Executive summary

A major transformation is underway to decarbonise UK energy generation and use in order to cut greenhouse gas emissions by 80% by 2050. Numerous potential pathways for achieving the 2050 emissions target demand significant new energy infrastructure in various forms, as well as substantial increases in energy efficiency across the economy.

The Sustainable Pathways to Low Carbon Energy (SPLiCE) research programme seeks to provide significant information about the wide-ranging potential environmental, social and economic impacts of decarbonising the UK energy system. Information needs to be presented in a way that enables informed choices to be made about different configurations of the energy system framed within a wider context. The intention is that the programme would seek to identify what is known and not known about the impacts of different energy system components and then fill any key evidence gaps, either directly or by encouraging others to do so. The full SPLiCE Programme was planned to be delivered in two or three phases. The key research questions for the whole programme are:

- How can Government compare all the significant impacts of the energy decarbonisation options available, so that evidence-based choices can be made about the best mix of options to pursue?
- How can developers, planners and regulators access comprehensive and authoritative information about the impacts of energy infrastructure and other energy choices in order to make decisions about investment, deployment and impact mitigation?
- How can Government, industry and the research community present reliable, easy to understand information on impacts in order to improve public understanding and help engage the public and other interest groups to debate and build consensus around future energy options?

Phase 1 was a scoping study to examine how these aims could be met and create a blueprint for possible future phases. The objectives for SPLiCE Phase 1 were couched in terms of six outputs to develop an understanding of the sustainability (environmental, social and economic) of energy supply and demand options. These are summarised as:

1. A report on the significant evidence gaps on the impacts of energy supply and demand options
2. A detailed written method for carrying out systematic evidence reviews on the environmental, social and economic impacts of energy supply and demand options
3. A design specification and a set of data requirements for a knowledge gateway/repository (KG) which would contain the sort of impact analysis developed in output 2 above
4. Recommendations on whether the very different impacts (environmental, social and economic) of a very diverse range of energy supply and demand options could be assessed and valued
5. Recommendations for how information about the impacts, risks and benefits of future energy options can be made more easily available and accessible to the public in order to inform debate about choices and trade-offs
6. A recommended process/roadmap/project plan for future work

Outputs 1, 2, 3 and 4 have been delivered. In a programme review, it was decided not to continue with work towards Output 5. This, in part reflects significant work in this area in other Government programmes. In May 2015, it was decided not to proceed to a formal Phase 2 of SPLiCE. That being the case, Output 6 was not required.

A prioritised list of evidence gaps was developed through a structured approach involving: an initial selection of energy system components for more detailed review through an online questionnaire; a meta-review of impacts of energy system components, complemented by interviews with experts; and prioritisation of the research gaps.

The highest priority impact areas and research gaps in existing literature reviews span a wide range of energy system components. It is difficult to draw any strong generalisation from this very diverse list although this diversity actually testifies that the methodology discussed in this report has been able to tackle a very wide range of impacts applying throughout the set of energy system components selected for further analysis. Gaps related to Carbon Capture and Storage, Nuclear Power, Land for Bioenergy, Electric Vehicles and Demand-Side Response are very prominent. Taken together these five energy system components comprise about 80% of the top 20 priority groups (where a group is a...
combination of an energy system component, such as Carbon Capture and Storage, and an impact area, such as impacts on human health, where there is an evidence gap. This evidence assessment methodology references Civil Service Guidance on Rapid Evidence Assessments (REAs)\(^1\). Natural England’s guidance on evidence reviews\(^2\), the UK Energy Research Centre (UKERC) Technology and Policy Assessment (TPA) mission statement and framework\(^3\) and a “How to guide” on “The production of Quick Scoping Reviews and Rapid Evidence Assessments” by the Joint Water Evidence Group (JWEG)\(^4\). It builds upon the author’s practical experience of undertaking REAs for government bodies and draws upon input and comments from a range of academic and policy stakeholders with experience of developing or referring to such reviews.

The assessment method started from the JWEG guidance, building on key steps in that approach. It identifies more detailed, additional or alternative practical methods for implementing each step that streamline or make more explicit what needs to be done. The method also makes use of, builds upon, adapts or provides alternatives to JWEG’s checklists and means of recording outputs associated with each step, as appropriate and pays heed to complementary elements of Natural England’s guidance and UKERC’s TPA.

The methodology was trialled on two case studies and subsequently revised to ensure greater clarity. The first case study examined the impacts (environmental, social and economic) of a single energy technology – small-scale district heating using biomass feedstocks. The second case study evaluated the cumulative environmental, social and economic impacts of a mix of energy supply and demand options in one region – the North Devon biosphere reserve.

For each case study, a plain English report card was produced.

The Knowledge Gateway (KG) design and data specifications were developed to contain the sort of impact analysis provided by the Rapid Evidence Assessment method mentioned above. In developing the KG’s specification, an initial review phase was undertaken to identify and prioritise the KG’s user needs; the "who, where and how" the KG’s users will want to interact with knowledge held in the platform. Three groups of users were considered as required in the specification for the work:

- Group 1 – central government policy officials
- Group 2 – local government, enforcement bodies and developers
- Group 3 – Non governmental organisations (NGOs) and the general public.

Priority has been given to the needs of Group 1 – central government policy officials though engagement has included all three groups.

There are 10 outputs defined by the standard REA methodology and requirements for each of these have been developed. To aid data collection, web forms could be used to collect the data and store directly in a database. However it is also possible to create a series of word/excel templates to be completed offline and uploaded to the KG. This template option would provide a lower cost of initial development build, but also provide the least options in terms of online search, comparison and automated quality control and therefore require much more manual intervention to manage the process. Indicative costs to build the Gateway were estimated as of the order of £100k for the primary option and of the order of £70k for the lower cost option, with annual ongoing costs estimated as £10k to £20k.

The impacts (environmental, social and economic) of the diverse components of energy pathways are very different. The activity on impact comparison and evaluation examined how these impacts might be assessed and compared, considering in particular the use of Ecosystem Services (ES) frameworks, where and how monetary valuation is appropriate in impact assessment, and the strengths, limitations and potential linkages of different methodologies. It aimed to propose an approach that can provide support for policy decisions about the choices among the diverse range of energy supply and demand options.

Expressing the impacts of energy developments in a common metric would facilitate the comparison of different policy options. Where this common metric is monetary value, the implications for natural resources can be considered at the same level as other economic costs and benefits. We identified

\(^1\) http://www.civilservice.gov.uk/networks/jer/resources-and-guidance/rapid-evidence-assessment/


\(^3\) http://www.ukerc.ac.uk/support/tiki/index.php?page=TPAFramework

the availability of existing values that may be amenable to benefits transfer, and considered how such valuations fit within the Natural Capital Committee framework. However, using monetary valuation is not straight-forward and we explored the issues related to this.

The purpose of the impact evaluation and comparison framework was to suggest a pathway and methods for evaluating environmental, social and economic impacts that have been reported using a range of different means of comparison.

The proposed assessment process has three key elements:

1. the process utilises the Natural Capital Committee approach as an overarching framework to identify the natural capital and ecosystem services information that should be considered;
2. macro-economic, social impact, health impact assessment methods can be used alongside to generate additional relevant data;
3. multi-criteria assessment (MCA) methods should be used to evaluate the resulting environmental, social and economic information.

The Better Regulation Framework Manual (BIS, 2013) and the Green Book (HM Treasury, 2013) note the potential use of MCA in evaluating non-monetary impacts, and supporting guidance is available (DCLG, 2009). Increased use of this approach would be welcome.

This project demonstrated the goodwill of the energy community to be involved with Defra and to try and help with evidence gathering and priority setting (e.g. many experts giving their time unpaid to contribute to the questionnaire on energy system components, and participating in interviews and workshops).

When considering future work, there are strong linkages between the different areas of work in SPLiCE Phase 1. For example work on rapid evidence assessments (REAs) can help to identify and clarify areas where there are significant evidence gaps and these can inform decisions of research funding organisations. There is also necessarily a strong link between the REA method and the Knowledge Gateway where the function is to contain and display the outputs from the REAs. In addition there are links between the evidence assessment and impact comparison – so coordinating processes are valuable to ensure that evidence is assessed that is needed to support decisions, and also for comparing the diverse impacts that the evidence describes. And finally, the assessed evidence and the impact comparison can inform the development of stimulus material to assist public understanding and help the public to engage in debate on energy system options.

The work of SPLiCE Phase 1 can potentially inform a range of activities in the area of assessing the environmental, social and economic impacts of energy system components to inform policy.
# Table of contents

1 **Introduction** ........................................................................................................................................ 1
   1.1 Objectives ..................................................................................................................................... 1
   1.2 Extent to which the objectives and planned outcomes have been met .............................................. 2

2 **Approaches used** .................................................................................................................................. 3
   2.1 Knowledge gap priorities ................................................................................................................. 3
   2.2 Assessment method and case studies ............................................................................................... 4
   2.3 Knowledge Gateway design and data specification ......................................................................... 4
   2.4 Impact evaluation and comparison framework ............................................................................... 5
   2.5 Engagement framework ................................................................................................................... 5
   2.6 Stakeholder workshops .................................................................................................................... 6
   2.7 Linkages across the project ............................................................................................................... 6

3 **Results obtained** .................................................................................................................................. 7
   3.1 Knowledge gap priorities ................................................................................................................. 7
   3.2 Assessment method and case studies ............................................................................................. 7
   3.3 Knowledge Gateway design and data specification ....................................................................... 11
   3.4 Impact evaluation and comparison framework ............................................................................. 13
   3.5 Engagement framework .................................................................................................................. 17

4 **Discussion** ......................................................................................................................................... 18
   4.1 Knowledge gap priorities ............................................................................................................... 18
   4.2 Assessment method and case studies ............................................................................................. 19
   4.3 Knowledge Gateway design and data specification .................................................................... 20
   4.4 Impact evaluation and comparison framework ............................................................................. 20
   4.5 Engagement framework .................................................................................................................. 21
   4.6 Across the project ............................................................................................................................. 22

5 **Possible future work** ....................................................................................................................... 23
   5.1 Knowledge gap priorities ............................................................................................................... 23
   5.2 Assessment method and case studies ............................................................................................. 23
   5.3 Knowledge Gateway design and data specification .................................................................... 23
   5.4 Impact evaluation and comparison framework ............................................................................. 23
   5.5 Engagement framework .................................................................................................................. 24
   5.6 Across the project ............................................................................................................................. 24

6 **References** ...................................................................................................................................... 26

**Appendices**

Appendix 1 References to project outputs and list of authors of contributing research
Appendix 2 Executive summary – Output on knowledge gap priorities
Appendix 3 Executive summary – Output on assessment method and case studies
Appendix 4 Executive summary – Output on Knowledge gateway design and data specification
Appendix 5 Executive summary – Output on impact evaluation and assessment framework
Appendix 6 Recommendations for informing public debate
Appendix 7 Complete list of energy system components and impact categories
Appendix 8 Exemplary Research Gaps for a Prioritised selection of Energy System Components and Impact Areas
1 Introduction

A major transformation is underway to decarbonise UK energy generation and use in order to cut greenhouse gas emissions by 80% by 2050. Numerous potential pathways for achieving the 2050 emissions target demand significant new energy infrastructure in various forms, as well as substantial increases in energy efficiency across the economy.

The Sustainable Pathways to Low Carbon Energy (SPLiCE) research programme seeks to provide significant information about the wide-ranging potential environmental, social and economic impacts of decarbonising the UK energy system. Information needs to be presented in a way that enables informed choices to be made about different configurations of the energy system framed within a wider context. The intention is that the programme would seek to identify what is known and not known about the impacts of different energy system components and then fill any key evidence gaps, either directly or by encouraging others to do so. The full SPLiCE Programme was planned to be delivered in two or three phases. The key research questions for the whole programme are:

- How can Government compare all the significant impacts of the energy decarbonisation options available, so that evidence-based choices can be made about the best mix of options to pursue?
- How can developers, planners and regulators access comprehensive and authoritative information about the impacts of energy infrastructure and other energy choices in order to make decisions about investment, deployment and impact mitigation?
- How can Government, industry and the research community present reliable, easy to understand information on impacts in order to improve public understanding and help engage the public and other interest groups to debate and build consensus around future energy options?

Phase 1 was a scoping study to examine how these aims could be met and create a blueprint for possible future phases.

1.1 Objectives

The objectives for SPLiCE Phase 1 were couched in terms of six outputs to develop an understanding of the sustainability (environmental, social and economic) of energy supply and demand options. These are summarised as:

1. A report on the significant evidence gaps on the impacts of energy supply and demand options, a recommended priority order for filling those gaps and ideas for how the gaps could be filled by the research community during phase 2 of SPLiCE and beyond
2. A detailed written method for carrying out systematic evidence reviews on the environmental, social and economic impacts of energy supply and demand options, based on published literature (both peer-reviewed and grey). The feasibility of this analytical approach must then be demonstrated by producing two case studies, one about all the impacts of a single energy supply option, and the other about the cumulative impacts of a typical mix of energy supply and demand options on a habitat. Each case study should be presented as a report and a more accessible format such as a report card
3. A design specification and a set of data requirements for a knowledge gateway/repository (KG) which would contain the sort of impact analysis developed in output 2 above and which could be populated more fully during phase 2 of SPLiCE
4. Recommendations on whether the very different impacts (environmental, social and economic) of a very diverse range of energy supply and demand options could be assessed and valued
5. Recommendations for how information about the impacts, risks and benefits of future energy options can be made more easily available and accessible to the public in order to inform debate about choices and trade-offs
6. A recommended process/roadmap/project plan for developing the knowledge gateway and comparison framework/interface recommended in outputs 3 and 4 and for populating them
through further research and analysis as part of phase 2 of SPLiCE in order to meet the key research questions for the whole programme.

1.2 Extent to which the objectives and planned outcomes have been met

Outputs 1, 2, 3 and 4 have been delivered. References to outputs are in Appendix 1. Executive summaries of the reports are in Appendices 2-5.

In a programme review in December 2014, it was decided not to continue with work towards Output 5. This, in part reflects significant work in this area in other Government programmes. A statement is in Appendix 6. Part of the uncommitted funding for Output 5 was reallocated to Output 1.

In May 2015, it was decided not to proceed to a formal Phase 2 of SPLiCE. That being the case, Output 6 was not required.
2 Approaches used

2.1 Knowledge gap priorities

Within the resources available for this work, a focused approach was undertaken. This involved:
identifying a sub-set of about 15 energy system components for more detailed consideration through a
web survey, confirmation of the impact categories to be assessed; data collection and analysis based
on a review of reviews and expert interviews; and identification, evaluation and prioritisation of the
research gaps.

2.1.1 Identification and selection of energy system components

The DECC 2050 Pathways Calculator (https://www.gov.uk/2050-pathways-analysis) is the starting
point to select energy system components for inclusion in this study, as this would ensure broad
coverage of the energy system and a taxonomy most stakeholders are familiar with. A number of
items were added to the list of energy system components contained in the DECC 2050 calculator,
while others were merged into more general categories in order to obtain a list which was both concise
and comprehensive. The complete list of energy system components for this study is presented in
Appendix 7. In order to ensure a comprehensive and inclusive selection mechanism a web-based
survey was implemented with a wide coverage of interested stakeholders to select a limited number of
energy system components for further analysis. An online, self-completion questionnaire was set up
and kept open for about three weeks. Respondents were recruited through a number of established
mailing lists. Respondents to the survey were asked to score each energy system component in
Appendix 7 through a number of criteria, chosen to enable analysis of the potential importance and
significance of impacts of a given component in future decarbonised energy systems. This led to the
identification of 16 energy system components for further consideration.

