trials of heat pumps in the UK have produced significantly poorer results than expected. If heat pumps continue to perform below expectations, it was noted that they could destroy consumer confidence, and therefore their own market, very quickly.

Solar thermal showed an 'expected' potential of 24%, a sharp drop from the 'preferred' value. Solar thermal alone would have difficulty in satisfying a UK house's heating needs, due to the need for central heating in the winter when days are dark and short. District heating, also seen as valuable by attendees, saw a drop of almost half to 20% for the 'expected' average, due in part to the difficulty and large upfront costs of installing these systems.

Conventional gas boilers were ideally seen to play a low part (11%) in the 2050 heating mix by attendees, however were 'expected' to still have a high penetration (38%) by that time. It was noted by several attendees that heating systems are generally 'distress' purchases, where householders will buy a new boiler or heating system only when their last one has failed. In these circumstances, more expensive, difficult and slow-to-install systems will be discriminated against by purchasers, even if the savings enabled by such a system will be significant over its lifespan.

Electric resistive heating was also brought up as a potential contributor to the future heat mix – assuming a low-carbon electricity source. It would be easier and cheaper to install than heat pumps, despite not being as efficient, and may be suitable for properties where heat pumps would be difficult or impossible to install.

Overall, the picture for heating by 2050 is a very uncertain one, with significantly less convergence than electricity supply. Several attendees made wider points, noting that future heating technology was likely to be very dependent on insulation, the quality of the housing stock available and energy efficiency. Consumer preference and ability to understand and effectively utilise low-carbon heating sources was also raised as an uncertainty.

Vehicle Transport

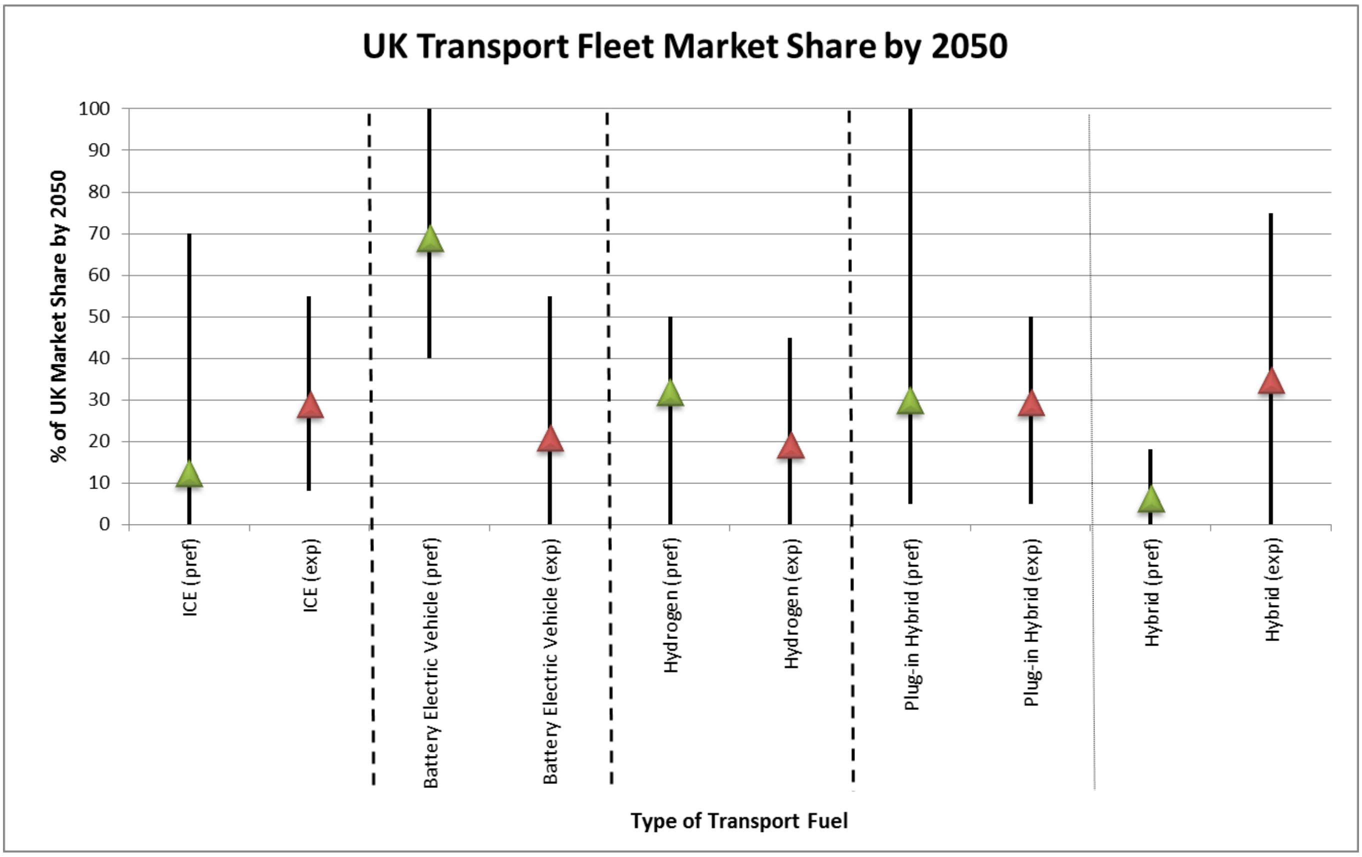

Figure 3: Preferred (green) and expected (red) ranges and mean average values for vehicle transportation technologies

	Average 'preferred'	*Average 'expected'*
Battery Electric Vehicle	**69%**	**21%**
Hydrogen	32%	19%
Internal Combustion Engine	13%	**29%**
Plug-in Hybrid	**30%**	30%
Standard Hybrid	6%	35%

Surface transportation accounts for a large part of the UK's energy demand, and as such will be an important driver for change if the UK is to meet its carbon targets. Currently, the vast majority of the UK's vehicle fleet are powered by internal combustion engines (ICE).

Battery electric vehicles can often be seen in scenarios as being the most logical pathway to decarbonising the transport sector, and this is reflected in these results – battery electric vehicles were by far the most 'preferred' technology, with an average of nearly 70% market share and a range from 40-100%. Results for what attendees "expected", however, were considerably more pessimistic – with an average of only 21%. This perhaps reflects the increasing concern over the high infrastructure costs and short travel ranges of current battery electric vehicles, and echoes recent scenarios with a lower proportion of battery electric vehicles.

Hydrogen powered vehicles attracted very similar ranges from 0-50% on both the 'preferred' and 'expected' graphs, but with the average higher for 'preferred' as opposed to 'expected' (32% vs 19%). Uncertainty over the sourcing of hydrogen and the infrastructure requirements may have led to this lower 'expected figure', as well as worries about the unsuitability of use of hydrogen in smaller vehicles due to storage and safety issues.

By 2050, attendees would 'prefer' the percentage of ICE vehicles to fall dramatically, to 13% on average. However, they 'expected' the proportion to drop to around 30%, considerably lower than today's near total penetration, but more than double the 'preferred' figure. A single participant preferred 100% plug-in hybrid vehicles, hence the large range.– However the rest of the results are clustered around the 0-50% range. Plug-in hybrids have been spotlighted as an important transition technology by many scenarios, and it is interesting that the average for attendees' 'preferred" and 'expected' scores were very similar (both 30%)..

Hybrid vehicles interestingly were preferred less (6%) than ICE vehicles. Several attendees considered traditional hybrid vehicles a transition technology, and by 2050 they expect consumers to have shifted to more sustainable technologies such as plug-in hybrids and battery electric vehicles. Hybrid vehicles recorded the highest average expected penetration of all surveyed vehicle technology types. This suggests that consumers are expected to transition to hybrids, but the difficulties associated with moving to other vehicle technologies leads to a large proportion of consumers still driving hybrid vehicles by 2050. Utilising a high proportion of biofuels in the fuel mix would reduce the carbon intensity of hybrid vehicles further.

