**Royal Society of Edinburgh: Scotland's Energy Future:**
**Consultation response by the UK Energy Research Centre (UKERC)**

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**Introduction**

The UK Energy Research Centre (UKERC) carries out world-class, interdisciplinary research into sustainable future energy systems. It is a focal point of UK energy research and a gateway between UK and international energy research communities. Our whole systems research informs UK policy development and research strategy. UKERC is funded by the Research Councils' UK Energy Programme. For information please visit www.ukerc.ac.uk. Given space restrictions, we have limited our written response to a selected number of the consultation questions. Our response is based largely on our (longer) response to the Scottish Government's draft energy strategy, available from the UKERC website. We would be happy to follow-up our response either in writing or in meetings with the RSE Energy Inquiry Committee members.

***Energy Landscape Q.1*** *What are the most significant challenges to, and influences on, the energy landscape that any future energy strategy needs to take into account?*

The 'energy landscape' includes a host of interacting technological, economic, institutional, political and behavioural issues. Influences on energy system development are generally characterised by the 'trilemma': reconciling decarbonisation, security and affordability, though industrial strategy, wider economic impacts and broad societal change are increasingly being recognised. The overall energy challenge is to manage a long term transition to a low carbon energy system under uncertainty. Policy making should be informed by robust evidence, leading to the identification of strategic priorities. However key uncertainties, such as those around the pace of innovation, cost reductions, changes in behaviour and the time taken for key infrastructure elements to be developed, lead to a need for decisions to be made at critical junctures, the identification of 'low regrets' interventions, and also 'keeping options open' by trialling and demonstrating a variety of potential solutions.

The Scottish Government's draft Energy Strategy (Scottish Government, 2017a) has a high-level commitment to a 'whole systems' approach and a 'managed transition' to a low carbon future. These are welcome aspirations, and resonate with UKERC's own view of energy research and policy advice. We endorse the Scottish Government's efforts to develop an integrated and comprehensive understanding of energy system change, alongside the wider role of energy and climate change policy. Without this, policy and regulation are at greater risk of unintended and undesirable impacts, such as poor connectivity between aims and outcomes, or the failure to strike an appropriate balance between consistency and stability, and responsiveness and flexibility.

We encourage the final version of the Energy Strategy to include a structured exploration of uncertainties to 'stress test' Scottish energy policy goals under different assumptions. This could include: sensitivities to assumed availabilities and costs of low carbon technologies (such as with or without CCS); levels of demand reduction and energy efficiency; lifestyle and behavioural changes; and fuel costs and availabilities. Such analysis has been carried out by the UK Committee on Climate Change (CCC) and UKERC among others (e.g. CCC, 2015; Watson et al., 2014), and while the analysis is strongly shaped by assumptions and problem framing, it allows for a systematic consideration of where effort might be best directed, how risks to delivery of objectives could be managed, and the timing of key decision points, according to agreed and transparent understandings of the future.

***Supply and Demand Q.2*** *What will energy demand in Scotland look like in 2030, 2040, and 2050?*

We welcome the prominence given to future demand within a whole systems setting. Consideration of demand-side aspects has often been secondary in energy policy discussions, and should be at the heart of a whole systems view of Scotland's energy transition. They also represent an area where the Scottish Government has key policy powers. However, demand projections are uncertain, and energy system planning requires an understanding of the plausible range of future demand. Chapter 4 of the Scottish Government's draft Energy Strategy notes the significant reduction in Scottish energy demand over the past decade, with total final demand 15% lower in 2014 than 2006. There has also been a significant reduction in heat demand (of around one-third) over the past decade, achieved through energy conservation, improved efficiency (for example in building insulation), technology changes and price effects. Recent research by UKERC notes similar UK wide trends, and notes the considerable potential for further public policy interventions to unlock future energy efficiency potential (UKERC/ CIED, 2017).