2.1.2 Identification of impact categories

Based on experience of the project team (Ricardo-AEA 2014a, Ricardo-AEA 2014b and Rowe et al
2008), and detailed feedback from the SPLiCE Management Board we decided to assess impacts on
the marine environment, water, land, air, biodiversity and human health, as well as social and
economic impacts. In a number of instances sub-categories were agreed to make the task of
identifying research gaps manageable within the allocated resources. (See Table A7.2 in Appendix 7)

2.1.3 Data collection and analysis

Bearing in mind the number of impact categories and energy system components described above
and the resources allocated to the project, a meta-review was conducted of review documents
discussing impacts of the selected energy system components. In a number of instances however we
relied on original studies rather than review studies as our search confined to reviews did not return
any matches. For each identified document we assigned a Quality Assessment Score which is based
on the research question being asked, the search strategy implemented by the authors of the review,
the weighting of evidence employed by the authors and on the way results are summarised. After
assessing the quality of each review, we collected information related to the intensity of the impacts
and to the level of confidence in the assessment of the impacts for each energy system component
considered.

2.1.4 Identification, evaluation and prioritisation of research gaps

Research gaps were identified by using evidence collated from published reviews, i.e. explicit calls for
further research, identification of limitations in the analysis and discussion of impact features which
were not adequately understood. For each energy system component we aimed at prioritising
importance of impacts and related research gaps in literature by using the scores discussed above for
intensity of impacts and confidence in the assessment. (Table 1)
Table 1. Framework for prioritisation of impacts and related research gaps – highest priority in strongest coloured cells

<table>
<thead>
<tr>
<th>CONFIDENCE</th>
<th>INTENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Medium</td>
<td>High priority</td>
</tr>
<tr>
<td>Low</td>
<td>Low priority</td>
</tr>
</tbody>
</table>

As the procedure above is applicable only to impacts for which we were able to find evidence in the reviews, the judgement of the analyst was crucial to prioritise research gaps related to impacts for which we could not find any evidence. The analyst had to decide whether the lack of evidence was related to a very pressing research gap or an impact not being relevant for the energy system component under analysis. We mitigated risks related to this decision by carrying out interviews with experts.

This gave a prioritisation with an energy system component. Prioritisation across energy system components also considered: likelihood of the need, mainly assessed through work of Ekins et al (2013); urgency of the need, from the web survey; and criticality of the need, again from the web survey.

2.2 Assessment method and case studies

This methodology references Civil Service Guidance on Rapid Evidence Assessments (REAs)⁵, Natural England’s guidance on evidence reviews⁶, the UK Energy Research Centre (UKERC) Technology and Policy Assessment (TPA) mission statement and framework⁷ and a “How to guide” on “The production of Quick Scoping Reviews and Rapid Evidence Assessments” by the Joint Water Evidence Group (JWEG)⁸. It builds upon the author’s practical experience of undertaking REAs for government bodies and draws upon input and comments from a range of academic and policy stakeholders with experience of developing or referring to such reviews.

The methodology was trialled on two case studies and subsequently revised to ensure greater clarity. The first case study examined the impacts (environmental, social and economic) of a single energy technology – small-scale district heating using biomass feedstocks. The second case study evaluated the cumulative environmental, social and economic impacts of a mix of energy supply and demand options in one region – the North Devon biosphere reserve.

For each case study, a plain English report card was produced.

2.3 Knowledge Gateway design and data specification

The Knowledge Gateway (KG) design and data specifications were developed to contain the sort of impact analysis provided by the Rapid Evidence Assessment method in the section above. In developing the KG’s specification, an initial review phase was undertaken to identify and prioritise the KG’s user needs; the “who, where and how” the KG’s users will want to interact with knowledge held in the platform. Three groups of users were considered as required in the specification for the work:

- Group 1 – central government policy officials
- Group 2 – local government, enforcement bodies and developers
- Group 3 – Non governmental organisations (NGOs) and the general public.

⁶ http://www.ukerc.ac.uk/support/tiki-index.php?page=TPAFramework
Priority has been given to the needs of Group 1 – central government policy officials though engagement has included all three groups. Engagement activities are summarised in Table 2.

### Table 2: Engagement activities to identify user needs for the Knowledge Gateway

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
<th>Number engaged</th>
<th>Number for each Group#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workshop</td>
<td>October 2014</td>
<td>10</td>
<td>3/1/6</td>
</tr>
<tr>
<td>Questionnaire</td>
<td>October 2014</td>
<td>4</td>
<td>1/0/3</td>
</tr>
<tr>
<td>Workshop</td>
<td>February 2015</td>
<td>6</td>
<td>3/0/3</td>
</tr>
<tr>
<td>Interviews</td>
<td>March – April 2015</td>
<td>10</td>
<td>8/2/0</td>
</tr>
</tbody>
</table>

# The academic community was not identified as a User Group in the specification for SPLiCE Phase 1. Academic respondents are included in User Group 3.

#### 2.4 Impact evaluation and comparison framework

The impacts (environmental, social and economic) of the diverse components of energy pathways are very different. This activity examined how these impacts might be assessed and compared, considering in particular the use of Ecosystem Services (ES) frameworks, where and how monetary valuation is appropriate in impact assessment, and the strengths, limitations and potential linkages of different methodologies. It aimed to propose an approach that can provide support for policy decisions about the choices among the diverse range of energy supply and demand options.

Consideration was first given to the different ES frameworks and classification systems and how these could be utilised as an overarching framework within SPLiCE to consider environmental impact in a societally relevant way. The number of conceptual frameworks and classifications for ES continues to increase, and the review focussed on those that are most relevant at the level of UK energy policy. Nationally and internationally accepted frameworks (such as the Natural Capital Committee approach, the UK National Ecosystem Assessment and The Economics of Ecosystems and Biodiversity (TEEB)) were therefore considered, but the review also provided examples of the application of frameworks in an energy context, and described tools that have been developed to facilitate ES assessment. Gaps or limitations in the ES frameworks were highlighted and recommendations generated on how to best apply ES frameworks for the purposes of SPLiCE, considering in particular their compatibility with the Natural Capital Committee objectives.

There are a variety of approaches to assess the economic, health and social impacts of energy options, which were also reviewed. Again, this component of the review was not intended to be exhaustive, but discussed key approaches that are widely employed. The review also included methods that seek to address the known limitations of other approaches (for example, how deliberative valuation builds on more traditional cost benefit analysis, and how Input-Output models can be extended to include environmental accounts). ‘Social appraisal’ methods were also considered, as these can accommodate data of various types and take account of wider preferences and values.

Expressing the impacts of energy developments in a common metric would facilitate the comparison of different policy options. Where this common metric is monetary value, the implications for natural resources can be considered at the same level as other economic costs and benefits. We identified the availability of existing values that may be amenable to benefits transfer, and considered how such valuations fit within the Natural Capital Committee framework. However, using monetary valuation is not straight-forward and we explored the issues related to this.

#### 2.5 Engagement framework

The first activity towards consideration of an engagement framework with the public was a review of methods of engagement with the public and other interested groups on sustainable energy options. An initial draft was prepared as background to the discussion at the SPLiCE workshop in October 2014. Following discussion with Defra, it was agreed that this would cover a broad range of potential approaches and a draft was prepared in December 2014. After considering the draft it was decided not to complete it or to proceed with work on an engagement framework.
2.6 Stakeholder workshops

Two stakeholder workshops were held in October 2014 and February 2015 to raise awareness of work in SPLiCE and to consult stakeholders on different aspects of the project. The workshops attracted 50 and 49 registrants respectively.

Breakout sessions of 90 minutes were held to discuss and provide input to elements of the programme as in Table 3.

**Table 3 Breakout sessions at SPLiCE Phase 1 stakeholder workshops**

<table>
<thead>
<tr>
<th>Programme area</th>
<th>Number of 90 minute breakout sessions in October 2014</th>
<th>Number of breakout sessions in February 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge gap priorities</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Rapid evidence assessment</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Knowledge Gateway</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Impact evaluation and comparison framework</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Engagement framework</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

2.7 Linkages across the project

There are a number of links between the work activity areas of SPLiCE Phase 1. The strongest has necessarily been between the work on an assessment method and that on a Knowledge Gateway that could contain and present assessments of evidence.

A further area of linkage between activity areas is that, in the assessment method, the form of the summary matrix of the significance of impacts of an energy supply or demand option also takes into account the separate development of a framework that is intended to value and compare the very different impacts of energy and demand options.
3 Results obtained

3.1 Knowledge gap priorities

Priorities for knowledge gaps related to decarbonised energy systems have been compiled based on the method discussed in Section 2. For the sake of conciseness we present in Appendix 8 only the prioritisation of the first 31 groupings of impact areas. For each area we present up to two exemplary research gaps. Prioritisation of all areas for which we could find evidence in the literature is presented in a separate report which contains an exhaustive discussion of identified research gaps for each area. Interested readers are referred to the material in Section 4 and Appendix 5 of that report. In Appendix 8 of this report we point out whether research gaps should be filled through commissioning new research or by commissioning a preliminary quick scoping review or expert paper (the latter option identified by the wording “Review” in column 3) of Table A8.1. The latter choice is motivated by the fact that by looking at existing reviews it is possible that certain gaps were identified only because no existing reviews have been published. It is fair to say that these cases would have been likely to have been flagged up in the interviews we held with experts but as a safety measure it would seem prudent in those instances to embark on a quick scoping review before commissioning new research. This preliminary reviewing step would also deliver the additional benefit of being able to further focus the research gap in a way which could not be delivered as part of the resources allocated to the current project.

Impact areas and research gaps in existing literature reviews shown in Appendix 8 span a wide range of energy system components. It is naturally difficult to draw any strong generalisation from this very diverse list although this diversity actually testifies that the methodology discussed in this report has been able to tackle a very wide range of impacts applying throughout the set of energy system components selected for further analysis. Gaps related to Carbon Capture and Storage, Nuclear Power, Land for Bioenergy, Electric Vehicles and Demand-Side Response are very prominent due to the priority score they received in the literature review and interaction with experts, and the high perceived likelihood of this gap needing filling. Taken together these four energy system components take up about 50% of the top 20 priority groups. Research gaps related to unconventional gas have also received a high priority score although their more uncertain contribution to a future decarbonised energy system implies a comparatively lower ranking than the four energy system components mentioned above. Research gaps from the Power Network, Aviation, Offshore Wind and Buildings and Insulation do not feature strongly in the top 20 list mainly because they received a somewhat lower score from the literature assessment and interaction with the experts. In the case of Onshore Wind this lack of prominence is mainly due to its more uncertain contribution to a future decarbonised energy system, especially related to recent policy announcements. No gaps related to Electricity Storage and Heat pumps appear in the top 20 list due to receiving a comparatively low score from the literature review and interaction with experts. As Electricity Storage is mainly related to batteries, the overlap with electricity vehicle implies that research gaps related to electric batteries might however be taken forward as part of the electricity vehicle component. Finally, it is worth mentioning that two sets of gaps related to Energy Intensity of the Industry can be found in the 20 most pressing sets of priorities identified in this study. From the discussion above this assessment is however somewhat uncertain due to the paucity of review information we could identify in the literature.

3.2 Assessment method and case studies

The JWEG guidance is generic and already synthesises many relevant methodologies, so has been used as a starting point and the current methodology:

- Builds upon the key steps in JWEG’s approach
- Identifies more detailed, additional or alternative practical methods for implementing each step that streamline or make more explicit what needs to be done
- Makes use of, builds upon, adapts or provides alternatives to JWEG’s checklists and means of recording outputs associated with each step, as appropriate
• Pays heed to complementary elements of Natural England’s guidance and UKERC’s TPA. The methodology is structured broadly in accordance with the JWEG guidance and explains reasons where it departs significantly from it. The entire process of undertaking an REA is outlined in Figure 1.
Figure 1. A flowchart of the outline process for REAs

A summary of the contents of each of the ten outputs is in Table 4 below.
### Table 4. A summary of the REA outputs (items in bold are to be included in a plain English report card)

<table>
<thead>
<tr>
<th>Output</th>
<th>Description</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The REA protocol</td>
<td>The protocol identifies all aspects of the background to the REA, including: a concise, plain English outline of the rationale behind the REA and policy context; the primary question and any secondary questions addressed; and details of the method that are specific to the individual REA.</td>
</tr>
<tr>
<td>2</td>
<td>Results of screening all individual papers</td>
<td>A spreadsheet of all the papers considered in each of two screening phases with column headers for: author(s); year; title of the document; and source, including hyperlink where available; and relevance to inclusion and exclusion criteria.</td>
</tr>
<tr>
<td>3</td>
<td>Data extraction form</td>
<td>A spreadsheet of all evidence extracted from each paper relevant to the REA’s primary question and any secondary questions. Column headers in Output 2 are supplemented by: literature type; location; study type; scale of study; relevance to each keyword; summary of quantitative evidence; subject detail; outcome variable(s) specifically measured, observed or modelled; metric(s); outcome detail, as reported in the study; summary of key messages in relation to the REA’s impact question and any secondary questions; summary of mitigation and enhancement measures; pedigree (the strength of evidence).</td>
</tr>
<tr>
<td>4</td>
<td>Confidence in evidence across multiple papers</td>
<td>Confidence in evidence across multiple papers in relation to each keyword or combination of keywords.</td>
</tr>
<tr>
<td>5</td>
<td>Volume and characteristics of the overall evidence base</td>
<td>Summary statistics in relation to the total number of pieces of evidence (i.e. papers, reports etc), also further broken down into the total number of pieces of evidence in a range of categories relevant to each keyword.</td>
</tr>
<tr>
<td>6</td>
<td>A concise summary of the evidence</td>
<td>A concise, plain English summary of the evidence which draws upon Outputs 3, addressing the REA’s primary question and any secondary questions with regard to the energy supply or demand option(s), their component drivers, associated pressures and resultant impacts, including cumulative impacts; supported by Output 7.</td>
</tr>
<tr>
<td>7</td>
<td>Significance of impacts of energy supply/demand option</td>
<td>A matrix of the significance of impacts assessed in terms of their magnitude and confidence in the evidence compiled from review of Outputs 3 and 4.</td>
</tr>
<tr>
<td>8</td>
<td>Mitigation and enhancement measures</td>
<td>A concise, plain English summary of mitigation and enhancement measures produced from those identified in Output 3, supported by a matrix transcribing relevant references from Output 3 and relating them to the impacts associated with the energy supply or demand option(s).</td>
</tr>
<tr>
<td>9</td>
<td>A list of knowledge gaps and research needs</td>
<td>Knowledge gaps relating to each keyword or combination of keywords where there is an absence of evidence or low confidence in the evidence across multiple papers and, hence, associated needs for further research.</td>
</tr>
<tr>
<td>10</td>
<td>Caveats arising from the REA process</td>
<td>Any specific caveats attached to the REA’s outputs provided as a series of short bullet points in plain English.</td>
</tr>
</tbody>
</table>

The REA method also includes, as an Appendix a comprehensive report template to ensure that all REAs are presented in a common format.

### 3.2.1 Case studies

Two case studies were undertaken to test a first draft of the REA methodology developed for SPLICE Phase 1. To test the method in a reasonable timeframe the initially wide question in each case was narrowed quickly to look at a few technologies. The method produces results in 10 output Excel workbooks to ease entry into a prospective Knowledge Gateway. These outputs were used to produce
case study reports and each report indicates where text is derived from those outputs or where those outputs should be referred to separately.