Overall, attendees have a clear preference for a high proportion of battery-electric vehicles, with lesser proportions of hydrogen and plug-in hybrids. However, they expected a fairly even spread of vehicle technologies by 2050 with high proportions of ICE and traditional hybrid vehicles, suggesting a worry that the infrastructure requirements and the high capital costs associated with the newer technologies would prevent large numbers of consumers from switching.

Many attendees commented on the use of biofuel as a transition to lower the carbon intensity of this sector in the short and medium term. However, there were worries that this may not be the best use for limited biofuel resources, compared to utilising them in CCS plant for negative emissions. There was considerable discussion over modal shifts, and the possibility that individual vehicle ownership and use would decline with increasing urbanisation of the population and the extension of public transport.

Disruptive Technologies and Scenarios

Figure 4 shows the main output from this station.

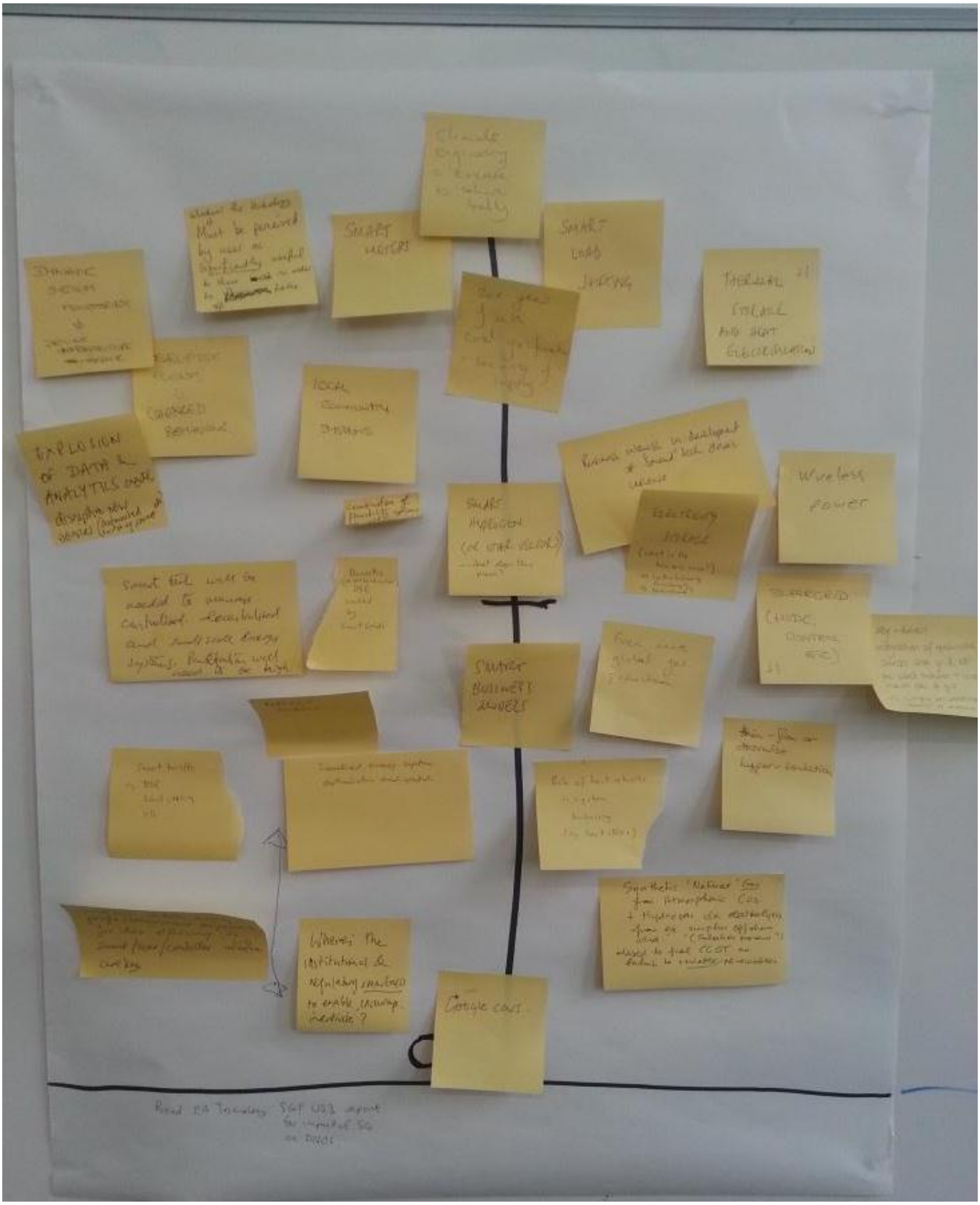

Figure 4: Photograph of disruptive technologies station

The results were collated and ranked in three categories, low, medium and high relating to the disruptive potential of the scenario.

LOW

- 'Google cars'/self-driving vehicles
- Institutional and regulatory arrangements for 'smart' technologies
- Synthetic 'Natural' gas from atmospheric CO2 and hydrogen via electrolysis
- Thin-film (or otherwise) hyper-insulation
- The role of heat networks in system balancing
- Localised energy system optimisation and control

MEDIUM

- Smart business models and market models
- Even more global gas production
- Supergrids (HVDC etc)
- Smart tech needed to manage centralised, decentralised and small-scale energy systems.
- Explosion of available data and analytics creates disruptive new services
- Smart hydrogen –or other vectors
- Electricity storage (what's the business case?)
- Wireless power
- Business interest in development of smart tech drives unease

HIGH

- Thermal storage and heat electrification
- Smart load shifting
- A potential 200 years of energy supply from UK coal gasification
- Local community systems
- Disruptive events -> change in behaviour
- Dynamic system monitoring to drive infrastructure harder
- Technologies needed to be perceived by users as significantly more useful than current to drive adoption
- Smart Meters
- Climate Engineering (excuse to behave badly?)

A few consistent themes can be drawn out from this distribution. The first is that of smart meters, load shifting and smart business models leading to direct consumer participation in the energy market. This has the potential to provide flexible load and demand-side response facilities, if adopted by a sufficient proportion of energy consumers. These technologies would be especially important in a decentralised energy system, as local load balancing will become crucial. However, as another comment points out, technologies need to be perceived by users to be significantly more useful than current models in order to drive adoption –poor uptake rates or an active backlash driven by consumer unease could disrupt these technologies significantly. Another interesting possibility is that the explosion of available data and analytics on energy usage patterns and prices could create the opportunity for disruptive new services and products.

Several comments centred on the heat system, primarily around heat networks, heat electrification and thermal storage. Heat networks are currently uncommon in the UK, and there would be significant infrastructural costs required to install larger-scale networks. Thermal storage, especially if combined with district heating, could potentially be a means of providing extra flexibility to the energy networks through absorbing excess electricity when needed.

The potential to create synthetic natural gas from CO_2 and H_2 was discussed – although still theoretical, this could provide a new low-carbon energy vector. One comment identified coal gasification as an energy source for the UK - a potential new domestic supply with up to 200 years of reserves, but very carbon-intensive.

Other comments included the potential for self-driving vehicles, which could disrupt the traditional pattern of transportation usage. Electricity storage, wireless power technologies and greater quantities of community energy are also potentially disruptive.

Energy Demand

This exercise constituted a freeform examination of how attendees expected total final UK energy demand to evolve by 2050. The points were transposed onto the graph below. Note that this was not a quantitative study – the height of the points in Figure 5 do not relate to absolute values.