The draft Energy Strategy fails to provide a whole systems analysis of the means, and impacts, of achieving demand reduction and efficiency improvements, such as reduced investment in network infrastructure due to expansion and reinforcement. The draft Climate Change Plan (Scottish Government, 2017b) also lacks analytical detail on the contribution

of demand and efficiency to system change. One key consideration relates to assumed change in the demand for a particular energy service and associated impacts on the wider economy. There are also key policy trade-offs that are not clearly articulated in the draft Strategy. For example, though the draft Strategy assumes significant improvements in the energy efficiency of travel – mostly through accelerated electric vehicle adoption – it has assumed that the total kms travelled per passenger will increase so that in the transport sector as a whole, modelled reductions in total energy demand are only modest (around 25% between 2017 and 2030). In its analysis, the CCC suggested that Scottish transport sector emissions could fall by over 50% by 2030 against a business as usual scenario, through measures such as conventional vehicle efficiency, adoption of ultra-low emission vehicles (ULEVs), reducing demand for car travel and improving the efficiency of freight operations. This suggests the need for greater consideration of more established technologies in the short term, and also demand-reducing and behavioural change measures (such as those identified in the Scottish Energy Taskforce Report, 2017).

Demand reduction and efficiency have the potential to offer important benefits for consumers and the economy as a whole, which could enhance the public acceptability of energy and climate policy. Recent CCC analysis found that average household energy bills fell by £115 between 2008 and 2016, and that additional efficiency measures could provide a 15% reduction in energy used for heating existing UK buildings by 2030 (CCC, 2016a). A recent analysis by UKERC and the Centre for Innovation and Energy Demand, using standard HM Treasury methodology, showed that a 25% further improvement in energy efficiency in UK households is economically viable, and would have benefits of £7.5bn to 2030 (UKERC/CIED, 2017).

The means of delivery of demand reduction and efficiency are key. Scotland's Energy Efficiency Programme (SEEP) is described in the draft Energy Strategy as a cornerstone of the Scottish Government's Whole System approach to energy policy. The overall aims of SEEP, and the principle of a phased approach that enables supply chains to react effectively, are welcome, with an initial pilot phase before full deployment after 2022. We also broadly welcome the designation of energy efficiency as a national infrastructure priority. However, this is only meaningful if backed up by detailed policies and measures to improve energy efficiency. These include long term signals for building energy efficiency standards – such as a target energy performance certificate rating for new and existing buildings by 2025 or 2030. It also includes appropriate use of regulatory powers such as those being considered by Scottish Government through the Local Heat and Energy Efficiency Strategy (LHEES) consultation, for example, on the regulation of district heating.

SEEP is also concerned with low carbon heat supply and we would welcome greater clarity on the relative emphasis over time within SEEP (and LHEES), on demand reduction and energy efficiency versus low carbon supply. For heat, in particular, the 'right' solution in respect of cost, deliverability and social acceptance depends on local conditions, and the draft Strategy, has correctly identified the need for local authorities and regional partnerships to play an important role. However, capacity to develop and implement area-wide plans, such as significant enhancement to electricity networks or development of hydrogen infrastructure, depends on national resources and expertise, and a clear understanding of how different local or regional plans fit within national strategies. Pilot projects, and their systematic evaluation, are critical to effective national and local policy development here.

The carbon envelopes for both industry and transport as set out in the draft CC Plan show relatively modest reductions to 2032. (Though we note that, more recently, the Scottish Government's Programme for Government 2017-18 includes a significant raising of ambitions for the transport sector, with the proposed phasing out petrol and diesel cars by 2032 (Scottish Government, 2017c)). The CC Plan also involves demonstrating key technologies, such as CCS and hydrogen injection by 2030, acknowledging that this will rely on UK support and international innovation, underpinned by both private and public sector investment. In its advice to the Scottish Government, the CCC (CCC, 2016b) recognised the challenges presented by industry sector abatement, suggesting that up to 2032, a combination of energy efficiency product and process improvements and a switch from direct combustion to the use of biogas and biomass, would be a more significant source of emission reductions than the use of CCS, although CCS becomes important after 2030.