Plain English report cards were developed comprising the elements of the REA outputs shown in bold in the list of outputs in Table 4

### 3.3 Knowledge Gateway design and data specification

The data gathered from the workshops, interviews along with other data collected has allowed a series of user stories to be created. User stories provide a concise way of describing what a user wants the system or a piece of functionality to do. In order to assess the priority of the functionality identified, and taking into account the priority associated with user groups, the requirements set out here are ranked in MoSCoW order:

M – Must Have  
S – Should Have  
C – Could Have  
W – Won’t have

Over 40 user stories were developed and a sample is in Table 5. The final column of the table indicates the functional area of the Knowledge gateway and also the REA outputs that relate to the user need.

**Table 5. Examples of user stories for the SPLiCE Knowledge Gateway**

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>User Story</th>
<th>Importance</th>
<th>Functional area/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Read summaries</td>
<td>As a policy researcher, I want to quickly find reliable summaries of the latest research into the social, economic and environmental impacts of a certain technology type (for example wind turbines), policy type or geographic area so that I can brief government decision makers.</td>
<td>Must Have</td>
<td>Search Outputs 6 - 10.</td>
</tr>
<tr>
<td>6</td>
<td>Review raw evidence</td>
<td>As an academic researcher, I want to see the detail of the evidence that has been assessed by the review teams and who was involved, so that I can assess its value and improve my understanding.</td>
<td>Must Have</td>
<td>Search, display Outputs 1-5</td>
</tr>
<tr>
<td>9</td>
<td>Comparing Impacts across technologies.</td>
<td>As a policy maker I would look for consistent impacts across options (eg biodiversity impacts across technologies to compare the options) and specific impacts within options (eg to identify the full range of impacts a potential technology may have)</td>
<td>Must Have</td>
<td>Search Relevant fields associated with outputs 7 across REAs</td>
</tr>
<tr>
<td>11</td>
<td>Quantitative comparison</td>
<td>As a policy maker I would use the qualitative knowledge to: input into impact assessments and guidance/business cases; state the impacts that would arise from a particular option being put forward; and be able to compare this with other options (ideally with red, amber, green type assessment)</td>
<td>Must Have</td>
<td>Search, display Output 7 of each REA and comparison of these outputs across REAs</td>
</tr>
</tbody>
</table>
As in section 3.2, there are 10 outputs defined by the standard REA methodology. They are structured and defined in a consistent way which enables searching, comparison and further analysis to be conducted by users. Each output has a series of requirements that need to be met.

The outputs comprise a mix of tabular information, and longer text sections, for example for output 1-the REA protocol - a table of roles and responsibilities is required to be completed, along with a larger text segment for ‘background rationale and policy context’ which has a 500 word maximum. To aid data collection, web forms could be used to collect the data and store directly in a database. However it is also possible to create a series of word/excel templates to be completed offline and uploaded to the KG. This template option would provide a lower cost of initial development build, but also provide the least options in terms of online search, comparison and automated quality control and therefore require much more manual intervention to manage the process.

While the requirements for the KG can be met in full by using only web forms or only offline templates, depending on the type of output one option may be more suitable than others. The table below provides a recommendation as to the type of data capture for two REA outputs as examples.

<table>
<thead>
<tr>
<th>Output</th>
<th>Description</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Results of screening all individual papers</td>
<td>A spreadsheet of all of the papers considered in each of two screening phases with column headers for: author(s); year; title of the document; and source, including hyperlink where available; and relevance to inclusion and exclusion criteria.</td>
</tr>
<tr>
<td>4</td>
<td>Confidence in evidence across multiple papers</td>
<td>Confidence in evidence across multiple papers in relation to each keyword or combination of keywords.</td>
</tr>
</tbody>
</table>

**Table 6. Two example REA outputs proposed for SPLiCE and recommendations for how these can be contained in a Knowledge Gateway**
Taking into account the user needs analysis, along with a detailed understanding of the REA outputs, the following key functional areas were identified:

- **Administration** – This allows various aspects of the KG to be administered including users, REA’s and notifications. This area will also include functionality to see dashboard style reports showing progress and the status of REA’s.
- **Data input** – This relates to the tools needed to support users entering data on the system.
- **Data review/approval** – This is concerned with the workflow and process that needs to be implemented to manage the REA’s successfully.
- **Data output/display** – This functionality will allow users to view and export KG data.
- **Search** – The search will allow users to interrogate all the information contained within the KG.

Each of these functions was considered in detail together with the possibility for a lower cost option based on use of offline templates rather than web forms.

The pros and cons of various technical architecture options for the KG were then set out based on a set of seven technical evaluation criteria. Three complementary options were considered: content management system; document management system and coding frameworks. It is likely that a combination such as a content management system plus a coding framework would provide the best outcome overall.

Indicative costs to build the Gateway were estimated as of the order of £100k for the primary option and of the order of £70k for the lower cost option, with annual ongoing costs estimated as £10k to £20k.

### 3.4 Impact evaluation and comparison framework

The purpose of the framework was to suggest a pathway and methods for evaluating environmental, social and economic impacts that have been reported in a range of metrics. The conceptual framework for the evaluation process (Figure 2) illustrates how the assessment of impacts on ecosystem services, health, society and the economy will produce outputs in different metrics, and shows the evaluation frameworks available for comparing impacts measured using these metrics.

The proposed assessment process has three key elements:

4. the process utilises the Natural Capital Committee approach as an overarching framework to identify the natural capital and ecosystem services information that should be considered;
5. macro-economic, social impact, health impact assessment methods can be used alongside to generate additional relevant data;
6. multi-criteria assessment (MCA) methods should be used to evaluate the resulting environmental, social and economic information.

The ecosystem services framework proposed by the Natural Capital Committee (NCC) has been recommended because it builds on the strengths and objectives of key national, regional and international work in this field. An additional strength of the NCC framework is that it includes stocks (the quality and quantity of habitats) alongside flows (the ecosystem goods and services generated) thus integrating existing natural resource management frameworks with developing approaches. The inclusion of stocks also provides a means, by inference, of acknowledging those ecosystem services that, at present, are rarely explicitly accounted for because the mechanisms of their delivery to people, and/or their relationship to the properties and functions of ecosystems are poorly understood. The NCC framework also allows for the inclusion of bio-physical and other non-monetary metrics. This is echoed in guidance for UK Government officials in appraising and evaluating policy, which encourages monetary valuation (and the associated cost-benefit analysis), but also recognises that this is not always appropriate or feasible (HM Treasury, 2013; BIS 2013).
Natural capital is one element of an impact assessment, and understanding the full implications of energy pathways and systems will also require consideration of wider health, social and economic impacts. There are established methods and best practice which should be applied when considering these different elements. For example, where cost benefit analysis is possible and valid it should be undertaken as a means of understanding key economic information, which can then be fed into a wider assessment.

Multi-criteria assessment (MCA) is recommended for the purposes of SPLiCE because it is widely used and provides scope for assessment by individuals or groups and for different degrees of direct stakeholder involvement. The Better Regulation Framework Manual (BIS, 2013) and the Green Book (HM Treasury, 2013) note the potential use of MCA in evaluating non-monetary impacts, and supporting guidance is available (DCLG, 2009).

The main steps of the proposed MCA approach are illustrated below (Figure 3), together with an indication of the interaction with a Rapid Evidence Assessment process. Within an MCA framework, there is the possibility for different pathways depending on specific circumstances (in terms of policy scales, approaches, contexts, information needs and availability, timescales and resource levels). Central to MCA is the performance or impact matrix, which shows how each option being assessed performs for each of the criteria considered. At its simplest, an MCA process can involve informal evaluation of the performance matrix. A more structured MCA process involves scoring the performance criteria such that all elements are on a consistent numerical scale (typically between 0 and 100) indicating the relative strength of preferences for each criteria (DCLG, 2009). These scores can simply be summed or averaged, or at the next level of complexity, a process of weighting is applied, to indicate the relative importance of each element in the decision (Linkov et al., 2006).

Best practice within MCA is to use a participatory process, as effective analysis requires accurate assessment of what changes are important and to whom, as well as the degree of relative change. As the Green Book (HM Treasury, 2013) notes the “weight to give to factors that are thought to be important by key players cannot be decided by ‘experts’”, and so the direct involvement of those key stakeholders is required. Ideally, these stakeholders should be involved in the framing of the MCA, and should have input into the choice of the criteria to be considered.
Figure 2. Conceptual framework for the impact evaluation process

**Natural capital assessment**

**Natural Capital Stocks**
Geological, physical, chemical and biological components of major marine and land-use categories

**Natural Capital Flows (Ecosystem goods & services)**

- Intermediate/supporting and poorly understood regulating services
  (e.g. biodiversity, primary production, larval and gamete supply, nutrient cycling, biological control)
- Most cultural services
  (heritage, cultural, aesthetic, symbolic, sacred/religious, existence, bequest)
- Provisioning services
  (nutrition, raw materials, energy)
- Selected cultural services
  (recreation, tourism)
- Well understood regulating services
  (carbon sequestration, control of flooding and erosion, water supply)

**Further assessment**

**Health Impact Assessment**

**Social Impact assessment**

**Macro-economic assessment**

**Assessment metrics**

- Bio-physical metrics
  (e.g. quantities, rates, condition indices), which should relate where possible to national environmental monitoring programmes
- Non-monetary values
  Qualitative and narrative information
- Monetary values

**Evaluation framework**

- Cost Benefit Analysis
- Deliberative monetary valuation
- Social appraisal methods
  - Multi-criteria Assessment
  - Multi-criteria mapping
  - Social multi-criteria evaluation
  - Qualitative participation deliberation
  - Q method

The criteria to be considered when assessing the impacts of an energy pathway or development will depend on the decision context. Ideally the criteria will be decided in a participatory process involving relevant experts and stakeholders and therefore it is not possible to design a universal matrix framework. There are a variety of sources of potential criteria and indicators. In the ecosystem services context, CICES (Haines-Young and Potschin, 2013) details specific ecosystem benefits that could form criteria, and more specific indicators for ecosystem services have been proposed in a number of studies (e.g. Hattam et al., 2014; van Oudenhoven et al., 2012). Environmental indicators that link to national monitoring programmes (such as under the Water Framework Directive and Marine Strategy Framework Directive) are potentially particularly useful criteria, as they are likely to be supported by regular data collection. Sources of possible social welfare indicators include the Office of National Statistics (ONS, 2014) and, internationally, Organisation for Economic Co-operation and Development (OECD, 2013), both of which have developed wellbeing indicators that consider categories such as housing, income, jobs, community, education, health and safety. An impact matrix incorporating economic, environmental and social information can rapidly become complex and unwieldy, suggesting a potential role for the development of indices to synthesise the large volume of information from individual indicators. For the ecosystem services component of an assessment, the hierarchical format of CICES already lends itself as a framework for progressively aggregating information. However, caution should be applied in the development of indices, as they can oversimplify complex issues and may be open to misinterpretation particularly if poorly constructed (Loomis and Paterson 2014).
3.5 Engagement framework

A draft review of methods of engagement with the public was developed and discussed with the Management Board for SPLiCE Phase 1. The Management Board decided not to complete this work. (See also section 4.6 on discussion)
4 Discussion

4.1 Knowledge gap priorities

4.1.1 Discussion of the results and their reliability

Our work implemented a comprehensive methodology, given allocated resources and time, to prioritise research gaps in published literature on the environmental, social and economic impacts of energy system components in a decarbonised future. In this section we briefly discuss lessons we have learnt from carrying out this assessment. It should be noted, that even where a gap is identified, some evidence may already be known or research may be underway – the method suggests where more evidence would be beneficial.

In terms of resources, a comprehensive, in-depth and exhaustive analysis of research gaps in published literature would need considerably more resources and allocated time than those we had available. It was also sometimes problematic to locate specialist expertise within the team related to some of the impacts of energy system components and consequently some of the evidence was assessed by analysts with a background not necessarily related to the topic being discussed in the reviews. Future studies might consider allocating some resources to bring in specialist knowledge when required. Expert interviewees were used to increase the reliability of the analysis but as at most one interview was conducted per energy system component, there is the possibility that some information might have been overlooked especially in topics which were very broad in scope. Future studies might consider engaging with a secondary expert in order to validate the feedback obtained from primary experts, although it is not clear how disagreement between experts would then be negotiated.

In terms of type of evidence, the analysis was designed around review studies. However, we found that in some areas there were few if any review studies - e.g. heat pumps - so there was a mismatch in some cases between the data available and our analysis framework. In these cases, single studies were used as data points, which clearly provides a considerably less comprehensive evidence base than using review studies. We used the interviews with the experts to verify whether the expert was aware of any reviews which had not been identified by us. Future studies might want to verify existence of reviews not identified by the research team before the interviews with experts take place and with a number of experts rather than only one.

In terms of the boundaries of energy system components and impacts, we noticed that different choices were adopted by different authors. In some cases, e.g. impacts of buildings, researchers have focused on specific methodologies, e.g. Life Cycle Analysis (LCA), while in other cases a more diverse set of methodologies has been employed. In the former case results from the studies and therefore our work might be influenced by assumptions in the methodology and limitations of the data. As an example, results from LCA used to assess impacts of the building stock can raise many questions, as the data sources used, and particularly the boundaries chosen, strongly influence the results.

Given the very limited amount of time available, and the number of reviewed documents, our work should be framed as a cautious attempt at drawing conclusions and making recommendations for filling research gaps in published literature.

4.1.2 Implications of the findings

Future studies would benefit from considering other methods to elicit research gaps, such as the use of expert panels. This option might lead to incomparable outputs from different expert outlooks, and lobbying for ‘pet projects’ but overall it would seem desirable to explore the use of mixed approaches based on systematic reviews of published evidence integrated with expert panels. Our mixed approach was based on interview with representative experts but future studies could reach a more comprehensive and inclusive outcome by engaging with panels of experts for each energy system component rather that a single representative expert. Research teams who might want to implement this option should however be mindful of the cost implications that this much more comprehensive engagement process could imply.
4.2 Assessment method and case studies

4.2.1 Discussion of the results and their reliability

This section notes comments arising from the case studies which were trials of a draft of the REA methodology. As noted previously, in order to test all REA outputs within the project resources the initially broad research question in each case was narrowed quickly to look at a few technologies.

4.2.1.1 Case study 1: Small scale district heating using biomass feedstocks

Feedback from the report authors identified a number of areas where the draft REA method could be improved or where potential uncertainties in what is required could be reduced or eliminated.

Comments and responses include the following. The authors considered that a fuller outline of the outputs of the REA would be helpful early in the document. This was addressed by adding the outputs to a summary figure (Figure 1 of this report).

It was also noted that the draft method gave no guidance on the size of the review team. Rather than suggest a team size – as this may vary with the nature of the topic – a section was added to the REA method for “Membership of the review team”. This includes a table for identifying the team member responsible at each stage of implementing the REA protocol, together with their role and responsibilities.

The authors also requested additional guidance on the population to be considered in the REA and this was addressed by adding to the REA method definitions for the population to be considered as well as for other elements of the REA question.

As a general point, the authors were concerned that the assumptions made during the analysis (e.g. relevance of studies, counterfactual, timeliness, scale etc.) may not be fully taken on board by users leading to potential over-interpretation of results and application to non-appropriate questions.