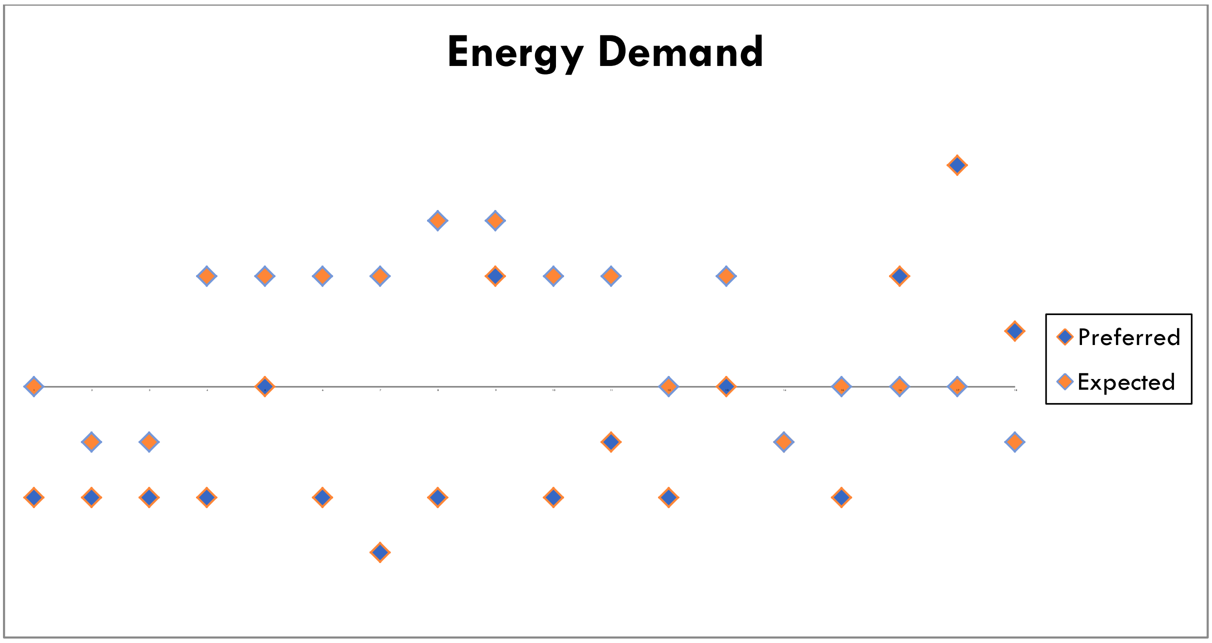

Figure 5: Chart of electricity demand preferred and expected values (not to scale)

There is a clear pattern discernible from the points – on average attendees 'preferred' energy demand in the UK to decrease while 'expecting' it to increase. This figure represents total demand, so it is possible that population growth in the UK by 2050 will lead to an increase even if per-capita energy demand falls.

Arguments for falling demand were made mostly on the basis of efficiency improvements and greater insulation, as well as rising energy costs. The point was made several times that one affects the other, with increasing costs in energy incentivising energy efficiency measures, as well as possible demographic shifts such as a fall in single-person households. The major drivers of energy cost rises were thought to be carbon prices as well as a tightening of supply, with the UK having to compete with developing nations for energy . One participant estimated a possible improvement in energy efficiency measures driving demand down 20% - however this could trigger a rebound effect as users use the savings to give themselves better comfort levels, leading to an overall smaller drop in demand. It was also stated that a drop in demand could be driven more by industry than the general public, as UK heavy industry becomes more efficient or moves overseas.

The arguments favouring higher demand focused on economic growth – GDP growth higher than the historic average would lead to greater energy demand. There were several comments arguing that greater energy demand by 2050 would be beneficial, assuming that energy supply would be mostly decarbonised by this point. Greater availability of cheap, carbon-free energy would help those in fuel poverty (with one comment suggesting giving a basic allocation of electricity and heat for free), as well as drive growth and innovation. Giving away a quantity of free or very cheap low-carbon electricity could also help drive a switch from gas-fired central heating to electric heating.

Overall, it was agreed that an increase in energy demand from low-carbon energy sources would be a good thing for the UK. Given the uncertainties surrounding the transition to a low-carbon energy system, the ideal energy demand in 2050 would still be lower than the present day, owing to efficiency improvements and possible demand-side participation measures. It was pointed out by one attendee that total demand is not necessarily the best metric to determine how well energy is used – what may be more useful to consider are the daily peaks in demand, because large peaks would require the use of higher-emission reserve plant. Demand-side measures to smooth peaks may therefore be more effective at reducing carbon emissions than across-the-board efficiency improvements.

Conclusions

The exercise was concluded by a plenary feedback and discussion session. Comments included:

- The exercise looked at technologies, but they are only one driver for change. Other factors such as social and cultural values, consumer reluctance and backlash against new technologies, and national and international economic conditions influence how the future UK energy system will develop.
- The exercise also looked at uncertainty, and indeed the difference between the ‘preferred’ and ‘expected’ charts are an effort to measure that. However, what about approaching the exercise from a different angle and start by discussing the certainties in the system, establishing them as a baseline?
- The exercise dealt mostly with supply-side technologies, and did not have a strong focus on demand-side technologies and how they might affect the system.
- The exercise has at its base point the 2050 carbon targets, and the mix of technologies that could achieve those. However, carbon targets may be forgotten in times of threat to energy security or economic stability. A less specific set of base assumptions may be needed.
- Regulation and legislation issues were described as the ‘gorilla in the room’ as these have a very strong effect on the development of the energy system and the adoption of new technologies.
- Importantly, it was mentioned that investment decisions are not taken between different energy technologies in the UK, for example ‘UK nuclear vs UK wind’, but instead on a global scale – for example ‘nuclear in the UK versus a new factory in China’. UK investments need to compete globally.

4. Session 3: Research Portfolios

The second break-out session was structured to stimulate discussion around which areas of the UK's energy research and development (R&D) portfolio the workshop participants considered to be strongest, specifically in terms of the UK's scientific and industrial capabilities. Furthermore, the session was designed to provide insight into how relevant the workshop participants believed these capabilities were likely to be in the UK's future energy system.

Methodology

The workshop attendees were split into five different groups of approximately four to five people, consisting of a mix of individuals, engaging with a variety of different aspects of the UK energy system. A workshop facilitator was paired with each group, who was primarily responsible for ensuring the discussion remained on topic and recording the outputs of the discussion.

At the beginning of the session the groups were asked to consider how strong they believed the UK currently was in terms of both scientific and industrial capabilities, relating to each of the different energy R&D fields that make up the UK's energy R&D portfolio. To assist the groups, they were provided with a consolidated version of the International Energy Agency's (IEA) energy R&D nomenclature, which represented an *aide memoire* to help ensure the groups considered the full range of different technologies and activities that make up the energy R&D system. In parallel, the groups were also asked to consider how relevant they believed these various R&D areas were likely to be to the future of the UK energy system. In summary, the groups were asked to assign a value for 'scientific capability'; 'industrial capability' and 'relevance to UK's energy future' relating to each of the key energy R&D categories. We briefly expand upon these:

> **Scientific capability –**The UK's capabilities with respect to research; applied research and development; and demonstration
>
> **Industrial capability –** The UK's capabilities with respect to the deployment and commercialisation of the products of R&D, such as technologies, processes, services etc
>
> **Relevance to UK's Energy Future –** How relevant the technology is in terms of meeting the UK's energy policy goals relating to climate change, energy security and affordability

The members of the break-out groups were given time to consider the various aspects of the UK energy R&D portfolio individually in terms of these three metrics, after which they were encouraged to present their majority verdict for each of these and communicate these to the facilitator.

To record these values a work-sheet was used that included two axes for 'industrial capability' (X-axis) and 'relevance to UK energy future' (Y-axis) (see Figure 6), each of which ranged from 0 - 100. Once values for these two metrics were agreed on by the group, a post-it note with the energy R&D category was located on the work-sheet accordingly. As the groups were working on paper there were only two axes, therefore values for 'scientific capability' had to presented differently. Consequently the groups were asked to consider whether they believed the UK possessed weak, moderate or strong capabilities with respect to a certain energy R&D field, which were subsequently represented as red, orange and green post-it notes on the work-sheet (Figure 6). It is important to note that in relation to the 'industrial capability' metric, the workshop groups were allowed to assign energy R&D areas with not only a value between 1 and 100 but also a value for 'no clear international lead' (Figure 6). This value was assigned when groups believed there was no clear international leader in relation to the deployment and commercialisation of a specific energy R&D field. By assigning this value, a group indicated that the R&D field was industrially immature in the UK but that it was also immature internationally. Consequently, the UK was as well-positioned as any other country to become an international leader of this industry in the future.