***The Energy Mix Q.5*** *What overall role should be played by various elements of the energy landscape, for example: Different sources of renewable energy; Offshore oil and gas; Unconventional oil and gas; Nuclear power; Energy storage; Others*

In our response to the Scottish Government's draft energy strategy consultation, we noted that addressing supply and demand separately risked them being discussed independently of each other, despite their increasing integration. For example, for low carbon heat – a priority concern in Scottish energy policy – integrated analysis is critical, as reducing heat demand through policy measures or otherwise, carries significant implications for the type and level of investment in low carbon heat supply (MacLean et al., 2016).

As part of its efforts to better integrate policy, Scottish Government commissioned a whole system energy model: 'Scottish TIMES'. By incorporating energy service demands, energy conversion and transfer costs, and constraints defined by the

user, Scottish TIMES develops 'optimal' (i.e. least total system cost) future energy paths for the Scottish territorial boundary, with flows in and out of the Scottish system seen as imports and exports. In practice, energy supply and use in Scotland is highly integrated within a GB system. For example, the decarbonisation of power generation in Scotland has been achieved within the operation and development of the GB power system, with revenue support from bills paid by consumers across GB and the techno-economic balancing of supply and demand on a GB basis. Down-playing the mutual support that can be provided by different regions across the UK and Europe risks imposing additional costs on energy users in any one region.

These cross-scale challenges also apply at smaller scales, for cities and regions. There is a continued need to develop models at different yet complementary scales, with each providing details at particular scales while also offering consistency across scales. A research priority is to better link Scottish TIMES and the UK TIMES model, as part of a broader effort to improve multi-scale modelling, while also incorporating regional and municipal scales. UKERC is among the supporters of initiatives aimed at the latter. It is also important that the limitations of optimisation models such as TIMES are well understood not just within Government but by the wider set of stakeholders. For example, TIMES-like models provide little insight into how investment decisions against a background of an uncertain future would actually be made within any given commercial environment. It is therefore important that other forms of evidence are also used to inform policy development and implementation.

Chapter 3 of the draft Scottish Energy Strategy identifies five supply and infrastructure-related priorities: continued support of oil and gas; demonstration of CCS; exploring new energy sources based on hydrocarbons; increasing renewables generation; and flexibility and resilience. The emphasis on continued support of oil and gas is understandable given the historic and on-going importance of the sector to the Scottish economy. However, this role has already declined significantly and the overall trend is for further reductions. The Energy Strategy also fails to acknowledge that significant proportions of global fossil fuel reserves will need to remain in the ground, even if CCS technologies are successfully commercialised on a large scale (McGlade and Ekins, 2015). More attention is also needed on the decommissioning and repurposing of Scottish oil and gas facilities, with expertise developed to anticipate and address the negative consequences of decline for affected communities.

It is widely recognised that renewables have made significant contributions towards the decarbonisation of Britain's electricity supply. In respect of simple levelised cost of energy (LCOE), significant reductions have been seen in the recent CfD auction for offshore wind. One may speculate about what that means for the cost of onshore wind. Given the challenges of offshore construction, operation and maintenance, onshore wind is likely to remain the cheapest source of renewable electricity; it therefore seems perverse for it to be excluded from UK CfDs. Any least cost pathway for Scottish and UK energy system change should include the option of further onshore wind deployment, and we welcome the Scottish Government's consideration of 'subsidy-free' ways of supporting such deployment. The Scottish Government proposes to supply the equivalent of 50% of all of Scotland's energy consumption from renewable sources by 2030. Supply of electricity from renewables in Scotland already exceeds demand in Scotland for many hours of a typical year; utilisation of supply therefore depends on adequate transmission export capability through Scotland and southwards through England to the main demand centres. Independent assessment of energy portfolios for Scotland consistent with the 50% renewables target in terms of their economic, technical and societal credentials are important to inform strategy and help to build confidence, and we therefore welcome the Scottish Government's intention to offer wider access to Scottish Government modelling and analysis.