Considerations of this type led to inclusion of a report template as an Appendix to the REA method. The template includes recording of the primary question and its population, intervention, control and outcome elements, detailed prompts for which are given in the REA method.

Further results from the REA are summarised in Appendix 3.

4.2.1.2 Case Study 2: North Devon Biosphere Reserve

The authors of both case studies found that the draft methodology was a useful step-by-step guide that was clear and easy to apply to multiple review topics. However, the request from DEFRA that Endnote not be used as a reference manager created challenges as many search engines are designed to export to this package and manually extracting citation information was unduly resource heavy. Therefore, Endnote was used to manage references, but the information obtained was exported into Excel such that it could be accessed without the need for the Endnote package.

The scope of the REA (effectively a full systematic review minus some meta-analysis) is challenging for broad studies within tight timeframes. Overall, there appeared to be a mismatch in effort across the process, with relatively more time being spent on developing and implementing the search and assessing the quality of the papers, and rather less on actually reporting the impacts in a meaningful way. Perhaps this is a reflection of the particular circumstances within SPLiCE, and with more time available the process might be more appropriately balanced. By contrast experience with the biomass case study was of a more balanced breakdown of effort with about one third each on setting up the search, doing the search and on analysis.

In terms of the outputs, there is some repetition between output tables, for example recording number of hits for each keyword and number of hits at each screening stage but this is understandable if a need to identify the keywords responsible for high/low returns of evidence is required. The impact tables also become quite subjective as the traffic light system hides the complexities and reasons for shortfalls, particularly given lack of precise forecasted impacts with climate change or lack of studies approaching that particular subject for specific topics in a review. A short description or summary of impact explaining the caveats (in the caveats section of the report) may however be able to identify weaknesses and explain further where confidence issues may arise. This was particularly the case with the completion of Output 7, and especially in terms of the duration and reversibility of impacts, as this was not discussed in the source material, meaning it had to be reported as unknown or else a subjective judgement made by the analyst.
Finally, the authors considered that it would be beneficial to systematically collect specific details from the source material in order to better use the REA outputs within the evaluation framework, namely:

- Subject detail (e.g., habitat type, economic sector)
- Outcome variable (e.g., species abundance, unemployment rate)
- Metric (e.g., GBP, individuals per m²)
- Outcome detail (the quantified impact, or qualitative description, as reported in the study)

4.2.2 Implications of the findings

The draft REA method was updated in the light of the findings from the two case studies. In particular it was noted that the two groups reported the findings from the assessments differently. This led to inclusion of a comprehensive reporting template. This is intended to provide sufficient information on the assessment process and terminology that each report could be stand-alone i.e. it would not need to be read alongside the REA methodology. The template is also intended to be sufficiently prescriptive to ease comparison between reports produced to the template by different groups at different times. Although this would not replace the comparability that could be achieved by including the REAs in a Knowledge Gateway, it will enable some degree of comparison.

4.3 Knowledge Gateway design and data specification

4.3.1 Discussion of the results and their reliability

The development of a design and data specification for the Knowledge Gateway does not lend itself to discussion of reliability and implications of results in quite the same way as the other elements of the programme. There are however areas of uncertainty.

One key area is the exact form of the Knowledge Gateway. At one extreme it could be a document management system for REAs prepared in PDF or other format. One key output from discussion with users was a preference for the method for Rapid Evidence Assessment to constrain the method of review and the presentation of results to a high degree. This would assist comparison of assessments and could be aided by providing one option where the Knowledge Gateway contains the information from the assessments in the form of a database. This is the prime option explored. A lower cost option has also been considered, which would still permit comparison of assessments. This would be to provide data templates which are completed offline and then uploaded to the Knowledge Gateway.

A range of costs has been estimated for development of the Knowledge Gateway. This is from £88k to £125k for the recommended option based on the use of web forms and from £53k to £85k for the lower cost option based on the use of template documents and upload. Ongoing annual costs are estimated as £10k to £20k.

4.3.2 Implications of the findings

The importance of the Knowledge Gateway in ensuring consistency, of REAs should be emphasised. The report template that has been produced is not a full substitute for the comparability that could be achieved through the constraints to the assessments that can be engendered through the Knowledge Gateway. Where it is required to build a set of consistent body of REAs that can be inter-compared, there would be substantial cost:benefits in developing a Knowledge Gateway with a mixture of controlled templates that could be downloaded, completed and uploaded by review teams along with online controlled data entry of those fields that it is vital are consistent (e.g., Output 7 on the Significance of impacts of energy supply/demand option – see Table 4). Without such control, quality assurance would be labour-intensive, and may be very difficult. The result may be a set of REAs each of which is internally consistent but that cannot be easily or fully compared.

4.4 Impact evaluation and comparison framework

4.4.1 Discussion of the results and their reliability

The structured framework provided by MCA has several advantages over informal judgement. In particular, it provides an open and explicit approach based on established techniques with a defined
audit trail, and the objectives and criteria used in the decision can be analysed and amended as required (DCLG, 2009). MCA thus avoids the dangers of informal approaches, which include the increased risks of generating the wrong decision or of failing to gain public acceptance due to a lack of transparency in the decision process (Mendoza et al., 1999). In many decision contexts this requirement to explain how decisions were reached is crucial, and the ability of MCA to track the decision process and separate its elements makes it an ideal communication tool (Mendoza et al., 1999).

This idea of ‘opening up’ a strategy or policy area through the inclusion of stakeholder input is not far removed from existing approaches: consultation is a key element of both policy development and planning decisions. The deliberative and participatory techniques proposed provide a structured approach that has the same goal as consultation (understanding the response of stakeholders to a policy or action) but allows its outcomes to be better assessed and accommodated within the decision framework. A typical consultation process would identify a range of opinions and issues amongst different stakeholders. A formal deliberative process can document the relative strength of concerns, and map where these converge and diverge between different stakeholders, providing quantified outputs and broader insight.

The increasing involvement of stakeholders (particularly through a heuristic process that allows their input into the context and framing of the assessment as well as at the scoring and weighting stage) increases the transparency and robustness of the approach compared to informal or even structured assessment by an individual analyst.

The proposed approach may be seen as downplaying techniques such as Cost Benefit Analysis (CBA). However, monetary valuation is not appropriate for all ecosystem services, particularly cultural services (with the exception of recreation). Although valuation is technically possible through stated preference assessments, it is questionable (and has long been debated in the literature) whether the outcomes are meaningful, so their use in an actual decision context may be difficult to justify. Also, on a practical level, gathering monetary values that capture all aspects of cultural and non-use values is likely to be particularly expensive and time consuming, and, due to the context-specificity, the values obtained may not be amenable to benefits transfer. The Treasury Green book already acknowledges these limitations on potential monetary valuation, and highlights that environmental and social impacts for which monetary metrics cannot be obtained should remain a key component of any appraisal or evaluation (HM Treasury, 2013). Therefore, the framework proposed takes account of the fact that not all impacts can be monetised (and so cannot be included in CBA), but allows the outputs of an economic appraisal such as CBA to be incorporated into the wider assessment. Engagement with decision-makers during development of the proposed framework included discussion with Government departments (DECC and DTI, as well as DEFRA) on the extent to which monetary and non-monetary appraisal methods are currently used. The proposed approach was also presented and discussed at a wider stakeholder workshop involving representatives from Government departments, statutory agencies, Non-Governmental Organisations and academia, at which a broad consensus on its suitability was obtained.

4.4.2 Implications of the findings

The proposed framework suggests a method to compare the diverse environmental, social and economic impacts of different energy pathways that can accommodate outputs from other appraisal methods such as Cost Benefit Analysis. The MCA approach proposed also has the advantage of flexibility, as it can be applied at a range of levels from a single analyst to a participatory process involving stakeholders, using methods of varying complexity depending on resource availability. As stated in section 3.4 the Better Regulation Framework Manual (BIS, 2013) and the Green Book (HM Treasury, 2013) note the potential use of MCA in evaluating non-monetary impacts, and supporting guidance is available (DCLG, 2009). Increased use of this approach would be welcome.

However, it remains a prototype and requires testing and evaluation if it is to be developed into an operational tool (see Section 5.4).

4.5 Engagement framework

The draft review of methods of engagement with the public was discussed with the Management Board for SPLiCE Phase 1, together with potential approaches to developing the output for Phase 1. Two approaches were considered:
- A generic approach to develop principles of providing information on the sustainability of energy systems.
- Recommendations on how to deliver the information coming out of SPLiCE.

On the development of generic principles it was noted that there is already significant research completed or ongoing in this area and information of this type is available from the Government’s Sciencewise programme9 and elsewhere10.

For the option of focusing on how to deliver information generated by SPLiCE the details of what is appropriate for any particular input to public debate will depend intimately on the purpose of the debate, together with the nature of the energy option and impacts being considered. It was also noted that there are several examples of how information relating to energy options, impacts, benefits and risks can be made available to the public to inform public debate11. Candidate materials could be developed, but it is very unlikely that these would be directly relevant to any specific input to inform public debate that may be required later in the SPLiCE programme. It was considered to be too early in the SPLiCE programme (Phase 1) to identify the specific areas in which information will be required and the shape of the outputs from the programme.

Bearing in mind the availability of generic guidance elsewhere, and the potential lack of more general applicability at the time of a SPLiCE focused approach, the Management Board decided that work stream 5 in Phase 1 of SPLiCE should stop.

4.6 Across the project

This section makes some general comments arising from the work.

This project demonstrated the goodwill of the energy community to be involved with Defra and to try and help with evidence gathering and priority setting (e.g. many experts giving their time unpaid to contribute to the questionnaire on energy system components (see section 2.1.1), and participating in interviews and workshops).

There are complex sets of evidence around the impacts of energy choices - gathering more evidence will not necessarily make decision-making easier. In fact it may make it more difficult, as additional impacts are taken into account. It is not just the evidence about each impact but that stakeholders may value them in different ways and sometimes inconsistently. This emphasises the importance of the structured approach suggested to comparison of impacts including identification of the pertinent impacts and consideration of how stakeholders value them.

Values and priorities will remain an important part of decision making, even with an improved evidence base, because many choices will have a mixture of positive and negative effects which need to be weighed against each other and compared with alternative choices.

---


11 Examples that are relevant to some or all of: energy options, impacts, risks and benefits are available from ongoing work or recently published reports from projects supported by the Government’s Sciencewise programme. Reports, including materials used to inform debates are published on the Sciencewise website. Recently published and ongoing projects include on: shale gas and oil, MRWS siting process, trajectories for carbon emission reductions, the national ecosystems assessment, nature improvement areas, and social impacts of marine renewable options in Scotland.
5 Possible future work

In line with changes in available funding it has been decided not to progress to a formal Phase 2 of SPLiCE as was originally intended. It may be that some follow-on work from SPLiCE Phase 1 may be funded as separate pieces of work and/or that the results from SPLiCE Phase 1 can inform current and future related work. Further comments are added below for each of the SPLiCE areas of activity.

The work and application of SPLiCE Phase 1 may be of value to Government, and particularly to Departments that have a lead or a strong interest in the impacts of energy system components. This includes but is not limited to the DECC (Department of Energy and Climate Change), Defra (Department for Environment, food and rural affairs, and DfT (Department for Transport). The work may also be of interest to Government agencies and other bodies such as the Environment Agency and the Committee on Climate Change, as well as to the research and education sector – research councils and universities.

5.1 Knowledge gap priorities

The prioritised list of knowledge gaps was developed to inform work in an originally intended SPLiCE Phase 2. It has been decided not to progress to Phase 2. The list, nevertheless, represents a structured approach to identifying knowledge gaps and may be used to inform the prioritisation of work of other research programmes and funding bodies considering work on the environmental, economic or social impacts of energy system components. The list may also be reviewed by policy leads in Government departments to inform their input into commissioning or advising on future research.

5.2 Assessment method and case studies

A Rapid Evidence Assessment methodology has been developed that is tailored to assessing the environmental, social and economic impacts of energy system components. This is available to be used or to be specified.

The methodology can also inform the work of other groups such as the UK Energy Research Centre (UKERC).

It is planned to publish aspects of this work in the peer-reviewed literature.

Development of a set of REAs for energy supply and demand options that are priorities is suggested as an important activity going forward. This will permit consistent and cost effective use of the very large amount of research that has already been published. It could be argued that, although it is important to seek to address knowledge gaps, it is at least as important to have comprehensive systematic and comparable assessments of evidence that has already been generated.

5.3 Knowledge Gateway design and data specification

The design and data specification for a Knowledge Gateway, fully compatible with the REA methodology developed for energy system components, are ready should funding become available.

5.4 Impact evaluation and comparison framework

There remains the need for a framework that allows the diverse environmental, social and economic impacts of different energy pathways to be compared in order to support energy policy decisions. The prototype developed within SPLiCE has suggested a means for comparing impacts reported in a range of metrics and has flexibility for different decision contexts and levels of resource availability.

Such a framework will be of interest to the wider energy community (e.g. the UK Energy Research Council (UKERC)) and, as a practical tool to incorporate the assessment of ecosystem services and natural capital, to UK, EU and international programmes including the Natural Capital Committee,
Common International Classification of Ecosystem Services (CICES), System of Environmental-Economic Accounting (SEEA), and the Valuing Nature Programme. The framework can be utilised for other policy and regulatory decisions that affect the environment.

However, in order to be taken forward as an operational tool, the prototype framework requires development, testing and evaluation. The key steps in this process would be:

i. Selecting specific Multicriteria Analysis (MCA) methods
   Individual MCA methods involve different treatment of issues such as uncertainty, missing data, and stakeholder engagement; have different resources requirements; and may be supported by particular analysis tools. Therefore, assessment of the strengths, weaknesses, opportunities, and threats (SWOT) associated with each is required.

ii. Identifying key ecosystem service indicators
   At present, it is rarely the case that data is collected on ecosystem services directly, and so it will be necessary to define a process for mapping existing data onto an ecosystem services framework.

iii. Identifying evidence types
   Central to MCA is the performance (or impact) matrix, which shows how each option being assessed performs for each of the criteria considered. The matrix is populated according to the criteria defined by those involved in the process. To understand how development of the matrix will progress, it is necessary to consider the types of evidence that are available concerning the impacts of energy supply and demand options. Suggested criteria for the performance matrix should be drafted, which then allow a range of environmental, social and economic evidence to be included. These should incorporate the ecosystem services indicators defined in the preceding step, but other criteria (such as the cost of energy) which lie outside the ecosystem services framework should also be included. For example, where cost benefit analysis is possible and valid it should be undertaken as a means of understanding and aggregating key economic information, which can then be fed into the wider MCA assessment.

iv. Producing draft methodological guidance
   Guidance is required so that the proposed MCA process can be carried out accurately and consistently, and it should provide sufficient methodological detail such that no supplementary materials are required.

v. Testing, evaluation and refinement
   The MCA framework should be tested based on energy issues/scenarios at different scales, evaluated and refined accordingly.

From the perspective of knowledge exchange, members of the SPLiCE consortium plan to publish (in peer-reviewed literature) aspects of the underlying reviews of ecosystem service frameworks and the conceptual framework itself to bring it to the attention of the wider research community.

### 5.5 Engagement framework

It is important in future work on impacts of energy system components that social impacts are considered alongside environmental and economic impacts. In several instances, such as public acceptability and visual intrusion this may best be achieved by direct public engagement. Guidelines on public engagement are available from the Government’s Sciencewise programme[^12] and elsewhere[^13].