Figure 6: An example of a completed exercise for the Break-Out Session 2

Results

In Figure 7 we present the groups assigned for each of the key energy R&D areas that make up the UK energy portfolio, with respect to the three metrics outlined in the previous section. Each value presented in the figure represents the average, taken across the different groups. The colour coding of the circles in the figure corresponds with the different groupings the IEA have assigned to the various different energy R&D areas e.g. *renewable energy sources*, *energy efficiency, fossil fuels etc*. Additionally, the size of the circles relates to the groups' assessment of the UK's scientific capability for each of these different energy fields. Here the larger the circle, the stronger scientific capability the groups believed the UK possessed in this field.

Figure 8 to Figure 10 present the broad range of values the different groups assigned to each of the energy R&D categories for the three different metrics as box-whisker diagrams.

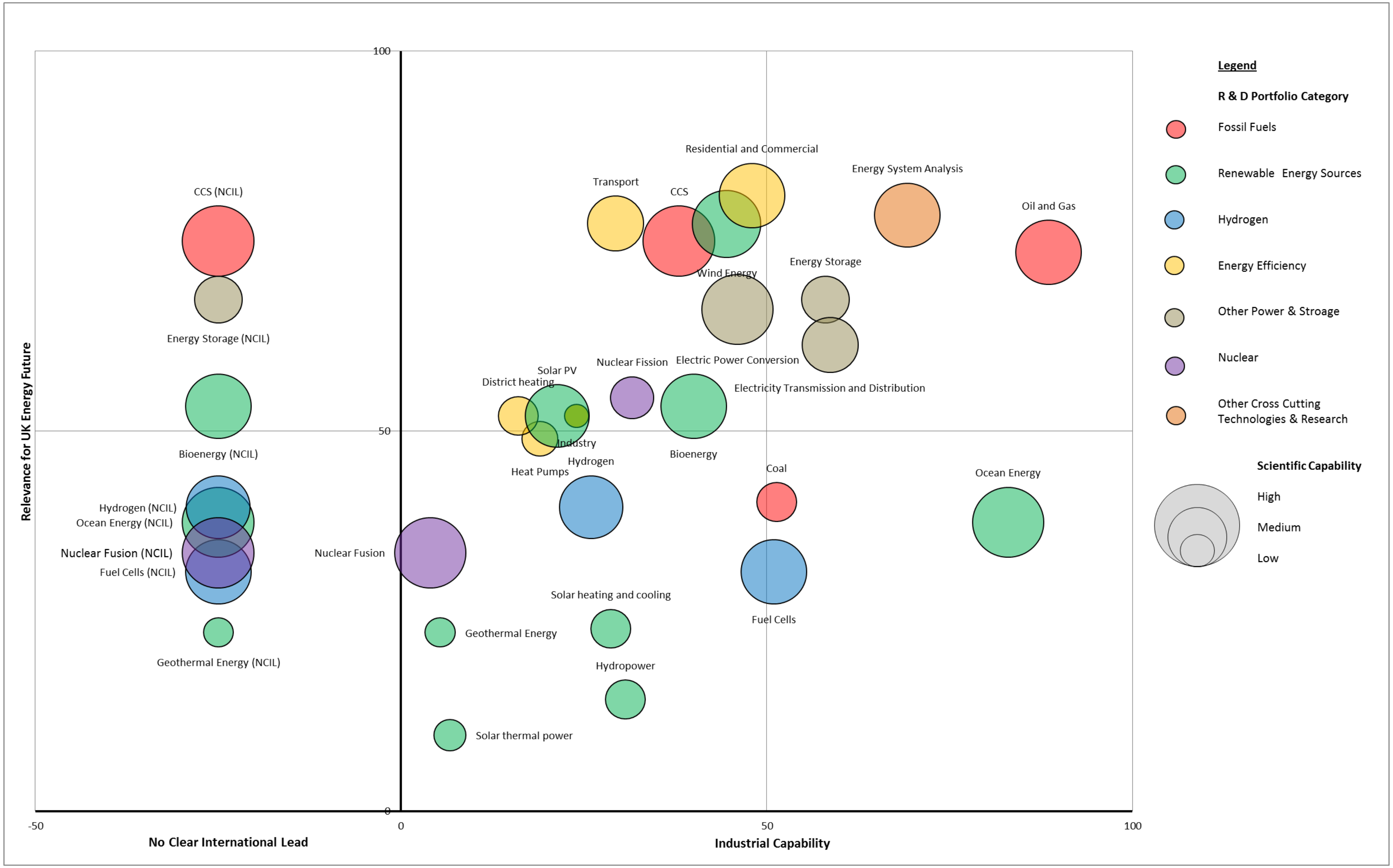

Figure 7: The UK's current and future energy R&D portfolio

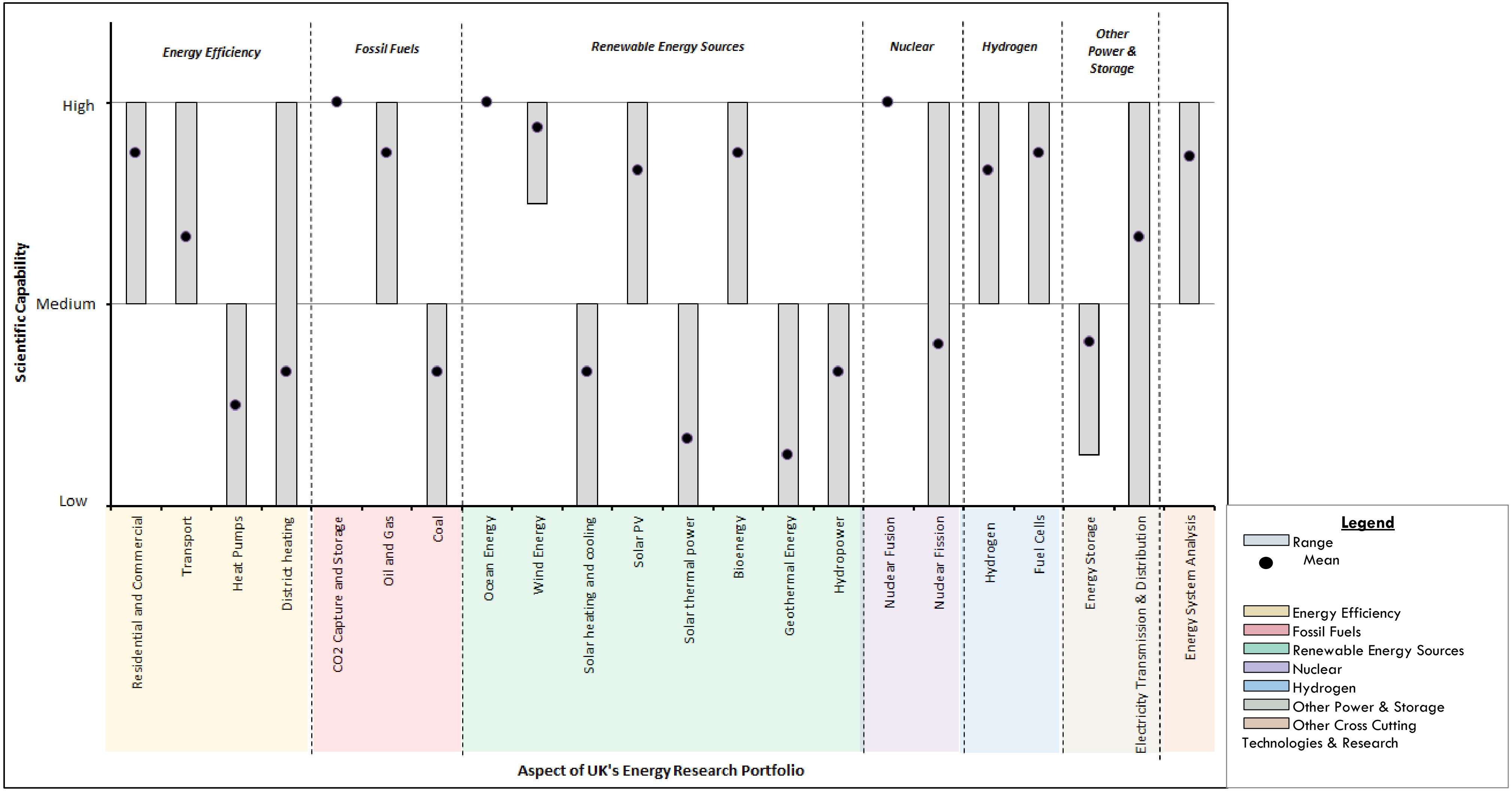

Figure 8: A diagram presenting the variety of responses from the workshop groups for 'scientific capability'