Power from wind and solar is inherently variable and uncertain. However, options including demand side response, flexible generation, and interconnection and storage, now exist to mitigate impacts and balance the increasingly complex electricity systems. UKERC's recent evidence review on the costs and impacts of intermittency (UKERC, 2017) concluded that the costs of integrating intermittent renewables remain modest up to a 30% share across the UK. Furthermore, the more flexible the UK electricity system is, the lower the cost of integration will be.

The location of schedulable sources of power will be especially important for Scotland in the coming years in order to enhance resilience. One particular recommendation is that the location of such sources of power is taken into account in the capacity market. Scotland has particular geographical features that may dictate particular solutions to system problems. This is especially the case for remote rural areas with low demand and weak connections to the main electricity system, but high dependency on electricity. In such circumstances, the value of battery energy storage relative to alternative means of enhancing service resilience can be significant. Lessons from recent battery demonstration projects in the Orkney and Shetland isles are likely to be useful in this respect, though it should be noted that in spite of recent reductions in cost batteries may not yet be the panacea that some assume.

There is a need to carefully consider the different ways that hydrogen can be most appropriately used in the Scottish and UK energy system, across different parts of the system (heating, transport, electricity and industry) over different timescales. including more incremental and shorter term opportunities such as power-to-gas and fuel blending using existing transmission and distribution pipeline infrastructure, as well as more radical and longer term transformations such as 100% hydrogen replacement of natural gas based on steam methane reformation (and perhaps ultimately electrolysis) that may require at least some transmission infrastructure replacement. Recent research (Staffell et al., 2017) suggests that the role of hydrogen in 2050 could vary from a small number of niche markets, such as those for HGVs and buses, to supplying most transport and heat demands. In the absence of dedicated scenario and pathway modelling, it is not clear whether these conclusions apply equally to Scotland, but there are significant GB-wide scale economies to infrastructure commitments and repurposing.

The evidence base for low carbon heating is developing, but much of this is based on desk-based assessments and modelling studies and, as the Scottish Government identifies, there is a need for demonstration projects to consider the hydrogen option in greater detail. Some trial and demonstration projects are in development, but it will be some time before the evidence base is sufficiently enriched. As with other vectors, the future of hydrogen will be best assessed within a whole systems framing, where different options for affordable and secure low carbon energy supply and use can be judged against each other, based on the best available evidence. The draft Energy Strategy rightly describes the next 5-10 years as a crucial preparation time for hydrogen (and other options), with a need to develop a hydrogen 'roadmap'. We would also welcome a Scottish low carbon heat roadmap, including all emerging options.

**Climate Change and Renewable Energy Q.*7*** *What are the factors and risks which may impact upon the Scottish Government meeting the targets it has proposed on sustainable and renewable energy?*

The draft Scottish Climate Change Plan and Energy Strategy suggest a significant divergence may be opening up between UK and Scottish policy in terms of the pace and direction of change. Scottish plans in key areas such as energy efficiency and buildings refurbishment, low carbon heat supply, and the deployment of carbon capture and storage, now appear to run several years ahead of UK Government timescales, and also ahead of the CCC's 5th carbon budget recommendations (CCC, 2015). This reflects the high Scottish ambition in energy and climate policy, but also the concentration of effort in particular sectors of the Scottish economy, particularly power generation and buildings' heating. Such a concentrated approach to system change inevitably carries concentrated risks. A more prudent approach would be to devise a pathway with a balanced spread of effort across the economy, with more emphasis on sectors such as transport, land use and industry, than seen in the draft Climate Change Plan. Analysis and advice by the CCC on meeting Scottish emission targets to 2032 (CCC, 2016b) featured a more evenly distributed pattern of emission reductions across the Scottish economy, with greater emphasis on demand reduction (and less disruptive technological change) than envisaged in the Climate Change Plan pathway; the CCC recently recommended the final version of the CC Plan offers a more balanced distribution of effort across the Scottish economy (CCC, 2017).