### 5.6 Across the project

When considering future work, there are strong linkages between the different areas of work in SPLiCE Phase 1. For example work on REAs can help to identify and clarify areas where there are significant evidence gaps and these can inform decisions of research funding organisations. There is also necessarily a strong link between the REA method and the Knowledge Gateway. In addition there are links between the evidence assessment and impact comparison – so coordinating processes are valuable to ensure that evidence is assessed that is needed to support decisions, and also for

comparing the diverse impacts that the evidence describes. And finally, the assessed evidence and the impact comparison can inform the development of stimulus material to assist public understanding and help the public to engage in debate on energy system options.

High levels of expertise combined with a very wide range of expertise was necessary for this project. This suggests that a future research programme in this area should to be structured to include work from experts from outside any research consortium formed, as even a broad consortium is unlikely to include all the expertise needed. This has been addressed within the current work by involving experts outside the project team through workshops, a questionnaire on prioritisation of energy system components and by interviews.

It is unclear whether a common framework for gathering evidence on demand-side and supply-side options makes sense, given the different methodologies used, different types of data and different priorities. Demand side options should be included in the decision-making framework. However, they do not (usually) raise potentially negative impacts of the same significance as supply options, so may not need to be in the same research framework. The multiple impacts of energy efficiency have been / are being investigated in a major International Energy Agency initiative 14.

The work of SPLiCE Phase 1 can potentially inform a range of activities in the area of assessing the environmental, social and economic impacts of energy system components to inform policy. One example of a programme in this area is the Valuing Natural Capital in Low Carbon Energy Research Programme, within which the ADVENT project 15, due to kick off in September 2015, covers some of the area of SPLiCE and can make use of and build on relevant results from SPLiCE Phase 1.


15 See http://www.nerc.ac.uk/latest/news/nerc/low-carbon-future/
6 References


7 Acknowledgements

Support is acknowledged for SPLiCE Phase 1 from the Department for Environment, Food and Rural Affairs (Defra) and the Natural Environment Research Council (NERC) through Defra contract CCM 0102.

We have benefitted from positive support and involvement from Defra and thanks are due to the project officer at Defra – initially Paul Nunn and latterly Iain Notman.

We would also like to extend thanks to the active Management Board or their helpful comments and direction and in this context thanks are due to: Stephen Elderkin (Defra, Chair), Maria Angulo (Defra), Paul Bailey (Department of Energy and Climate Change – DECC), Andy Boston (Energy Research Partnership), Julian Harlow (Defra), Sarah Keynes (NERC), Christalla Kyriacou (DECC), William Lecky (DECC), Michelle Truman (NERC), Robyn Thomas (NERC), Jim Watson (UK Energy Research Centre – UKERC), Glenn Watts (Environment Agency).

We also appreciated input and comments from the Defra Quality Assurance Steering Group for this project on the milestone reports and draft outputs from the project. Here, thanks are due to: Maria Angulo (Defra – Chair), Alex Coley (Defra), Thomas Counsell (DECC), Lee Davies (Defra), Roald Dickens (Defra), Paro Konar (DECC) and Andrew Wharrad (Defra).

We have already noted appreciation of the input of the energy community in the main text in participation in the online survey on energy system components and also in the workshops in October 2014 and February 2015. Their input has been valuable in guiding the work.

Finally we extend our thanks to the project team. Many are listed as authors of reports associated with SPLiCE Phase 1 in Appendix 1. In addition thanks are due to Alexandra Humphris-Bach (Ricardo-AEA), Charlotte Johnson (UCL), Steve Robinson (Ricardo-AEA) and Daniel Start (Ricardo-AEA) for their contribution to the work.
Appendices

Appendix 1: References to project outputs and list of authors of contributing research
Appendix 2: Executive summary – Output on knowledge gap priorities
Appendix 3: Executive summary – Output on assessment method and case studies
Appendix 4: Executive summary – Output on Knowledge gateway design and data specification
Appendix 5: Executive summary – Output on impact evaluation and assessment framework
Appendix 6: Recommendations for informing public debate
Appendix 7: Complete list of energy system components and impact categories
Appendix 8: Exemplary Research Gaps for a Prioritised selection of Energy System Components and Impact Areas
Appendix 1 - References to project outputs and list of authors of contributing research

Outputs are organised by the programme area. Key outputs are available at the Defra Science Research website here. Other documents, marked with an asterisk are available from Ricardo-AEA.

Knowledge gap priorities

Report on significant evidence gaps
Paolo Agnolucci\(^{16}\), Marius Biedka\(^{17}\), Josie Coburn\(^{18}\), Carolina Downey de Oliveira\(^{17}\), Paul Drummond\(^{16}\), Tina Fawcett\(^{19}\), Heather Haydock\(^{17}\), David Howard\(^{20}\), Pat Howes\(^{17}\), Nick Hughes\(^{16}\), Gavin Killip\(^{19}\), Moira Nicolson\(^{16}\), Steve Pye\(^{16}\), Richard Smithers\(^{17}\), Andrew Stirling\(^{18}\), James Tweed\(^{17}\), Peter Warren\(^{16}\) and Paul Ekins\(^{16}\) (2015), SPLiCE Phase 1 - Significant evidence gaps on the environmental, social and economic impacts of energy system components. Ricardo-AEA report Ricardo-AEA/R/ED59332/OP1, Ricardo-AEA, August 2015

Report on web survey for energy system components for assessment of research gaps
Paolo Agnolucci\(^{16}\), Josie Coburn\(^{18}\), Tina Fawcett\(^{19}\), Heather Haydock\(^{17}\), David Howard\(^{20}\), Pat Howes\(^{17}\), Tara Hooper\(^{21}\), Gavin Killip\(^{19}\), Moira Nicolson\(^{16}\), Steve Pye\(^{16}\), Richard Smithers\(^{17}\) and Peter Warren\(^{16}\) (2015), SPLiCE Phase 1 - List of energy system components for assessment of research gaps. Ricardo-AEA report Ricardo-AEA/R/ED59332/M7.1, Ricardo-AEA, May 2015.

Assessment method and case studies

Report on Rapid Evidence Assessment Methodology

Reports on case studies

Report on case study on small scale district heating and biomass
Paolo Agnolucci\(^{16}\), David Howard\(^{20}\), Jeanette Whitaker\(^{20}\), Nick Hughes\(^{16}\), Richard Smithers\(^{17}\), Pat Howes\(^{17}\) and Josie Coburn\(^{18}\) (2015), SPLiCE Phase 1 - Rapid Evidence Assessment Case Study 1: Small-Scale District Heating Using Biomass Feedstocks. Ricardo-AEA report Ricardo-AEA/R/ED59332/OP2a, Ricardo-AEA, June 2015.

This report is supported by the following files (all are xls files):

- * WS2 Biomass CS - OUTPUT 1 - Protocol 29Mar15
- * WS2 Biomass CS - OUTPUT 2 - Combined 29Mar15
- * WS2 Biomass CS - OUTPUT 2 - Environmental screening 29Mar15
- * WS2 Biomass CS - OUTPUT 2 - Socioeconomic screening 29Mar15
- * WS2 Biomass CS - OUTPUT 3 - Combined data extraction 29Mar15
- * WS2 Biomass CS - OUTPUT 3 - Environmental data extraction 29Mar15
- * WS2 Biomass CS - OUTPUT 3 - Socioeconomic data extraction 29Mar15
- * WS2 Biomass CS - OUTPUT 4 - Ranking 29Mar15
- * WS2 Biomass CS - OUTPUT 5 - Evidence base 29Mar15
- * WS2 Biomass CS - OUTPUT 6 - Impacts Summary Text 29Mar15
- * WS2 Biomass CS - OUTPUT 7 - Summary of impacts table 29Mar15
- * WS2 Biomass CS - OUTPUT 8 - Implications 29Mar15
- * WS2 Biomass CS - OUTPUT 9 - Knowledge gaps and research needs 29Mar15
- * WS2 Biomass CS - OUTPUT 10 - Caveats 29Mar15

16 UCL
17 Ricardo-AEA
18 University of Sussex
19 University of Oxford
20 CEH
21 Plymouth Marine Laboratory
Report on case study on the North Devon Biosphere Reserve

Tara Hooper\textsuperscript{22}, Matthew Ashley\textsuperscript{22} and Melanie Austen\textsuperscript{22} (2015), SPLiCE Phase 1 - Rapid Evidence Assessment Case Study 2: The North Devon Biosphere Reserve. Ricardo-AEA report Ricardo-AEA/R/ED59332/OP2b, Ricardo-AEA, June 2015.

This report is supported by the following files (all are xls files):

- * NDBR OUTPUT 1 Protocol 6May15
- * NDBR OUTPUT 2 Evidence 6May15
- * NDBR OUTPUT 3 Data extraction 6May15
- * NDBR OUTPUT 4 Ranking 6May15
- * NDBR OUTPUT 5 Evidence base 6May15
- * NDBR OUTPUT 6 Impacts summary text 6May15
- * NDBR OUTPUT 7 Summary of impacts table 6May15
- * NDBR OUTPUT 8 Implications 6May15
- * NDBR OUTPUT 9 Knowledge gaps and research needs 6May15
- * NDBR OUTPUT 10 Caveats 6May15

Reports on report cards

Report card on case study on small scale district heating and biomass (This is a summary based on the case study)

* Paolo Agnolucci\textsuperscript{23}, David Howard\textsuperscript{24}, Jeanette Whitaker\textsuperscript{24}, Nick Hughes\textsuperscript{23}, Richard Smithers\textsuperscript{25}, Pat Howes\textsuperscript{25} and Josie Coburn\textsuperscript{25} (2015), SPLiCE Phase 1 – Report card: Small-Scale district heating using biomass feedstocks. Ricardo-AEA report Ricardo-AEA/R/ED59332/OP2c, Ricardo-AEA, July 2015.

Report card on case study on the North Devon Biosphere Reserve (This is a summary based on the case study)


Knowledge Gateway design and data specification


Impact evaluation and comparison framework

Melanie C Austen\textsuperscript{22}, Tara Hooper\textsuperscript{22}, Matthew Ashley\textsuperscript{22}, Eleni Papathanasopoulos\textsuperscript{22}, David Howard\textsuperscript{24}, Lindsay C. Maskell\textsuperscript{24}, Paolo Agnolucci\textsuperscript{23}, Tina Fawcett\textsuperscript{27}, Ruth Mayne\textsuperscript{27}, Josie Coburn\textsuperscript{26}, Andy Stirling\textsuperscript{26} (2015), SPLiCE Phase 1 - Investigation of methods for comparing impacts and prototype framework for comparison. Ricardo-AEA report Ricardo-AEA/R/ED59332/OP4, Ricardo-AEA, August 2015.

Stakeholder workshops

Notes from stakeholder workshop on 9\textsuperscript{th} October 2014


---

\textsuperscript{22} Plymouth Marine Laboratory
\textsuperscript{23} UCL
\textsuperscript{24} CEH
\textsuperscript{25} Ricardo-AEA
\textsuperscript{26} University of Sussex
\textsuperscript{27} University of Oxford
Notes from stakeholder workshop on 10th February 2015


List of authors of contributing research

The full list of contributing authors to the research in SPLiCE Phase 1 is as follows:

Centre for Ecology and Hydrology
Mike Brown, David Howard, Lindsay Maskell, John Watkins and Jeanette Whitaker

Plymouth Marine Laboratory
Matthew Ashley, Melanie Austen, Tara Hooper, Matthew Ashley and Eleni Papathanasopoulos

Ricardo-AEA
Ian Behling, Marius Biedka, Carolina Downey de Oliveira, Heather Haydock, Pat Howes, James Jaggers, Phil Long, Lee Sims, Richard Smithers and James Tweed

University College London
Paolo Agnolucci, Paul Drummond, Paul Ekins, Nick Hughes, Moira Nicolson, Steve Pye and Peter Warren

University of Oxford, Environmental Change Institute
Tina Fawcett, Gavin Killip and Ruth Mayne

University of Sussex, Social Policy Research Unit
Josie Coburn and Andrew Stirling
Appendix 2 - Executive summary – Output on knowledge gap priorities

Modern energy systems are extraordinarily complex including a high number of actors (e.g. government, private investors, utilities, banks, pensions funds, consumers, NGOs) driven by different objectives and operating across very different timescales. Future energy systems in a decarbonised world are likely to be at least as complex as the current energy system, as trade-offs between reduction in CO₂ emissions and other important characteristics of decarbonisation unfold and demand attention from the policy-making and academic community, as well as from a more inclusive set of stakeholders. The purpose of this report is to present the results of research aimed at identifying and prioritising evidence gaps from published literature on the impacts of the most salient energy system components of a future decarbonised system. We implemented a multistep mixed methodology to produce a prioritised list of research gaps in the literature which is both comprehensive and detailed bearing in mind the resources allocated to the project.

As a starting point we chose the DECC 2050 Pathways Calculator (https://www.gov.uk/2050-pathways-analysis) to select energy system components for inclusion in this study, as this would ensure broad coverage of the energy system and a taxonomy most stakeholders are familiar with. In order to ensure a comprehensive and inclusive selection mechanism we implemented a web-based survey with a wide coverage of interested stakeholders to select a limited number of energy system components for further analysis. An online, self-completion questionnaire was set up on Survey Monkey (https://www.surveymonkey.com) and kept open for about three weeks. Respondents were recruited through a number of established mailing lists (e.g. UKERC and the SDRN newsletters). Respondents to the survey were asked to score each energy system component through a number of criteria, chosen to enable analysis of the potential importance and significance of impacts of a given component in future decarbonised energy systems. These criteria included: Potential Contribution of Energy System Components; Criticality of Energy System Components; Persistence of Impacts; Local Social, Environmental or Economic impacts: Uncertainty of Impacts; and Uncertainty in Decision Making. As a consequence of this process we selected the following energy system components for further analysis.

<table>
<thead>
<tr>
<th>Carbon dioxide storage</th>
<th>Heat pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCS power stations</td>
<td>Electric vehicles</td>
</tr>
<tr>
<td>Nuclear fission power stations</td>
<td>Offshore wind</td>
</tr>
<tr>
<td>Unconventional gas</td>
<td>Land dedicated to bioenergy</td>
</tr>
<tr>
<td>Energy storage</td>
<td>Power interconnectors and transmission / distribution</td>
</tr>
<tr>
<td>Carbon dioxide transmission network</td>
<td>Energy intensity of industry</td>
</tr>
<tr>
<td>Demand-side Response</td>
<td>Onshore wind</td>
</tr>
<tr>
<td>Aviation</td>
<td>Insulation and building fabric</td>
</tr>
</tbody>
</table>

Identification of impact categories from energy system components used in our study was based on previous work of the project team, and detailed feedback from the SPLiCE Management Board. The following impact areas were selected: marine environment; water; land; air; biodiversity; human health; social impacts; and economic impacts. In a number of instances sub-categories were agreed to make the task of identifying research gaps manageable within the allocated resources. In order to collect data on the environmental, social and economic impacts of energy system components, and related research gaps, we conducted a meta-review of review documents discussing impacts of the selected energy system components. In a number of instances however we relied on original studies rather than review studies as our search confined to reviews did not return any matches. The literature search, according to the adopted protocol, was implemented in Web of Science (http://wok.mimas.ac.uk). We mitigated the risks of not searching for reviews published in the grey literature through expert interviews, and an ad-hoc Google Scholar search for those impacts not returning any match.