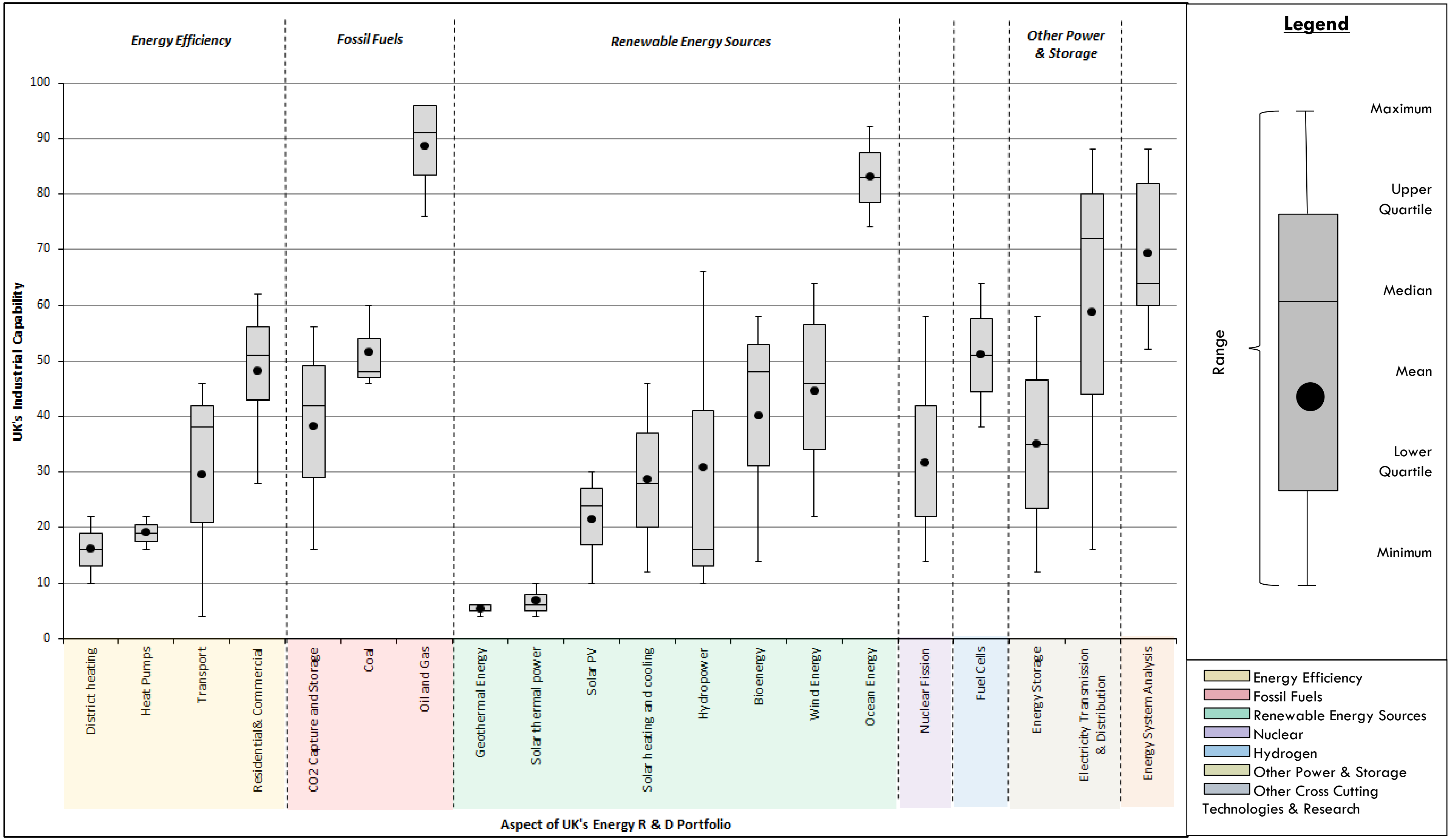

Figure 9: A box whisker diagram presenting the variety of responses from the workshop groups for 'industrial capability'

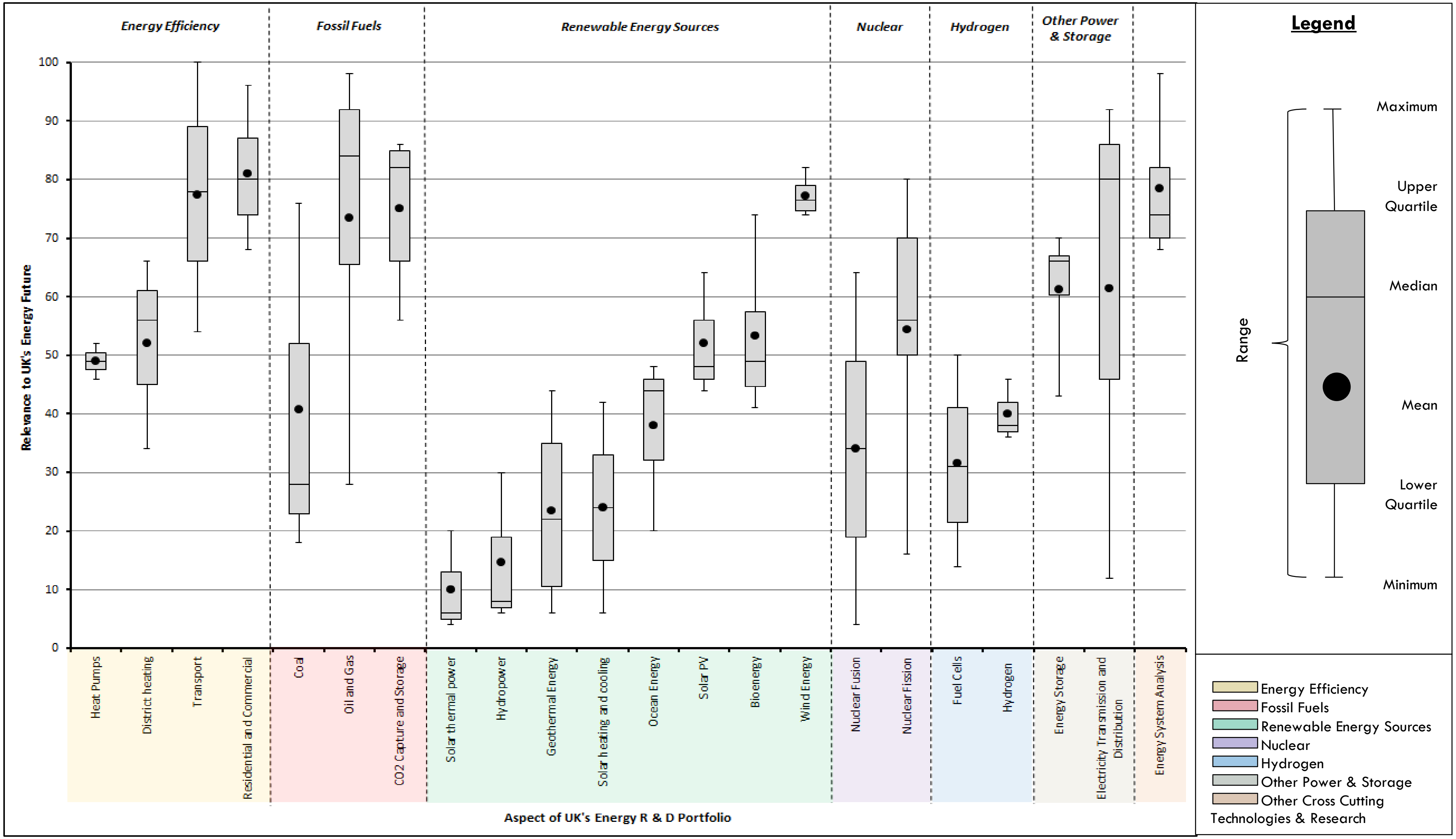

Figure 10: A box whisker diagram presenting the variety of responses from the workshop groups for 'relevance to UK's energy future'

Discussion

This sub-section discusses the results of break-out session 2.