In the electricity sector, the CC Plan suggests the arrival of 'negative emissions' for the Scottish power system by 2027, based largely on onshore and offshore wind power, but also seemingly in-part on negative emissions technologies such as bioenergy with carbon capture and storage (BECCS). CCS, although still credibly seen as a key part of the least cost path to decarbonisation, has suffered from successive false starts in the UK and other countries over the past decade, and BECCS has yet to be deployed at scale anywhere globally (Smith et al., 2016).

Regarding building heating, the CCC's 5$^{th}$ Carbon Budget suggested that only around 1 in 7 UK homes, and half of UK non-domestic buildings will be supplied by low carbon heating in the early 2030s, with strategic decisions on low carbon heat supply deferred until the early 2020s (CCC, 2015; CCC, 2016a). By contrast, the draft CC Plan pathway has 80% of Scottish domestic buildings, and 94% of non-domestic buildings being supplied by low carbon heating by 2032, with this transition compressed wholly into the period 2025-2032. This implies a near-wholesale and disruptive intervention in the heat supply of Scottish buildings. There is therefore the risk that the assumed levels of carbon savings will lack credibility and, as a consequence, fail to build the confidence among investors necessary for their achievement (CCC, 2017; Scottish Parliament, 2017a; 2017b).

***Ethics, Social Issues and Impact on Communities Q.11*** *What are the particular advantages enjoyed, and challenges faced, regarding energy; and what lessons can be learned on a national scale from community energy schemes undertaken by:* ***a)*** *Rural and remote communities b****)*** *Urban Communities*

Local energy is the third pillar of the Scottish Government's energy strategy. Local, distributed energy is attracting international interest, reflecting the rapid cost reduction globally of smaller scale power generation and storage, the impact of IT on energy network management, and a political trend in some areas toward regionalisation and devolution. There are significant potential opportunities and benefits from localisation and decentralisation: greater community

empowerment; local growth opportunities; reduced dependency on regulated utilities; and the clearer articulation of the interaction between supply and demand, and the benefits of demand side flexibility.

However, there are also some concerns: a UK Parliamentary select committee recently argued that there are risks of inconsistency and piecemeal development in contrast to the energy sector's established commitments to universal service and – to some degree – socialisation of costs and benefits across national populations (BEIS Committee, 2017). 'Local' or 'decentralised' does not necessarily mean cheapest, either for the individuals involved in a local scheme or for society as a whole. In some circumstances, economies of scale and the low costs of existing, almost fully depreciated networks and an expectation of a high reliability with minimal impact on consumers' behaviour mean that 'local' or 'community' energy has limited value. In a similar way to district heating schemes, local or community energy schemes tend to require a minimum level of commitment from consumers, both in terms of numbers and duration, placing limits on consumer choice that may be unacceptable to some.

While there is encouraging evidence emerging in terms of the potential for 'smart' network operation to assist localisation and decentralisation, the evidence is still tentative, often based on modelling simulations and small local trials rather than larger-scale demonstration and deployment. There is also a need for financial appraisal methods to be further developed so that the wider costs and benefits of local energy projects can be captured. Financial appraisal methods for government supported finance (capital grants, Scottish Investment Bank) or those supporting access to finance (e.g. Scottish Futures Trust) should take clear account of multiple and long-term outcomes. A clear distinction should be made between use of grants or low cost loans to aid financing, and those that compensate for a negative net present value. The latter should only be used as part of a coherent energy strategy that clearly states the benefits of cross-subsidy, or to accelerate innovations towards commercial viability, which implies that similar energy system investments in future should be self-supporting. Ideally, local energy systems potential should also be assessed through multiscale modelling and evidence synthesis, to complement the Strategy's focus on particular cases or examples. However, multiscale analytical methods and tools are still emerging.