After assessing the quality of each review, we collected information related to the intensity of the impacts and to the level of confidence in the assessment of the impacts. Intensity of impacts is based on the assessment of the authors of the reports we reviewed and how they describe the impact.

Ref: Ricardio-AEA/R/ED59332/M7.1/Issue Number V1.0
Confidence was considered to be a function of the agreement in the evidence discussed in the study and the type of evidence being discussed. After reviewing all the papers we produced an overall assessment of the intensity and confidence in the assessment for each impact category arising from each energy system component selected for further study through the web-survey.

For each energy system component we aimed at prioritising importance of impacts and related research gaps in literature by using the scores for intensity of impacts and confidence in the assessment. The aim was to place each impact in one of the cells of Table ES1 which combines intensity of impacts with confidence in the assessment. This procedure has the advantage of providing an automated and objective prioritisation of impacts and related research gaps for each energy system component, which is suggested by the colour coding in the table. For each energy system component, it would seem natural firstly to fill research gaps related to the impacts with 'High' intensity and 'Low' confidence, i.e. the red cell; secondly, to fill gaps related to the orange cells; thirdly gaps related to the yellow cells; and finally, to fill gaps related to the white cells. We validated our procedure and results by holding 10 interviews with selected experts.

Table ES1. Framework for prioritisation of impacts and related research gaps

<table>
<thead>
<tr>
<th>CONFIDENCE</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTENSITY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After producing a prioritisation of research gaps for each energy system component, we prioritised research gaps in the literature across energy system components. Our methodology considered the following criteria:

- **Priority of the need.** This is taken from our assessment of impacts and research gaps through the literature review and expert interaction described above;
- **Likelihood of the need.** This is taken mainly from Ekins et al (2013) which presents a review of established UK energy system scenarios. When energy system components selected in this study were not discussed at length in Ekins et al (2013) we have used other more focused scenarios presented in the literature;
- **Urgency of the need.** This is related to one of the criteria used in the web survey, namely “Potential Contribution of Energy System Components”;
- **Criticality of the need.** This is also related to one of the criteria in the web survey, namely “Criticality of Energy System Components”.

Our methodology to prioritise research gaps in the literature across energy system components comprises the following steps.

- We ranked each combination of impact and energy system component based on their score under the Priority of the need criterion;
- As scores above are discrete, we used scores for the Likelihood of the need criterion, to prioritise any combination of energy system component and impact obtaining the same score under the Priority of the need criterion;
Finally, as scores for both the Likelihood of the need criteria are discrete, we computed the average of the rank obtained from the Urgency and Criticality of the need criteria to prioritise any combination of energy system component and impact obtaining the same score under the criteria for Priority and Likelihood of the need.

As a consequence of the comprehensive and multistep methodology employed in our study, our final list of research gaps in the literature span a wide range of energy system components. Gaps related to Carbon Capture and Storage, Nuclear Power, Land for Bioenergy, Electric Vehicles and Demand-Side Response are very prominent in the list we produced. Research gaps in the literature related to unconventional gas have received a lower priority due to their more uncertain contribution to a future decarbonised energy system. Research gaps related to the Power Network, Aviation, Offshore Wind and Buildings and Insulation do not feature strongly in the top 20 list mainly because they received a somewhat lower score from the literature assessment and interaction with the experts. No gaps related to Electricity Storage and Heat pumps appear in the top 20 list due to receiving a comparatively low score from the literature review and interaction with experts.

As a result of the methodology discussed here, we have obtained a granular prioritisation of impacts and related research gaps identified through systematic assessment of published reviews and feedback from experts. It should, of course be noted that even where a gap is noted, this does not necessarily mean that there is no evidence or ongoing work in the area, rather that this study suggests that additional information is required. Our work could be refined based on further engagement with experts on specific gaps which have been identified in this fairly high level assessment. Another option would be to commission reviews of selected impacts of some energy system components for which we could not identify any published review. This preliminary reviewing step would also help to further focus research gap related to specific energy system components in a way which could not be delivered as part of the resources allocated to the current project.
Appendix 3 - Executive summary – Output on assessment method and case studies

Assessment method

Note – there is no Executive Summary for the Assessment Method as it is more of the nature of an instruction manual for users of the REA method.

Case studies

These studies are demonstrators of aspects of a rapid evidence assessment (REA) with the intention of testing a draft REA protocol produced in Work Stream 2 of the Sustainable Pathways to Low Carbon Energy (SPLiCE) project to allow high quality, consistent reviews of published literature (Smithers, 2015). To test the method in a reasonable timeframe the initially wide question was narrowed quickly to look at a few technologies. The method produces results in 10 output Excel workbooks to ease entry into a prospective Knowledge Gateway. These outputs were used to produce reports and the document indicates where text is derived from those outputs or where those outputs should be referred to separately. A complete list of the output workbooks can be found in Appendix 1 of the specific case study report.

The studies present a REA as prepared following the draft REA protocol. Lessons learned that informed the development of the REA method are given in Appendix 2 of the specific case study report.

Please note that, as the purpose of the case studies is to test a draft REA method, they are not, and are not intended to be taken as, full REAs covering the research questions.

Please also note that, as these case studies present a record of how the draft REA method was applied, some details and clarifications that, with hindsight, may be useful are not included. These were considered for inclusion in the final REA method.

Case study 1: Small scale district heating using biomass feedstocks

Primary Question

<table>
<thead>
<tr>
<th>Question</th>
<th>What are the life-cycle impacts of a small-scale district heating facility using biomass feedstocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>The subject or unit of study UK: environment, economy and society</td>
</tr>
<tr>
<td>Intervention/exposure</td>
<td>Small district heating unit (50-300 kW) consuming biomass feedstocks, typical of developments currently used in Britain. Life-cycle includes construction, commissioning, operation, decommissioning &amp; interactions with other sectors.</td>
</tr>
<tr>
<td>Comparator</td>
<td>No installation of district heating</td>
</tr>
<tr>
<td>Outcome</td>
<td>Direct, indirect and cumulative impacts on the environment, society and the economy (positive, negative and neutral)</td>
</tr>
</tbody>
</table>
Evidence summary

There is considerable literature on the use of district heating (DH) including references to the use of a range of forms of biomass as feedstocks. However, much of the material is not relevant to issues surrounding the potential development of small-scale DH using biomass in the UK. Several levels of filter were applied before eventually identifying 34 publications from which detailed information was drawn. The evidence can be divided into material derived from two distinct disciplines environmental science and socio-economics. This report describes the results presented in 10 tables defined in the REA protocol (Smithers, 2015) and are presented in Excel format to ease entry into the Knowledge Gateway. These are cited in the text and should be referred to for further details and additional notes for qualification.

Environmental
- There is broad agreement from the studies that DH fuelled by biomass has a significantly lower impact on the climate and lower greenhouse gas (GHG) emissions than DH using fossil fuel (with natural gas, heating oil and coal as comparators). For example, GHG reduction potentials quoted as 90-98% in one study depending on types of feedstock, form of feedstock (e.g. chip, pellet,) and boiler efficiency and loading. Highest GHG savings come from using waste wood or forest residues (HIGH AGREEMENT, ROBUST EVIDENCE).
- For other environmental impact indicators including acidification, eutrophication, terrestrial toxicity, air, water and soil quality the issue is less clear. Biomass DH is typically worse for air quality than DH burning natural gas due to particulates and NOx but there are differences dependent on feedstock types; a number of studies highlight that this is likely to be an issue in urban rather than rural areas (HIGH AGREEMENT, ROBUST EVIDENCE). These impacts differed significantly between feedstocks. For example, straw had the highest impacts for acidification and eutrophication due to compensatory fertiliser application to balance straw removal from land. Long rotation forestry had low impacts due to minimal management e.g. low fertiliser applications and low diesel use in machinery. (Generally MEDIUM AGREEMENT, ROBUST EVIDENCE).
- Different parts of the lifecycle are responsible for specific impacts. Feedstock production has greatest impact on GHG savings due to changes in biomass and soil carbon (C) stocks or through the use of waste wood or straw. Combustion is the greatest contributor to air quality impacts and human toxicity. (Generally MEDIUM AGREEMENT, ROBUST EVIDENCE).
- The main impacts arising from boiler manufacture are from steel production.
- A long-term temporal scale should be used to account for carbon impacts of growth of energy crops and forestry.

Socio-economic
- The labour requirements of constructing and operating a biomass district heating plant, and of supplying it with feedstock biomass, are reasonably likely to result in a net employment benefit within the region concerned (MEDIUM AGREEMENT, MEDIUM EVIDENCE).
- Most averaged plant-lifetime and lifecycle estimates of net employment impact are in the range of 2-4 FTEs / MW installed plant capacity, or 0.001 – 0.002 FTEs / MWh input biomass (MEDIUM AGREEMENT, MEDIUM EVIDENCE).
- Over the lifetime of the plant, the extent of the impact on employment, and whether it is net positive or net negative, is significantly affected by the type of feedstock which is used (HIGH AGREEMENT, MEDIUM EVIDENCE).
- Forestry based feedstocks may have stronger net positive employment impacts than agricultural energy crops. If agricultural energy crops directly compete for land use with, and ultimately displace non-energy crops such as wheat which are more labour intensive, there could be a net negative impact on employment within the region as a whole, as a result of growing biomass for energy (MEDIUM AGREEMENT, MEDIUM EVIDENCE).
- Other important counterfactuals are which source of energy for heat the biomass is assumed to be replacing – whether it is competing with fossil fuels or other types of renewables. Biomass has been suggested to have positive employment impacts in comparison to both types of competition, however the evidence is limited (LOW AGREEMENT, LIMITED EVIDENCE).

Caveats arising from the REA process
- This study should not be viewed as a comprehensive review of small/medium scale district heating powered by biomass. The study was performed to test the guidance and
instructions developed in SPLiCE and the reviews (sources and interpretation) were very selective. Outputs were produced as demonstrations and exemplars to feed into the specification of SPLiCE's Knowledge Gateway (work stream 3).

- **District heating is not currently common in the UK**, so many of the relevant studies describe other nations, especially those in northern Europe and the USA. The REA has made specific assumptions about the relevance of these studies to UK, but the assumption must be born in mind whilst viewing the output.

- **Counterfactual analysis** – much of the literature claims that biomass based energy generates more employment than other energy options, both fossil and low carbon. However the literature is limited in the extent to which such counterfactuals are systematically analysed, which weakens the claims that can be made for the net employment benefits of bioenergy compared to other options. Further research should more systematically explore competition effects both in the energy and the agricultural sectors, and how these impact upon net employment creation of bioenergy

- **Imported bioenergy** – most supply analyses assume that the biomass is grown and sourced within the same region that uses it for energy. However, imported woody biomass from large scale producers for example in the USA or Canada, might become cost competitive with locally grown supplies especially if activities by large electrical companies create economies of scale for imports. Further research should analyse how net employment is affected by a supply chain with imported biomass compared to one with domestically sourced biomass.

---

**Case study 2: North Devon Biosphere Reserve**

**Primary Question**

<table>
<thead>
<tr>
<th>Question</th>
<th>What are the environmental, social and economic impacts of specific energy supply and demand options individually on habitats and communities comparable to those of the North Devon Biosphere Reserve?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Habitats and communities comparable to those of the North Devon Biosphere Reserve</td>
</tr>
<tr>
<td>Intervention/exposure*</td>
<td>Nuclear, onshore and offshore wind, tidal range, tidal current, solar PV, biomass, domestic insulation and domestic car use.</td>
</tr>
<tr>
<td>Comparator</td>
<td>Increasing implementation of the intervention/exposure (above)</td>
</tr>
<tr>
<td>Outcome</td>
<td>An assessment that considers what can be inferred about cumulative effects based on studies of the impacts of single energy options on habitats and communities that are characteristic of, or particularly important within, the North Devon Biosphere Reserve area.</td>
</tr>
</tbody>
</table>

**Evidence summary**

There was a lack of evidence specific to the North Devon Biosphere Reserve, and only 33 studies considered cumulative impact as a topic. Screening at abstract level revealed that they all approached this in terms of the cumulative impacts of one energy option (e.g. offshore wind), usually also on just one species or sector (such as birds or fishing), and so did not provide relevant information on the cumulative effects of different energy supply or demand options. Therefore, only the broadest iteration of the primary question was addressed.

Distinct themes emerged in the evidence returned by searches for the impacts on benthic habitats by the foundations of tidal current and offshore wind turbines:

- Positive impacts were reported for fish, lobster, edible crab and velvet swimming crab, which had a high abundance and/or biomass near the device foundations compared to the control situation. The relationship appeared species specific with fish: cod and pouting exhibited an association with or attraction to device structures, while a weaker or negative association was seen for flatfish species, particularly dab. The association of commercial species with energy structures was reported across multiple studies, but there were no studies empirically evaluating the implications of these effects beyond the footprint of the device foundations and so effects on fisheries are unknown.
Evidence was similarly positive for mussels, barnacles, and similar colonising epifauna, suggesting an increase in their biomass at marine renewable energy device foundations. However, certain species colonising turbine foundations (such as the ascidian, *Ciona intestinalis*) can dominate and hence limit biodiversity.

Evidence of specific impacts on sandbank, mudbank and reef habitats and associated benthic fauna from seven studies provided mixed positive and negative results.

Consistent results across studies suggest changes in sediment particle size.

An increase in the density and diversity of infauna was also reported with some consistency. However, a negative effect may be that the composition of the communities was different before and after turbine construction, and so the natural community may be lost. These effects on benthic communities appear to be limited to the immediate footprint of device foundations.

Although studies used robust data collection methods and included before/after control/impact (BACI) comparisons, the limited temporal scale on which baseline data was collected may be insufficient to detect patterns of natural variability, reducing confidence in conclusions drawn about the impacts of the energy devices.

The duration and reversibility of impacts remains unknown, due to a lack of long terms studies or experience of decommissioning.

There is a greater body of evidence for offshore wind, and more variables have been studied in that context than for tidal current turbines. Where similar parameters were assessed (sediment, fish abundance), the impacts were broadly consistent across both technology types, and so the cumulative impacts or different marine renewables are likely to act in the same direction. Whether the magnitude of the impact would increase in a linearly additive manner, or through a more complex relationship is unknown.

In terms of the perceptions of the public and stakeholders:

There was high agreement across the four studies which identified NIMBYism: people showed a general recognition of the benefits from renewable energy and the need to address climate change but were reluctant to accept developments near their homes.

A positive perception of employment opportunities and potential economic benefits from cheaper electricity or community ownership was found across multiple studies and multiple technologies.

Perceived negative impacts were reduced visual amenity, reduced house prices, and a loss of fishing and tourism opportunities.

Evidence was repeated across multiple studies but the limited number of studies within the data extraction process limits confidence in the evidence.

**Caveats arising from the REA process**

The following caveat should be attached to this report:

The work undertaken was part of a scoping exercise to assess the Rapid Evidence Assessment methodology developed as part of SPLiCE Phase 1 (Smithers, 2015), for which limited resource was available. Therefore, a comprehensive assessment of the available evidence was not undertaken, and so the outputs should be considered as examples only and should not be interpreted as providing evidence that can be used in addressing the primary and secondary questions posed.
Appendix 4 - Executive summary – Output on Knowledge gateway design and data specification

This report provides a high level functional data specification and technical architecture options available for the provision of a Knowledge Gateway (KG) for the SPLiCE project. Phase 1 of the SPLiCE project includes the development of user stories, a high level functional data specification and technical architecture options to support the project requirements. In the original plan, Phase 2 of the project would focus on building the Knowledge Gateway and on its population.