Energy Efficiency

As illustrated in both Figure 7 and Figure 9, the workshop participants broadly considered the UK to possess relatively modest industrial capabilities across the energy efficiency R&D categories. The groups generally felt that the UK possessed a moderate degree of industrial strength in both *residential and commercial* energy efficiency and *transport*. One group attributed the UK's relative strength in the field of *residential and commercial* energy efficiency to the introduction of stringent low-carbon building regulations. However, this same group emphasised the UK's poor ability to retrofit older commercial and residential properties, with a view to improve their energy efficiency standards. Turning to *transport*, the groups identified centres of UK industrial excellence at Nissan, Rolls Royce and amongst the Formula 1 affiliated companies, such as McLaren.

The groups assigned a much lower value for industrial capability to *industry, heat pumps* and *district heating*. For instance, one of the groups highlighted that the UK has traditionally imported *heat pumps* from other countries and is home to only a handful of large-scale *district heating* schemes. There was a strong degree of convergence between the groups' responses for both *district heating* and *heat pumps*. However, there was less agreement around the UK's industrial capabilities in relation to *residential and commercial* energy efficiency and particularly *transport*.

In line with the results for industrial capability, the groups considered the UK's scientific capabilities in energy efficiency to be strongest in *residential and commercial*, followed closely behind by *transport*, with the groups considering the UK to possess above average scientific capabilities in these areas. In relation to the latter, one of the groups highlighted centres of academic excellence for transport including the Low Carbon Vehicle Partnership and the Institute for Transport Studies at the University of Leeds. In contrast, the groups considered the UK to possess below average scientific strength in the fields of *district heating, heat pumps* and particularly, *industrial energy efficiency*, which had also been scored poorly in terms of industrial capability. Interestingly, there was a particularly broad range of responses from groups relating to the UK's scientific capabilities in the field of *district heating*.

Again in line with the values they assigned to industrial and scientific capabilities, the groups indicated that *residential and commercial* energy efficiency was likely to be most relevant to the UK's energy future, with *transport* positioned a close second. One of the groups emphasised that *residential and commercial* energy efficiency was likely to be particularly relevant to the UK's energy future because of the important role it could potentially play in reducing carbon emissions and improving the affordability of energy services. Whilst the groups were generally in agreement that *residential and commercial* energy efficiency would play an important role, there was less consensus around the relevance of *transport*. Broadly, the groups felt that *industry, heat pumps and district heating* would be of average relevance to the UK's energy future. Although there was only weak consensus around the relevance of *district heating*, the groups' responses converged around the future relevance of *heat pumps*. Importantly, one group emphasised that the relevance of heat pumps would very much depend on the support provided by both DECC and the Committee on Climate Change.

Fossil Fuels

The results of the workshop exercise indicate that the UK currently possesses very strong industrial capabilities in the *oil and gas* industry, which some of the groups attributed to the industrial capabilities that have been developed in the UK during its decades of extracting fossil fuels from the North Sea. Broadly the groups indicated that the UK possessed average industrial capabilities in both *coal* and CCS. Whilst there was there was a great deal of agreement between groups around the UK's industrial capabilities in the *coal* and *oil & gas* industries there was much less consensus in relation to

CCS. Furthermore, some of the groups explained that there was currently 'no clear international lead' in this field, considering how immature the industry currently is.

In terms of scienitific capability, there was a very strong consensus amongst the groups that amongst fossil fuel R&D categories, the UK currently possesses strongest scientific capabilities in CCS. One group emphasised that much of the UK's CCS research efforts are currently located within the UK Carbon Capture and Storage Research Centre (UKCCSRC). The groups generally indiciated that the UK also possesses strong scientific capabilities in the field of *oil & gas*, which was in line with the value they had assigned for industrial capability. It was explained that much of the UK's current *oil & gas* related scientific research was centred around the environmental and social impacts of oil and gas extraction, as well as the processes relating to the extraction of shale gas.

In contrast to the fields of *oil & gas* and CCS, it was believed the UK possessed limited scientific capabilities in relation to the extraction and processing of *coal*. One of the groups attributed this in part to the decline of the UK coal industry and thus the diminishing demand and available funding for research into coal. However, the same group explained that the UK still possessed some scientific strengths around the combustion of coal and the development of the supply chain necessary for a healthy coal industry.

We now turn to how relevant the groups believed each fossil fuel R&D category's was likely to be to the UK's energy future. On balance, the groups expected both CCS and *oil & gas* to play a key role in the UK's energy future, ranking these as one of the most relevant categories of energy R&D. Importantly, one of the groups emphasised that the relevance of CCS will very much depend on whether it becomes commercially viable in the near future. Turning to *oil & gas*, some of the groups attributed the high relevance of *oil & gas* to the burgeoning shale gas industry in the UK. However, there was very little consensus amongst the groups regarding the future relevance of *oil & gas*, with one of the groups forseeing the area having little relevance for the UK over the coming years. On balance however there was a positive correlation amongst all three metrics for *oil & gas*. In contrast to *oil & gas* and CCS the groups did not expect *coal* to be particularly relevant to the UK's energy future. However, in a similar fashion to *oil & gas*, there were very low levels of consenus amongst the groups relating to this matter.

Renewable Energy Sources

The groups assigned a broad range of industrial capability values to the various renewable energy industries. Within this group *ocean energy* was assigned the highest industrial capability, which also represented the second highest value across all the energy R&D areas, after *oil & gas*, *ocean energy*. Additionally, the *wind energy* industry was also assigned a relatively high value. In contrast, both *solar thermal* and *geothermal* were assigned the lowest industrial capability values in this field, which were in fact the lowest across all energy R&D areas, after *nuclear fusion*. Industrial capability was considered to be slightly stronger for *solar PV*, however its relatively modest value was attributed by one group to the damaging effect the feed-in-tariff cuts had had on the solar PV industry over the past year.

It is extremely important to note however that many of the groups emphasised that there was 'no clear international lead' in a number of the renewable energy fields. For example, even though two of the groups indicated that the UK possessed very strong industrial capabilities in the field of *ocean energy*, the remaining three groups indicated that there was 'no clear international lead' in the *ocean energy* industry. Additionally, one the groups also explained that there was 'no clear international lead' for both the *geothermal* and *bioenergy* industries too.

Consensus regarding the UK's industrial capability in the renewable energy industry was strongest for *geothermal*, *solar thermal* and *solar PV*, all of which were given relatively low values. There was in contrast much less consensus amongst the groups for *wind energy, bioenergy* and particularly, *hydropower*.

Turning to the UK's scientific capability, *ocean energy, wind energy, solar PV* and *bioenergy* all scored very highly. Centres of scientific excellence in the UK identified by the groups included the Supergen hub led by Strathclyde and Durham Universities and the National Renewable Energy Centre at Blyth for *wind* and the Supergen hub for *bioenergy* led by a consortium of universities across the UK. In contrast, the groups generally considered the UK to have much poorer industrial capability in relation to *solar heating & cooling, solar thermal power, geothermal power* and *hydropower*. Consensus was strongest around the UK's scientific capabilities around *ocean energy*, closely followed by *wind energy*, with the remaining fields eliciting moderate consensus amongst the groups.

In terms of the relevance of renewable energy sources to the UK's energy future, there was a very strong degree of consensus amongst the groups that *wind energy* would play one of the most important roles amongst all R&D energy categories. Some of the groups emphasised that this was likely to be centred around offshore wind rather than onshore wind, mainly due to the abundance of suitable offshore locations, the lower degree of associated controversy with such locations and the ability to harness greater economies of scale with offshore wind farms compared to onshore. It was also foreseen that *bioenergy* and *solar PV* would play important roles, however there was less agreement between the groups relating to this. One of the groups emphasised that *bioenergy* could play a very important role in the future if a commercially viable means was found for capturing and storing the carbon emissions generated via biomass combustion, which would result in a net carbon negative means of generating energy. However, concerns were raised around the impacts wide-scale adoption of bioenergy would have for arable and crop farming in the UK and beyond. Broadly the groups agreed that *solar thermal power, geothermal, hydropower* and *solar heating & cooling* would all have relatively little relevance for the UK's energy future.