***Informed Debate Q.13*** *How can we best encourage objective, evidence-informed debate around energy while also acknowledging the differing perspectives and priorities held by businesses, civil society and government?*

There is a need for continuous engagement between Scottish Government and the public, private and third sectors as the Energy Strategy is implemented. The Scottish Government has offered some welcome proposals for reform of existing advisory structures. The draft Energy Strategy proposes that Scotland's advisory bodies be refocussed around new strategic priorities, with a support network of industry and consumer-led advisory groups, and an increasing role for Local Authorities, enterprise and skills agencies, and supply chains. The draft Climate Change Plan included detailed proposals and measures for policy monitoring and evaluation, and the establishment of a new governance body to provide advice to Government.

Our view is that these structures should also include space for independent organisations to carry out research analysis and assemble evidence. This will help to ensure that decisions are evidence-based, whilst recognising that these decisions will also be influenced by political priorities and pragmatic trade-offs. The energy strategy is being formed in a highly dynamic and contested period for energy futures. In addition to sectoral and technology-specific expertise, there is an important role for independent, interdisciplinary and holistic expertise able to synthesise the emerging evidence base. Scotland's interdisciplinary energy research base has tended to be fragmented and patchy and there are important roles for interdisciplinary networks and centres such as UKERC, ClimateXChange and the Energy Technology Partnership to play in co-ordination and building capacity within the community as it develops in response to policy and stakeholder needs. Any new advisory body should operate relatively independently from Government; one option is to strengthen and formalise the relationship between the UK CCC and Scottish Government.

An independent analytical body could differentiate between areas where supporting evidence is relatively robust and consistent (such as the increasing affordability of large-scale offshore wind, and opportunities for energy efficiency improvements in some sectors), and areas where there is still considerable uncertainty and variability in the evidence base (such as low carbon heating supply technologies and the benefits and costs of local energy systems). Simple presentation of evidence consensus and confidence are already used by public bodies such as the ONS and DEFRA. It is also important that distinctions are made between areas of policy for which the Scottish Government has responsibility, and those where the UK government (or, for the time being, the EU) plays a leading role.

We welcome the proposal for the Scottish Government to broaden its engagement with civil society on the transition to a sustainable energy future. We note, however, that the proposed 'approach to deepening public engagement' set out in chapter 6 is very brief, located at the end of the consultation document. There is increasing awareness and evidence that achieving low carbon energy transitions in a fair and effective way depends on the meaningful engagement of wider society

(Chilvers and Pidgeon, 2016). This suggests that a more comprehensive approach to public and stakeholder engagement is required, one that is properly integrated into all aspects of the Scottish Government's energy strategy.

***Meeting the Challenge Q.15*** *What issues arise regarding innovation for Scotland's energy future; how might this interact with an industrial strategy for Scotland?*

The energy system is ultimately needed to provide affordable, secure and environmentally sustainable services to society. Innovation and industrial strategy therefore need to be considered within this 'whole systems' approach. Some technology-specific support is essential; technology-neutral policies only bring forward technologies that are closest to market, and fail to develop those which are currently less competitive but which may be required for deeper decarbonisation, or which may have the greatest long-term potential. There is a wealth of evidence noting the importance of design variety and technology-specific support in early stage energy innovation, with a move toward technology-neutral support for more mature technologies (Gross et al., 2012).

It makes sense for government – in whichever jurisdiction – to directly support the initial demonstration of potentially key long term technologies and systems such as BECCS and hydrogen. Given the strong role of regulation and the investor perceptions of regulated network companies as being low risk (thus giving low cost of capital), policy support has a particularly important role in network infrastructure innovation. There is a need to anticipate the potential loss of significant R&D and technology investment funding when the UK leaves the EU, including that from the European Investment Bank, European Structural and Investment Funds, and to consider the size of the taxpayer base across which the cost of large demonstration projects can be spread, and where any ensuing industrial opportunities might arise. Recent UKERC research argued that replacing EU sources of finance should be a priority within the Brexit negotiations (Froggatt et al., 2017)

In UKERC's response to the UK Government's Industrial Strategy Green Paper (Bell et al., 2017a), we stressed the importance of an evidence-based approach to priority-setting. We identified a number of criteria that should inform policy priorities: the potential Scottish, UK and global market for different low carbon technologies; the potential for cost reductions (including the effect of policy on such cost reductions); the potential value to the domestic components of supply chains (and also the need for investment to develop them, including in respect of skills); and the extent of existing scientific and industrial capabilities. For an integrated energy strategy, policy support should also be judged against the likely future contribution to national energy systems.