The requirement of the KG is to contain analyses of the environmental, economic and social impacts of energy system components required to deliver emissions reductions by 2050. In another output from SPLiCE Phase 1, a method for analysing impacts was developed through Rapid Evidence Assessments (REAs)\(^\text{31}\). This draft specification for the KG is based on the REA method and guidance. This report provides analysis of the requirements, functionality and options so that the KG can contain and provide access to the REAs.

The options included in this report have been designed based on inputs from a number of sources including a workshop, response to a questionnaire, and desk based research.

Three groups of users were considered as required in the specification for the work:

- Group 1 – central government policy officials
- Group 2 – local government, enforcement bodies and developers
- Group 3 – Non governmental organisations (NGOs) and the general public.

Priority has been given to the needs of Group 1 – central government policy officials though engagement has included all three groups. Engagement activities are summarised in the table below.

<table>
<thead>
<tr>
<th>Engagement activities to identify user needs for the Knowledge Gateway</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity</strong></td>
</tr>
<tr>
<td>Workshop</td>
</tr>
<tr>
<td>Questionnaire</td>
</tr>
<tr>
<td>Workshop</td>
</tr>
<tr>
<td>Interviews</td>
</tr>
</tbody>
</table>

The data gathered from the workshops, interviews along with other data collected has allowed a series of user stories to be created. User stories provide a concise way of describing what a user wants the system or a piece of functionality to do.

The options presented in this report focus on the functional, data and non-functional requirements of the system and are driven by the user stories collected in the workshop, questionnaires and interviews. The Non-functional requirements are analysed in the Technical Architecture Options Section. A proposed data-model.

This document should be read in conjunction with the REA Methodology (see footnote) as this provides full detail of what is required for each of the 10 outputs defined (shown in the table below) under the methodology.

<table>
<thead>
<tr>
<th>Output</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The REA protocol</td>
</tr>
<tr>
<td>2</td>
<td>Results of screening all individual papers</td>
</tr>
<tr>
<td>3</td>
<td>Data extraction form</td>
</tr>
</tbody>
</table>

---

One key output from discussion with users was a preference for the method for Rapid Evidence Assessment to constrain the method of review and the presentation of results to a high degree. This will assist comparison of assessments and can be aided by providing one option where the Knowledge Gateway contains the information from the assessments in the form of a database. This is the prime option explored here. A lower cost option has also been considered, which would still permit comparison of assessments. This would be to provide data templates which are completed offline and then uploaded to the Knowledge Gateway.

Indicative costs to build the Gateway are estimated as of the order of £100k for the primary option and of the order of £70k for the lower cost option, with annual ongoing costs estimated as £10k to £20k.

| 4 | Confidence in evidence across multiple papers |
| 5 | Volume and characteristics of the overall evidence base |
| 6 | A concise summary of the evidence |
| 7 | Significance of impacts of energy supply/demand option |
| 8 | Mitigation and enhancement measures |
| 9 | A list of knowledge gaps and research needs |
| 10 | Caveats arising from the REA process |
Appendix 5 - Executive summary – Output on impact evaluation and assessment framework

Purpose
1. The impacts (environmental, social and economic) of the diverse components of energy pathways are very different. This report examines how these impacts might be assessed and compared, through valuation and other approaches, and the strengths, limitations and potential linkages of different methodologies. In doing so it aims to provide support for policy decisions about the choices among the diverse range of energy supply and demand options.

Focus
2. The focus of the report is the assessment and comparison of the impacts on the environment in societally relevant ways. Social, health and economic impacts are also considered.

Approach
3. The approach has been to review different methodologies for impact assessment: ecosystem services assessment; monetary valuation and economic approaches; health impact and social impact; and social appraisal and to identify where they have or have not been applied to energy related issues. The key assessment approaches have been subjected to an evaluation through a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis.

Findings of the review
Ecosystem service assessment
4. Ecosystem service assessment approaches provide a framework to organise information about environmental attributes important to society. Their broad aim is to relate the environment to a policy and decision making context, and their anthropocentric perspective facilitates monetary and non-monetary valuation.

5. The steps required to apply ecosystem service assessment within impact assessment have been demonstrated, although rarely empirically applied in the context of energy options, and so issues of appropriate spatial and temporal scales must be considered in applying ecosystem service approaches in this context.

6. The National Ecosystem Assessment and Natural Capital Committee approaches have been developed for the UK context but are derivative from, and hence rather similar to, previous key frameworks and typologies, and so they are the most appropriate to use in assessing environmental impacts of different energy supply and demand options.

7. Ecosystem service classifications should be tailored and applied according to the environmental context in which they are being used. To assess impacts of different energy pathways on the environment, classifications should include abiotic services. The Common International Classification of Ecosystem Services (CICES) provides a useful starting point for considering the ecosystem services that should form part of the assessment.

8. In order to understand any trade-offs in environmental impacts it is essential to consider a comprehensive suite of ecosystem services (rather than selecting easily quantified elements).

Valuation of ecosystem service benefits
9. Economic valuation of natural resources seeks to better quantify the societal value of ecosystem goods and services and can also provide a common metric to allow the disparate services within an ecosystem to be better compared when evaluating costs and benefits.

10. There are some ecosystem services for which it is feasible and appropriate to use monetary valuation as a metric, assuming that the limitations of particular methods are taken into account in any assessment. Monetary valuation is particularly applicable to provisioning and carrier services (such as food, raw materials and transport), for which market prices are available. With the notable exception of recreation (usually valued through revealed preference methods) monetary valuation is not appropriate for most cultural services. It may also be possible to obtain monetary values for certain regulating services.

11. The TEEB ecosystem service Valuation Database, available from the Ecosystem Services Partnership website (http://www.tse.nl/esp), holds information from a large number of empirical studies, the results of which could potentially be applied in a UK energy context. However, this database does not appear to have been updated since 2010.

Methods for assessment of diverse impacts
12. Health impact analysis is an established procedure that takes into account wider socio-economic and environmental considerations and considers vulnerable groups. Its inclusion in the assessment of different energy options could help identify threats, but also opportunities and actions to improve health.

13. Social impacts are the direct or indirect effects an action, activity, programme, or policy has on a society, community, family or individual. Complementary quantitative and qualitative methods are available that can be usefully combined to capture the full range of possible social impacts.

14. While market and monetary values can approximate reasonably well for social impacts in some cases, in many cases it is just not possible to monetise an outcome, or capture its full value through monetary valuation in a meaningful way.

15. Macro-economic approaches (e.g. computable general equilibrium models and input-output analysis) can provide additional tools for assessment of impacts on the broader economy and specific sectors impacts, especially in terms of outputs, employment and GDP, due to changes in the use of different environmental resources.

**Evaluation of impacts**

16. By using a formal and established procedure, cost-benefit analyses and deliberative monetary valuation encourage the identification of economic benefits and costs in a way which aims to be systematic and objective in order to form an opinion of the social desirability of a proposal.

17. Whilst cost-benefit analyses provide a simple and potent approach to legitimate decisions, they lack scope for public and stakeholder engagement, and do not readily indicate the uncertainties and ambiguities that are particularly associated with environmental impact and ecosystem service valuation.

18. There are a number of different social appraisal methods that can be applied to compare and hence evaluate different impacts (environmental, social and economic) of a very diverse range of energy supply and demand options. Each may be implemented in a wide variety of different ways, subject to a range of different general and context-specific evaluative imperatives and hence each method comes with its own set of pros and cons.

19. The choice of an evaluative framework will depend on the focus of the issues being evaluated and the intended use of the evaluation. A cost-benefit analysis approach is more suited to supporting the justification of policy and decisions, with legitimation and acceptance potentially being driven by the most powerful policy actors supported by experts and key stakeholders.

20. A more inclusive approach (such as multi-criteria mapping, which considers different perspectives on policy options) would arguably be more suited to addressing divergent interests in society, and hence increasing robustness, accountability and legitimacy.

**Proposed evaluation framework**

21. A conceptual framework for the process of evaluating impacts arising from different energy options shows how the elements of the review interact and interlink (Figure 5.1, reproduced overleaf).

22. Changes in natural capital stocks and flows (ecosystem goods and services) can be assessed with various metrics (biophysical, monetary and non-monetary values, health and social metrics) as well as qualitative and narrative information. This range of information can, and should, all inform decisions related to energy pathways.

23. Cost-benefit analysis will not permit full evaluation of all environmental and social impacts as not all of them can be monetised.

24. Multi-criteria assessment methods, however, can accommodate information in a range of metrics, including the outputs of economic appraisals such as cost-benefit analysis, and thus forms basis of the evaluation framework proposed.

25. The choice of pathways within the evaluation framework is context dependant and will need to be tailored to the questions posed and the purpose for which the answer is sought, as well as to the resources available.

**Key recommendations**

26. The assessment process should utilise the Natural Capital Committee approach as an overarching framework to identify the natural capital and ecosystem services information that should be considered in comparing energy options.

27. Economic values should be used where available and appropriate, supported by additional relevant data (quantitative and qualitative) on environmental, social and health impacts.
28. The structured framework provided by multi-criteria assessment methods should be used to evaluate the resulting environmental, social and economic information, ideally using an inclusive approach that allows the perspectives of a range of stakeholders to be incorporated.
Figure A5.1. Conceptual framework for the impact evaluation process

Natural capital assessment

**Natural Capital Stocks**
Geological, physical, chemical and biological components of major marine and land-use categories

**Natural Capital Flows**
(Ecosystem goods & services)

Intermediate/supporting and poorly understood regulating services
(e.g. biodiversity, primary production, larval and gamete supply, nutrient cycling, biological control)

**Most cultural services**
(heritage, cultural, aesthetic, symbolic, sacred/religious, existence, bequest)

**Provisioning services**
(nutrition, raw materials, energy)

**Selected cultural services**
(recreation, tourism)

Well understood regulating services
(carbon sequestration, control of flooding and erosion, water supply)

Further assessment

**Health Impact Assessment**

**Social Impact Assessment**

**Macro-economic assessment**

Assessment metrics

**Bio-physical metrics**
(e.g. quantities, rates, condition indices), which should relate where possible to national environmental monitoring programmes

**Non-monetary values**
Qualitative and narrative information

Monetary values

Evaluation framework

**Social appraisal methods**
- Multi-criteria Assessment
- Multi-criteria mapping
- Social multi-criteria evaluation
- Qualitative participation deliberation
- Q method

**Cost Benefit Analysis**

**Deliberative monetary valuation**
Appendix 6 - Recommendations for informing public debate

Overview

The SPLiCE programme on Sustainable Pathways to Low Carbon Energy will fill gaps in knowledge about the sustainability of different mixes of energy supply and demand options needed to deliver 2050 greenhouse gas emissions targets.

One of three questions to be addressed by SPLiCE is:

- How can we provide accessible, clear information to the public and other stakeholders to support future debates on sustainable energy choices?

The current Phase 1 of the SPLiCE programme includes establishment of a preliminary framework for engaging the public with the required output being recommendations for how information about the impacts, risks and benefits of future energy options can be made more easily available and accessible to the public in order to inform debate about choices and trade-offs.

Current position

The first milestone is delivery of a review of methods of engagement with the public and other interested groups on sustainable energy options. An initial draft was prepared as background to the discussion at the SPLiCE workshop on 9th October. Following discussion with Defra, it was agreed that this would cover a broad range of potential approaches. A draft was issued to Defra on 18th December.

This was discussed with the Management Board for SPLiCE Phase 1 in January 2015, together with potential approaches to developing the output for Phase 1. Two approaches were considered:

- A generic approach to develop principles of providing information on the sustainability of energy systems.
- Recommendations on how to deliver the information coming out of SPLiCE.

On the development of generic principles it was noted that there is already significant research completed or ongoing in this area and information of this type is available from the Government’s Sciencewise programme32 and elsewhere33.

For the option of focusing on how to deliver information generated by SPLiCE the details of what is appropriate for any particular input to public debate will depend intimately on the purpose of the debate, together with the nature of the energy option and impacts being considered. It is also noted that there are several examples of how information relating to energy options, impacts, benefits and risks can be made available to the public to inform public debate.34 Candidate materials could be developed, but it is very unlikely that these would be directly relevant to any specific input to inform public debate that may be required later in the SPLiCE programme. It is currently too early in the SPLiCE programme (Phase 1) to identify the specific areas in which information will be required and the shape of the outputs from the programme.

Bearing in mind the availability of generic guidance elsewhere, and the potential lack of more general applicability at this time of a SPLiCE focused approach, the Management Board decided that work stream 5 in Phase 1 of SPLiCE should stop.

---


34 Examples that are relevant to some or all of: energy options, impacts, risks and benefits are available from ongoing work or recently published reports from projects supported by the Government’s Sciencewise programme. Reports, including materials used to inform debates are published on the Sciencewise website. Recently published and ongoing projects include: shale gas and oil, MRWS siting process, trajectories for carbon emission reductions, the national ecosystems assessment, nature improvement areas, and social impacts of marine renewable options in Scotland.
Appendix 7 - Complete list of energy system components and impact categories

Table A7.1. List of energy system components used in the survey and related sector.

<table>
<thead>
<tr>
<th>Energy system component</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas power stations</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Coal power stations</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Biomass power stations</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Power Sector</td>
</tr>
<tr>
<td>CCS power stations</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Onshore wind</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Wave power</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Tidal Stream</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Tidal Range</td>
<td>Power Sector</td>
</tr>
<tr>
<td>PV</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Geothermal power</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Hydroelectric power</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Energy-from-waste plants</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Land dedicated to bioenergy</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Unconventional gas</td>
<td>Power Sector</td>
</tr>
<tr>
<td>Gas Transmission and Distribution Grid</td>
<td>Networks</td>
</tr>
<tr>
<td>Power Interconnectors and Transmission/Distribution Network</td>
<td>Networks</td>
</tr>
<tr>
<td>Hydrogen Transmission and Distribution Grid</td>
<td>Networks</td>
</tr>
<tr>
<td>District Heating</td>
<td>Networks</td>
</tr>
<tr>
<td>CO₂ Transmission Network</td>
<td>Networks</td>
</tr>
<tr>
<td>Average Internal Temperature of Buildings</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Insulation and building fabric</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Heating and Cooling Demand</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Lighting, Cooking and Demand from Appliances</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Energy intensity of industry</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Biomass Boilers</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Heat pumps</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Gas Boilers</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Biogas (including anaerobic digestion of bio waste)</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Biomass for industrial heating</td>
<td>Built Environment and Industry</td>
</tr>
<tr>
<td>Electricity Storage</td>
<td>Storage</td>
</tr>
<tr>
<td>H₂ Storage</td>
<td>Storage</td>
</tr>
<tr>
<td>CO₂ Storage</td>
<td>Storage</td>
</tr>
<tr>
<td>Electric Vehicles</td>
<td>Transport</td>
</tr>
<tr>
<td>Fuel Cell Vehicles</td>
<td>Transport</td>
</tr>
<tr>
<td>Hybrid vehicles</td>
<td>Transport</td>
</tr>
<tr>
<td>Energy system component</td>
<td>Sector</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Plug-in Vehicles</td>
<td>Transport</td>
</tr>
<tr>
<td>Liquid Biofuels</td>
<td>Transport</td>
</tr>
<tr>
<td>Domestic freight</td>
<td>Transport</td>
</tr>
<tr>
<td>Aviation</td>
<td>Transport</td>
</tr>
<tr>
<td>Shipping</td>
<td>Transport</td>
</tr>
<tr>
<td>Domestic Passenger Transport Demand</td>
<td>Transport</td>
</tr>
</tbody>
</table>

**Table A7.2.** Impact categories and sub-categories used in the current study

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Impact sub-category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Environment</td>
<td>Water quality&lt;br&gt;Waste to water&lt;br&gt;Water availability</td>
</tr>
<tr>
<td>Water: to include</td>
<td>Land use, i.e. land change&lt;br&gt;Below ground&lt;br&gt;Waste to land&lt;br&gt;Above ground</td>
</tr>
<tr>
<td>Land</td>
<td>NOx&lt;br&gt;SO₂&lt;br&gt;Particulate matter (PM)</td>
</tr>
<tr>
<td>Social Impacts</td>
<td>Public acceptability&lt;br&gt;Energy security&lt;br&gt;Visual intrusion&lt;br&gt;Differential incidence of impacts across specific locations (rural vs urban), income distribution and specific groups e.g. age groups, gender, minority groups</td>
</tr>
<tr>
<td>Economic Impacts</td>
<td>Employment&lt;br&gt;Economic activity / revenues</td>
</tr>
<tr>
<td>Human Health</td>
<td></td>
</tr>
<tr>
<td>Biodiversity</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 8 - Exemplary Research Gaps for a Prioritised selection of Energy System Components and Impact Areas

Table A8.1. Ranking of energy system components according to the Urgency and Criticality criteria and the composed ranking

This list should be considered in the light of the methodology used. A discussion of the limitations of the methodology is in Section 4.1.1. of this report.