Nuclear

The general consensus between the groups was that the UK possesses relatively weak industrial capabilities in *nuclear fission*, in comparison to other energy areas. Although agreement around this was not particularly strong amongst the groups, it was felt the UK possessed relatively little experience of delivering nuclear power stations in recent years. One group also warned that the industrial skills and experience the UK had gained in delivering its first generation of nuclear power stations were gradually being lost. However, centres such as the Nuclear Fission Research, Science and Technology Centre for Doctoral Training were considered to be playing an important role in attempting to halt this decline. Some groups explained that the UK did possess strengths in specific aspects of the nuclear industry, particularly nuclear decommissioning, fuel cycle and nuclear waste management. Furthermore, companies such as Rolls Royce possess extensive experience of developing nuclear reactors. Turning to *nuclear fusion*, one of the two groups that analysed this R&D area considered there to be 'no clear international lead' in this field. Similarly, the other group indicated that the UK possessed very low industrial capabilities relating to *nuclear fusion*.

However, there was a strong consensus that the UK possessed excellent scientific capabilities in the *nuclear fusion* area. One group highlighted that the Joint European Torus (JET), located at Culham Centre for Fusion Energy, represented the pinnacle of UK nuclear fusion research. In contrast, the groups indicated that the UK possessed much weaker scientific capabilities in the field of *nuclear fission,* when compared to *nuclear fusion*. However, some of the groups indicated that the UK did possess some scientific strengths in areas such as nuclear decommissioning, fuel cycle and nuclear waste management.

There was a great degree of uncertainty surrounding how relevant nuclear energy was likely to be to the UK's energy future. Broadly the groups expected *nuclear fission* to be moderately relevant to the

UK's energy future, constituting a noteworthy share of the energy mix during the period leading up to 2050. Surprisingly, the groups assigned *nuclear fusion* a value not that much lower than *nuclear fission* for relevance to the UK's energy future, despite it still not representing a proven technology. One group emphasised that the role of fusion in the long-term remained uncertain considering that the technology has not yet been proven on a commercial basis.

Hydrogen and fuel cells

There was little consensus around the UK's industrial capabilities relating to *hydrogen* and *fuel cells*. With regards to *fuel cells*, two of the four groups that analysed this R&D category believed there was 'no clear international lead' in the *fuel cell* industry. Although the other two groups did feel there was an international leader in this field, they differed substantially in their assessment of the UK's industrial capabilities. One of the groups highlighted that Rolls Royce in particular had experience in this field, as well as a number of SMEs, however they were quick to point out that the majority of this activity was pre-commercial. With respect to *hydrogen*, the same group explained that the UK had most experience in hydrogen production but was weak with respect to hydrogen storage and infrastructure.

The groups considered the UK to have a similar degree of scientific capabilities in the fields of both *hydrogen* and *fuel cells*, exhibiting a moderate degree of consensus with regards to this assessment. One group explained that the UK's scientific capabilities around *hydrogen* and *fuels cells* are generally stronger than most other countries, whilst another highlighted that much of the UK's *hydrogen* related research has been conducted as part of the SUPERGEN XIV - Delivery of Sustainable Hydrogen, led by universities such as Newcastle and Birmingham.

Turning to the relevance of the hydrogen R&D field to the UK's energy future, it was believed that *hydrogen* was likely to play a more important role than *fuel cells* in the long-term. Importantly, there was very strong consensus between groups on the relevance of *hydrogen*, however one group reported a 'split opinion' on the matter. There was much lower inter-group consensus around the role of fuel cells, partly because it was felt that political support for these areas tended to oscillate from strong to weak, increasing uncertainty around its relevance. Broadly, the groups did not believe *hydrogen* and *fuel cells* were likely to be particularly relevant to the UK's future energy landscape in part because scientific developments in this field remain pre-commercial. Importantly, one group emphasised that if hydrogen technologies were to become commercially viable and proliferate, they would have the greatest impact upon the transport sector.

Other Power & Storage

There was very little consensus between the groups in relation to the UK's capabilities in the fields of *electric power conversion, energy storage* and *electricity transmission & distribution*, particularly with regards to the latter, which elicited the broadest range of responses from groups for any energy R&D area. However, on balance, there was a strong correlation between the values the groups assigned to the UK's industrial capabilities in 'other power & storage' R&D areas and the relevance of these to the UK's energy future (Figure 7). Broadly, the groups felt that the UK possessed average capabilities in the fields of *electric power conversion, energy storage* and *electricity transmission & distribution*. Focusing on the latter, companies such as the National Grid and other Transmission and Distribution Network Operators where highlighted as examples of the UK's industrial capability in this field. Turning to *energy storage*, it is important to note that two out of the four groups explained that there was 'no clear international lead' in this field.

Turning to scientific capabilities in this area, it was believed that the UK possessed strong scientific capabilities in the fields of both *electric power conversion* and *electricity transmission & distribution* but its capabilities were somewhat weaker in the field of *energy storage*. The groups highlighted the University of Strathclyde, the University of Manchester and Imperial College as centres of excellence for *electricity transmission & distribution* research. It was explained that whilst research in this area had increased in recent years in order to address potential issues surrounding electricity generation intermittency, the UK still undertakes little research into the field of superconductivity.

Generally, the different groups agreed that *energy storage* was likely to be highly relevant to the UK's energy future, taking various different forms such as battery, thermal, photochemical and kinetic energy storage. It was believed that the *energy storage* industry was likely to experience major growth considering the expected proliferation of intermittent energy generation technologies, such as *wind*, *solar PV* and *solar heating and cooling*. In contrast, there was much less consensus around the relevance of *electricity transmission and distribution*, with one of the three groups that analysed this area having assigned a score very close to zero, whilst the other two groups believed it would play a critical role over the coming years.

Other Cross-Cutting Technologies & Research

One of the energy R&D fields that received the highest scores for industrial capability, scientific capability and relevance to the UK's future energy system was *energy system analysis*. Furthermore, there was a relatively strong degree of consensus amongst the groups that this was the case. The groups emphasised that the UK's expertise in this field centred mostly around the sociological, economic and environmental impact of energy, such as the impact of energy related policy, regulation and innovation. They also emphasised the UK's strengths with regards to energy scenario development, energy system modelling and socio-technical analyses of energy systems. Turning to scientific capabilities, one group highlighted the strengths the University of Cardiff, University College London and Imperial College possessed in the field of *energy system analysis*. However, another group warned that the UK has traditionally been concerned with UK-centric energy system analyses rather than international energy system analyses.

Relationship between the Three Metrics

Figure 7 illustrates how *oil & gas*, *energy system analysis, solar thermal power, geothermal power, hydropower* and *solar heating & cooling* exhibit a strong correlation between the three metrics of 'scientific capability', 'industrial capability' and 'relevance for the UK's energy future'. It is important to note that *oil & gas*, *energy system analysis* and *solar thermal power* are consistently high across these three metrics, whilst *geothermal power, hydropower* and *solar heating & cooling* are consistently low.

One of the groups emphasised that this relationship can to some extent be explained by positive feedbacks, where higher levels relating to one metric are likely to result in higher levels of another. This can be illustrated by the relationship between scientific and industrial capabilities, where strong scientific capabilities can encourage growth in industries as organisations seek to commercialise scientific advances for financial gain. In addition, a strong industrial sector can provide a combination of necessary funds and impetus to undertake additional scientific research in a specific energy R&D area. One group provided an example where the commercialisation of an energy technology may highlight valuable opportunities for additional scientific research. They highlighted for example how the commercialisation of tidal barrages might raise questions relating to their geomorphological effects and how the deployment of offshore wind farms might impact upon marine ecosystems.