**References**


BEIS Committee (2017) Industrial Strategy: First Review, House of Commons Business, Energy and Industrial Strategy Committee, London.

Bell, K., J. Barrett, P. Ekins, N. Eyre, R. Gross, J. Watson and L. Wright (2017a) 'Building our Industrial Strategy: Response to the Green Paper from the UK Energy Research Centre'

CCC (2015) The Fifth Carbon Budget: The next step towards a low-carbon economy, Committee on Climate Change, London

CCC (2016a) Next steps for UK Heat Policy, Committee on Climate Change, London.

CCC (2016b) Scottish Emissions Targets 2028-2032: The High Ambition Pathway Towards a Low Carbon Economy, Committee on Climate Change, London.

CCC (2017) Reducing emissions in Scotland: 2017 Progress Report, Committee on Climate Change, London.

Chilvers, J. and Pidgeon, N. (2016) 'A social energy transition' in Review of UK Energy Policy: A UKERC Policy Briefing. London: UKERC.

Froggatt, A., G. Wright and M. Lockwood (2017) 'Staying Connected: Key Elements for UK–EU27 Energy Cooperation After Brexit', University of Exeter and UK Energy Research Centre, London.

Gross R., Stern, J., Charles, C., Nicholls, J., Candelise, C., Heptonstall, P., Greenacre P. (2012) 'On picking winners: The need for targeted support for renewable energy' ICEPT, Imperial College, London.

MacLean, K., Sansom R., Watson, T. and Gross R (2016) 'Managing Heat System Decarbonisation Comparing the impacts transitions in heat infrastructure', Imperial College Centre for Energy Policy and Technology (ICEPT), London,

McGlade, C. and Ekins, P. (2015) 'The geographical distribution of fossil fuels unused when limiting global warming to 2 °C' *Nature* 517: 187–190. doi:10.1038/nature14016

Scotland's Future Energy Taskforce (2017), Vision for Scotland's 2030 Energy System, WWF Scotland, Edinburgh.

Scottish Government (2017a) Draft Scottish Energy Strategy: The Future of Energy in Scotland, Scottish Government, Edinburgh

Scottish Government (2017b) Draft Climate Change Plan: the draft Third Report on Policies and Proposals 2017-2032, Scottish Government, Edinburgh

Scottish Government (2017c) A Nation with Ambition: The Government's programme for Scotland 2017-18, Scottish Government, Edinburgh.

Scottish Parliament (2017a) Economy, Jobs and Fair Work Committee, Report on the Draft Climate Change Plan, Scottish Parliament, Edinburgh.

Scottish Parliament (2017b) Economy, Jobs and Fair Work Committee, Draft Energy Strategy: EJFW Committee response.

Smith, P. et al. (2016) 'Biophysical and economic limits to negative CO2 emissions', Nature Climate Change 6, 42–50, doi:10.1038/nclimate2870.

Staffell I., P. Dodds, D. Scamman, et al., 'The Role of Hydrogen and Fuel Cells in Future Energy Systems' Available from: http://www.h2fcsupergen.com/download-role-hydrogen-fuel-cells-future-energy-systems/

UKERC (2017) 'The costs and impacts of intermittency - 2016 update: A systematic review of the evidence on the costs and impacts of intermittent electricity generation technologies' UKERC, London

UKERC / CIED (2017) Unlocking Britain's First Fuel: The potential for energy savings in UK housing, UK Energy Research Centre, London.

Watson. J., R. Gross, I. Ketsopoulou and M. Winskel (2014) UK Energy Strategies Under Uncertainty: Synthesis Report, London, UK Energy Research Centre