<table>
<thead>
<tr>
<th>RANKING</th>
<th>ENERGY SYSTEM COMPONENT</th>
<th>IMPACT AREA</th>
<th>EXEMPLARY RESEARCH GAP BASED ON ANALYSIS OF PUBLISHED LITERATURE REVIEWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CCS - Storage</td>
<td>Long-term Safety</td>
<td>Systematic assessment of factors affecting the variability of estimates found in the literature</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Developing appropriate, credible and long term mechanisms to deal with risks and their associated liabilities</td>
</tr>
<tr>
<td>2</td>
<td>DSR</td>
<td>Energy Consumption</td>
<td>Evidence on the way consumers implement DSR including identifying shifted loads and intensity of price responses</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Persistence of energy reductions from DSR for different types of DSR measures</td>
</tr>
<tr>
<td>3</td>
<td>Nuclear Power</td>
<td>Human Health</td>
<td>Uncertainty related to biological distributions and biochemical transfers of radionuclides, including impact of low doses to large populations over long periods of time</td>
</tr>
<tr>
<td></td>
<td>Land</td>
<td></td>
<td>Uncertainties related to risk appraisal and management of low-probability, high consequence events</td>
</tr>
<tr>
<td>4</td>
<td>CCS - Storage</td>
<td>Marine environment and biodiversity</td>
<td>Robust assessment of impacts of CO₂ leakages in subseabed storage, focused on UK-based experience. Topics may include: impacts on chemistry in the sediment water, dissolved metal concentrations and local biogeochemical cycles; secondary geochemical effects; factors affecting the variability in species responses; impacts of organism-level responses on the community and ecosystem response</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Uncertainty of economic impacts of Enhanced Oil Recovery (EOR) in depleted fields in the North Sea (if latter experience is judged relevant)</td>
</tr>
<tr>
<td>4</td>
<td>CCS - Storage</td>
<td>Economic</td>
<td>Systematic assessment of factors influencing the quantification of benefits of EOR in the UK and abroad</td>
</tr>
<tr>
<td>5</td>
<td>Land for Bioenergy</td>
<td>Land (Indirect)</td>
<td>Integrated modelling for studying environmental (GHG, biodiversity, water management), economic and social impacts of Indirect Land Use Change</td>
</tr>
<tr>
<td>5</td>
<td>Land for Bioenergy</td>
<td>non-UK impacts</td>
<td>Applies to both direct and indirect, environmental, social and economic. For example, impacts of large scale 2nd generation bioenergy demand in USA/EU and in the Global South. Integrated approaches would be substantially beneficial</td>
</tr>
<tr>
<td>6</td>
<td>DSR</td>
<td>Social</td>
<td>Implications of the social impacts (allocation of net benefits across different types of customers) of DSR</td>
</tr>
<tr>
<td>RANKING</td>
<td>ENERGY SYSTEM COMPONENT</td>
<td>IMPACT AREA</td>
<td>EXEMPLARY RESEARCH GAP BASED ON ANALYSIS OF PUBLISHED LITERATURE REVIEWS</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------</td>
<td>---------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>6</td>
<td>DSR</td>
<td>Economic Review</td>
<td>Estimates of net benefits at system level of DSR measures, including critical assessment of factors influencing the variability of the estimates — through RAE or expert paper.</td>
</tr>
<tr>
<td>7</td>
<td>Electric Vehicles</td>
<td>Air</td>
<td>Air impacts depending on EV uptake, future electricity mixes and vehicle performance and development from both car passengers and other vehicles, e.g. buses and road freight.</td>
</tr>
<tr>
<td></td>
<td>Electric Vehicles</td>
<td>Human Health</td>
<td>Human health impacts related to air quality improvements.</td>
</tr>
<tr>
<td></td>
<td>Electric Vehicles</td>
<td>Economic Review</td>
<td>Impacts of adoption of EVs in terms of value (and related employment) of UK industry in a global market - through RAE or expert scoping paper.</td>
</tr>
<tr>
<td>8</td>
<td>Energy Intensity of Industry (EII)</td>
<td>Biomass</td>
<td>Life cycle comparison of the environmental impacts of using biomass in the chemical sector as a fuel or as a feedstock.</td>
</tr>
<tr>
<td>9</td>
<td>Onshore Wind</td>
<td>Biodiversity</td>
<td>Assessment of impacts and development of guidelines for use of real-time monitoring to tailor windfarm operational management to bird flight behaviour.</td>
</tr>
<tr>
<td></td>
<td>Unconventional Gas</td>
<td>Air (Fugitive Emissions)</td>
<td>Extent (likelihood of occurrence and quantity) of accidental venting of methane to the atmosphere, including strategies to manage this matter.</td>
</tr>
<tr>
<td></td>
<td>Unconventional Gas</td>
<td>Mechanisms of fugitive emissions release and their pathways, for example how gas leaks out of a hole in a casing.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power Network</td>
<td>Review</td>
<td>Impact of cross-border connections on the economy e.g. electricity price and system stability.</td>
</tr>
<tr>
<td>12</td>
<td>Aviation</td>
<td>Economic Review</td>
<td>Impacts of aviation on local, regional and national economies.</td>
</tr>
<tr>
<td>13</td>
<td>Land for Bioenergy</td>
<td>Land (Direct)</td>
<td>Methodologies to increase transparency of Land Use Change modelling efforts, including lifetime-end land use reversion and large scale production (and use) impacts.</td>
</tr>
<tr>
<td></td>
<td>Land for Bioenergy</td>
<td>Biodiversity</td>
<td>Site-specific and species-specific factors influencing impacts on biodiversity.</td>
</tr>
<tr>
<td></td>
<td>Land for Bioenergy</td>
<td>Water</td>
<td>Impact of large scale bioenergy production, intensification of production, and use of marginal land.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Management requirements in areas with limited supply to avoid risk of water availability.</td>
</tr>
<tr>
<td>RANKING</td>
<td>ENERGY SYSTEM COMPONENT</td>
<td>IMPACT AREA</td>
<td>EXEMPLARY RESEARCH GAP BASED ON ANALYSIS OF PUBLISHED LITERATURE REVIEWS</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------</td>
<td>-------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>14</td>
<td>Buildings</td>
<td>Environmental Impacts</td>
<td>Review Relative importance of factors affecting water quality including crop type and management and usage of fertiliser and pesticide</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extent to which environmental impacts from LCA studies of buildings can be reliably generalised and compared - through a REA or expert scoping paper</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>More empirical data on building performance so that comparison can be robustly implemented</td>
</tr>
<tr>
<td>15</td>
<td>Energy Intensity of Industry (EII)</td>
<td>Waste</td>
<td>Assessment of potential conflicts between strategies aimed at reducing waste and security of supply to plants using it as feedstock</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Comparison of the environmental impacts of using wastes as feedstock either through life cycle analysis or a review of existing studies</td>
</tr>
<tr>
<td>16</td>
<td>Unconventional Gas</td>
<td>Water</td>
<td>Structure and dynamics of near-surface groundwater system, including how different formations, geology and locations respond to specific interventions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Properties of chemical additives and related by-products, as well as their fate and pathways in the field. This includes better understanding of the relationship between chemicals and different stakeholders (operators, residents, etc.)</td>
</tr>
<tr>
<td>17</td>
<td>Power network</td>
<td>Human Health</td>
<td>Review Exposure to electromagnetic fields – through REA or expert scoping paper</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Impacts on seabirds and noise-sensitive marine mammals including consequences that site-specific, species-specific and seasonal factors may have on the population of affected species and services provided by the ecosystems</td>
</tr>
<tr>
<td>18</td>
<td>Offshore Wind</td>
<td>Biodiversity</td>
<td>Uncertainty related to the total effects of artificial reefs, including impact on fish density and biomass</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Robust estimates of costs of radioactive waste storage and decommissioning</td>
</tr>
<tr>
<td></td>
<td>Nuclear Power</td>
<td>Economic</td>
<td>Robust estimates of damages associated with major accidents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social</td>
<td>Factors affecting public acceptability</td>
</tr>
<tr>
<td></td>
<td>Nuclear Power</td>
<td>Social</td>
<td>Impact of incidents and the way in which they are reported in shaping public acceptability of nuclear</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td></td>
<td>Water consumption for mining and processing nuclear fuel</td>
</tr>
<tr>
<td></td>
<td>CCS - Storage</td>
<td>Social</td>
<td>Discharge of waste waters and antifouling chemicals from ships transporting construction material</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Factors influencing the success of specific projects and how they can be mitigated</td>
</tr>
<tr>
<td>20</td>
<td>Aviation</td>
<td>Air</td>
<td>Robust quantification of impacts of airports to local air pollutants, in particular Particulate Matters</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Assessment as to whether PM emitted by aircraft in flight can be treated and modelled differently from those emitted at ground level</td>
</tr>
<tr>
<td>RANKING</td>
<td>ENERGY SYSTEM COMPONENT</td>
<td>IMPACT AREA</td>
<td>EXEMPLARY RESEARCH GAP BASED ON ANALYSIS OF PUBLISHED LITERATURE REVIEWS</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------</td>
<td>-------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Aviation</td>
<td>Human Health</td>
<td></td>
<td>Generally accepted dose-response functions between pollutants and health impacts</td>
</tr>
<tr>
<td>Aviation</td>
<td>Social</td>
<td>Review</td>
<td>Any potential relationship between aircraft noise and learning disruptions, mental health and hormone changes</td>
</tr>
<tr>
<td>aviation</td>
<td>Review</td>
<td></td>
<td>Extent to which neighbourhoods near the airports are disproportionately affected by local pollution</td>
</tr>
<tr>
<td>Land for bioenergy</td>
<td>Economic</td>
<td></td>
<td>Impacts of bioenergy on food prices, food security and trade patterns as function of fuel prices and scale of production, increased use of biomass has an effect on specific sectors, e.g. forest based industries such as pulp and paper.</td>
</tr>
<tr>
<td>Land for bioenergy</td>
<td>Social</td>
<td>Review</td>
<td>Impacts of increased use of biomass on specific sectors, e.g. forest based industries such as pulp and paper.</td>
</tr>
<tr>
<td>Buildings</td>
<td>Social</td>
<td></td>
<td>Data simultaneously covering a number of indicators to assess the importance of occupancy behaviour among other factors influencing the difference between theoretical and actual building performance</td>
</tr>
<tr>
<td>Buildings</td>
<td>Water</td>
<td></td>
<td>Profitability and impact of water-saving measures in current regulatory setting given trade-offs between consumption of water, energy and materials</td>
</tr>
<tr>
<td>DSR</td>
<td>Air</td>
<td></td>
<td>Air and related human-health impact of DSR as a function of marginal generating technology, level of power demand, ability to shift consumption and sector in which DSR takes place</td>
</tr>
<tr>
<td>DSR</td>
<td>Human Health</td>
<td></td>
<td>Factors affecting profitable applications of batteries and compressed air energy storage systems in the UK</td>
</tr>
<tr>
<td>Electricity Storage</td>
<td>Economic</td>
<td>Review</td>
<td>Factors influencing societal safety concerns around large stores of energy</td>
</tr>
<tr>
<td>Electric Vehicles</td>
<td>Social</td>
<td>Review</td>
<td>Allocation of potential benefits from EVs across geographic areas, income brackets, and population groups based on age and gender - through QSR and subsequent modelling</td>
</tr>
<tr>
<td>Heat Pumps</td>
<td>Social</td>
<td>Review</td>
<td>Factors influencing public acceptability and adoption of heat pumps - through a REA or expert scoping paper</td>
</tr>
<tr>
<td>Heat Pumps</td>
<td>Economic</td>
<td>Review</td>
<td>Employment impacts and industry-wide schemes to ensure rapid uptake of skills required to install and service heat pumps - through a REA or expert scoping paper</td>
</tr>
<tr>
<td>Onshore Wind</td>
<td>Social</td>
<td></td>
<td>Factors influencing local opposition to development of wind farms (NIMBYism) and general public acceptability of wind energy</td>
</tr>
<tr>
<td>Onshore Wind</td>
<td>Social</td>
<td></td>
<td>Assessment of local community effects including visual impacts on landscape, importance of remoteness and local economic benefits</td>
</tr>
<tr>
<td>RANKING</td>
<td>ENERGY SYSTEM COMPONENT</td>
<td>IMPACT AREA</td>
<td>EXEMPLARY RESEARCH GAP BASED ON ANALYSIS OF PUBLISHED LITERATURE REVIEWS</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------</td>
<td>-------------</td>
<td>---------------------------------------------------------------------</td>
</tr>
<tr>
<td>28</td>
<td>Unconventional Gas</td>
<td>Human Health</td>
<td>Systematic tracking of exposure in conjunction with ancillary stressors (e.g. noise, light, traffic and rapid change) especially at the population scale</td>
</tr>
<tr>
<td></td>
<td>Unconventional Gas</td>
<td>Social</td>
<td>Social and economic impacts of unconventional gas in the USA (e.g. boomtown growth, migration patterns and pressure on public services, and how they could apply to an UK context)</td>
</tr>
<tr>
<td></td>
<td>Unconventional Gas</td>
<td>Economy</td>
<td>Review</td>
</tr>
<tr>
<td>29</td>
<td>Nuclear Power</td>
<td>Marine Environment</td>
<td>Sensitivity of impacts of nuclear plants as a function of changes in storm surge, flooding, tidal ingress and nuclear islanding expected in response to change in the climate</td>
</tr>
<tr>
<td></td>
<td>Nuclear Power</td>
<td>Biodiversity</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Aviation</td>
<td>Land (Impact of Biofuels)</td>
<td>A Life Cycle Assessment (LCA) to identify feedstocks with lowest level of impacts in case deployment targets (e.g. EU Biofuel FlightPath Initiative) are reached or increased</td>
</tr>
<tr>
<td>31</td>
<td>Energy Intensity of Industry (EII)</td>
<td>Environmental impacts of energy efficiency heating options</td>
<td>Review</td>
</tr>
</tbody>
</table>