The same kind of positive feedback may exist between 'relevance' and the other two metrics, where a stronger scientific and industrial base in a certain energy field is likely to mean that it will play a more prevalent role in the UK's energy future. Conversely, if a certain field of energy R&D is thought to have greater relevance to the UK's energy future than others another amongst key energy stakeholders, then that field is likely to attract more resources to support its related scientific and industrial activities. The relationships between these metrics can also be said to happen in reverse, for example where all three metrics are assigned low values, which was the case for *solar thermal power, geothermal power, hydropower* and *solar heating & cooling*.

By way of contrast, Figure 7 shows us that for some energy R&D categories there is no such correlation between all three metrics. For example, for some categories such as *hydrogen* and *nuclear fusion* the groups assigned a strong value for scientific capability but believed there was 'no clear international lead' in terms of industrial capability and that these fields were considered to have little relevance for the UK's energy future. This indicates that for some R&D areas the UK is scientifically strong even though it is industrially weak and that the field is unlikely to play a key role in the UK's energy future. Alternatively, categories such as industrial *energy efficiency*, *district heating* and *nuclear fission* were assigned a weak value for scientific and industrial capability despite the groups expecting them to be of above average relevance to the UK's energy future. These examples help to illustrate how in some cases there was a positive correlation between all three metrics for some energy R&D areas, this was certainly not the case for all the energy areas.

Group Feedback on Workshop Exercise

Broadly the groups appeared very comfortable with the break-out group exercise and engaged productively with one another to generate insightful evidence relating to the UK's existing and future energy R&D landscape. However, during the break-out sessions the group members also provided a broad range of feedback relating to the effectiveness of the exercise.

One point which the groups highlighted was the difficulty of divorcing the UK's scientific and industrial capabilities from that of other countries. For instance, one group emphasised that many of the organisations and institutions that harbour these capabilities operate internationally and may transfer their capabilities from one nation to another with relative ease. This means that it is difficult in some cases to accurately measure the UK's capabilities in relation to the various different energy R&D areas. On a similar note, one of the groups emphasised that by focusing on the UK specifically, the exercise to a certain extent treated the UK as a separate and bounded entity, as opposed to a node within a wider energy system. For instance, they explained that the UK's energy system is intrinsically linked to other nations via infrastructure (e.g. electricity interconnectors, pipelines etc) and the trading of energy imports and exports. Finally, another group explained that it was difficult to draw comparisons between the values assigned to the UK for scientific and industrial capabilities, as well as the relevance of these to the UK's future energy relationship with other countries. This was because the groups were primarily experts on the UK energy system, as opposed to other countries' energy systems, and could not therefore draw an accurate comparison.

Another focus for constructive feedback was the provision of a consolidated version of the IEA's energy R&D categories to guide the groups' analysis of the UK's energy system. Although none of the groups chose to ignore the *aide memoire* provided to them, some of them were critical of the way in which it shaped the analytical process. For instance, one of the groups explained that the categories in many cases coarsely grouped together numerous differentiated foci for energy R&D, which made analysis somewhat challenging. Furthermore, the same group criticised the technological basis of the IEA's categories, which they believed prioritised technology over more socially oriented areas of energy R&D, such as energy services, business models, community engagement etc. However, this technological focus did not prevent the groups emphasising the importance of non-technological aspects of the UK's energy system, such as its socio-economic and socio-technical dimensions.

Finally, two other pieces of feedback were provided by the groups. The first was that many of the group members tended to focus their analysis predominantly on the categories they were most familiar with, often at the expense of those areas they were less familiar with. The second was the use of the metric 'relevance for the UK's energy future'. One group explained that this was sufficiently 'open-ended' to be interpreted in a variety of different ways by the groups. For instance, it could be interpreted as relevance in terms of how relevant these R&D categories were likely to be in the future or how relevant they believed they *should* be.

5. Final Discussion

The final session drew out some high level points arising from the exercise and turned to dissemination of the workshop findings and follow-up. Key discussion points included:

- There had been a strong divergence across the table groups in terms of the assessment of UK academic strengths, and it was not immediately clear why;
- The degree of disaggregation of technologies may affect the assessment of capability. For example, the UK may be strong at carbon storage but less so at carbon capture. At too high a level of aggregation the strengths may be averaged out;
- Although fossil fuels did not feature strongly in the report-back, individual group discussions had noted UK strengths in terms of both research and industrial capability;
- We need to take care where using the term 'research capability', e.g. there may be a lot of oil and gas research strengths in the private sector, but perhaps less so in academia
- The UK's capability in certain fields could radically change between now and 2050, highlighting the possibility that, thus impacting upon their relevance to the UK's future;
- Capabilities can deteriorate over time. If the UK did not make efforts to maintain capabilities in certain energy R&D areas then it may cease to retain its lead in these fields, thus having a negative impact upon their relevance to the UK's energy future;
- The UK's capabilities were not considered to be spread evenly across the full range of its energy R&D portfolio, meaning that it was strong in certain pockets of energy R&D but weak in others;
- The Research Council representatives noted that we may have pockets of strength in various areas that may not have been ideally captured in this exercise as our own perceptions, experiences and contacts played a big role. There were also differences between the different branches of science, e.g. social, environmental.
- The "technocratic" focus of the workshop was discussed. A wider perspective was needed. For example, PV is not just a technology, it has the potential to give households a stake in energy supply. The second workshop would address alternative, non-technological ways of framing energy research issues.
- The need for dialogue with end-user communities was stressed.
- The group had not identified any technologies "coming from left field"
- External factors such as climate change and market reform have had an important bearing on the shape the UK's R&D portfolio has taken. This emphasises the point the that UK's portfolio is not only developed in accordance with decisions taken by key public and private sector actors but is also a product of external developments that radically alter the energy landscape.

Finally, the follow-up to the workshop would include: a written report which to be published online; slides published online; and the hand-over of key messages to subsequent workshops.

Annex: A: Workshop Programme

Plenary Session on Energy Strategies and Scenarios

10:30	Welcome and overview of the workshop and wider process	Jim Skea

10:45	Review of energy scenarios and projections	Aidan Rhodes
11:00	Committee on Climate Change perspective	Adrian Gault, Committee on Climate Change
11:15	A utility company perspective	Andy Boston, E.ON UK
11:30	Discussion	

Facilitated Session on UK Energy Futures

12:00	Introduction	Facilitated by Aidan Rhodes
12:15	Individual and team working	
13:15	Lunch	

Break-out Groups on Research Portfolios

14:00	Introduction	Facilitated by Jim Skea
14:05	Group working	
15:00	Tea-break	
15:15	Report back	
15:30	Discussion and next steps	
16:00	Close	

Annex B: List of Attendees

Kate	Hamer	BBSRC
Mike	Stephenson	British Geological Survey
Catherine	Butler	Cardiff University
Nick	Jenkins	Cardiff University
Adrian	Gault	CCC
Simon	Roberts	Centre for Sustainable Energy
Davinder	Lal	Defra
Andy	Boston	E.ON
Stuart	Haszeldine	Edinburgh University
Jonathan	Radcliffe	Energy Research Partnership
Sarah	Darby	Environmental Change Unit, Oxford
Gavin	Salisbury	EPSRC
David	Ridley	ESRC
Philipp	Gruenewald	Imperial College London
Stefan	Pfenniger	Imperial College London
Robert	Sansom	Imperial College London
David	Vincent	Independent
Peter	Taylor	Leeds University
Tim	Foxon	Leeds University
Jenny	Cooper	National Grid
Blanche	Coleman	NERC
Jeffrey	Hardy	Ofgem
Matthew	Hannon	RCUK Energy Strategy Fellowship
Aidan	Rhodes	RCUK Energy Strategy Fellowship
Jim	Skea	RCUK Energy Strategy Fellowship
Rufus	Ford	SSE
Rob	Saunders	Technology Strategy Board
Ilkka	Keppo	UCL
Nicola	Combe	UKERC

Annex C: List of Energy Strategy Fellowship Reports

Report 1: *Summary of Stakeholder Views and Way Forward*, September 2012

Report 2: *Energy Strategy and Energy Research Needs*, November 2012