

Unconventional Hydrocarbons in the UK Energy System

What are the research gaps around induced seismicity and shale gas? A summary of the findings of the first UKUH Integration Event (May 2019)

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Executive Summary

The NERC-ESRC Unconventional Hydrocarbons in the UK (UKUH) Energy System Programme (the UKUH Programme) comprises five Challenges. The ambition of which is to deliver a holistic programme for researching the shale gas system in the UK from the resource potential through to potential environmental and social impacts. Challenge 1 is responsible for the coordination, integration and synthesis of the six research projects that comprise the other four Challenges. A series of workshops is one of the primary channels to integrate the social science and geoscience elements of the UKUH Programme. The inaugural workshop of this integration series was held on 9 May 2019 in The Shard, London on the topic of induced seismicity. This publication summarises the outcomes of this workshop.

The inaugural Challenge 1 workshop aimed to discuss the key unknown and uncertain research questions (issues) relating to induced seismicity caused by hydraulic fracturing for shale gas extraction, with the objective to collectively identify potential research gaps within the deliverables of the UKUH Programme. The workshop theme (induced seismicity) was chosen by the Challenge 1 team as the focus as it was deemed timely and important to all research projects within the UKUH Programme. It is intended that future workshop topics will be identified by other Challenge members.

The workshop led to the identification of three priority areas for further research that are relevant to the UKUH Programme. These topics include **reliable predictions** around induced seismicity, issues around **scaling-up** shale gas development and the associated **cumulative impacts**, and the need for **common and consistent language** and terminology around induced seismicity.

This publication is particularly timely as it follows the UK Government's decision (announced 2nd November 2019) to suspend hydraulic fracturing activities in England¹ until further notice. The moratorium follows a series of seismic events up to Magnitude 2.9 associated with hydraulic fracturing activities by Cuadrilla at the Preston New Road 2 (PNR-2) well as well as the publication of an Oil and Gas Authority (OGA) report¹ summarising the results of scientific analysis of data from Cuadrilla's operations at Preston New Road 1 (PNR-1). This scientific analysis, commissioned by OGA, has led to the publication of four independent studies¹ and two overview reports¹. The interim report prepared by OGA (published on 1 November 2019) concludes that it is not currently possible to predict with certainty the maximum magnitude of seismic events of UK hydraulic fracturing operations¹. Specifically, the OGA's report³ states that 'the possibility of larger [seismic] events could not be excluded, and these could cause damage and disturbance unacceptable under the current BEIS policy guidance'. The overarching implications of the report are that the methods for predicting maximum magnitude cannot be relied on with certainty and further research is required to have confidence in future predictions.

The topic of uncertainty of making reliable predictions of maximum magnitude was identified and discussed at this inaugural integration event. As such, the Challenge 1 team will work with the other academics and researchers across all Challenges to identify where additional research could be carried out, supported by the Challenge 1 flexible fund, to address this uncertainty. Furthermore, research into potential cumulative impacts and communication and language challenges around induced seismicity will become foci for future flexible fund projects.

1. Background to the project

In the summer of 2018, the Natural Research Council (NERC) and Economic & Social Research Council (ESRC) co-funded the Unconventional Hydrocarbon in the UK Energy System (UKUH): Environmental and socio-economic impacts and processes programme (<http://www.ukuh.org/>). The UKUH Programme aims to provide an independent scientific evidence base to understand potential environmental and socio-economic impacts of unconventional hydrocarbon extraction. Seven multi-institution consortium projects were funded to address the five key Programme Challenges identified by NERC and ESRC:

- Challenge 1: Assessing and monitoring the UK Shale Gas Landscape (UKSGL), led by Professor Richard Davies at Newcastle University.
- Challenge 2: An integrated assessment of UK Shale resource distribution based on fundamental analyses of shale mechanical and fluid properties, led by Professor Alastair Fraser at Imperial College, London
- Challenge 3: Impact of hydraulic fracturing in the overburden of shale resource plays: Process-based evaluation (SHAPE-UK), led by Professor Michael Kendall at University of Oxford.
- Challenge 4: Evaluation, Quantification and Identification of Pathways and Targets for the assessment of Shale Gas RISK (EQUIPT4RISK), led by Professor Robert Ward at the British Geological Survey (BGS).
- Challenge 5: This challenge comprises the following three projects focusing on the socio-economic impacts:
 - The social construction of unconventional gas extraction: Towards a greater understanding of Socio-economic impact of unconventional gas development, led by Professor Paul Stretesky at Northumbria University.
 - 'Fracking', Framing and Effective Participation, led by Professor Benjamin Sovacool at the University of Sussex.
 - Understanding the spatial and temporal dynamics of public attitudes and community responses to shale gas: an integrated approach, led by Professor Patrick Devine-Wright at the University of Exeter.

Challenge 1 has responsibility for managing a flexible fund to support additional research to address research gaps that may be required in response to the changes in the political, economic, social, technological, environmental and legal landscape in the UK.

2. Background to Integration Events

The Challenge 1 team is responsible for the coordination, synthesis and integration of all research projects within the overarching UKUH Programme. One mechanism for achieving effective coordination between the different Challenges has been to develop a series of Integration Events; each one focusing on a specific theme or topic that is of concern or relevance to all Challenge projects. The Challenge 1 team aims to hold at least one Integration Event per year during the 4-year UKUH Programme. These events are open to all members of the UKUH Programme, including members of the UKUH advisory boards and Challenge 1's interdisciplinary research team as well as invited stakeholders. Academics or researchers from within the UKUH programme can nominate themes or topics for consideration for future Integration Events.

The objectives of the Integration Events are to:

- (1) bring UKUH researchers together to share information about current knowledge on a topic of shared relevance based on UKUH research and activities to date, and to encourage the exchange of perspectives, knowledge, understanding, and experiences; and
- (2) map the range and breadth of issues and challenges relevant to the topic of the Integration Event and, if possible, to identify where current knowledge is well established, where there are knowledge gaps. The

events will be used to identify where these gaps will be addressed by the UKUH Programme, and where future work (potentially supported by Challenge 1 flexible funds) should focus.

The first integration event has the additional objective to introduce UKUH researchers to the integration programme and give them the opportunity to shape the topics and formats of future Integration Events.

3. Integration Event 1: topic, attendees and programme

Induced seismicity was selected to be the topic of the first Integration Event in the series. The topic was identified by the Challenge 1 lead as timely and relevant to all Challenge projects.

In total the Integration Event was attended by 46 participants, which included:

- academics and researchers funded by the UKUH Programme;
- members of the Programme's advisory board,
- stakeholders of the UKUH programme including regulators, operators, members of government departments, Town and Country planners
- Representatives from UKRI funding bodies, NERC and ESRC.

The Integration Event support team comprised of 5 researchers and Challenge 1 staff, with responsibility for organising, facilitating, and observing. There was also one dedicated observer whose role was to act as ethnographer/evaluator. The team aimed to deliver the smooth running of an event which achieved its objectives, and to gather information with which to evaluate the veracity of the outcomes from the day. The team also captured some of the key organisational learnings which can be built on to improve future Integration Events. These are presented in Sections 5 and 6 of this report.

The Integration Event was held over one day (10 am - 4 pm) and was organised into two parts:

Part 1: The first half of the day was committed to knowledge transfer via plenary presentations, allowing Challenge researchers to update each other on the leading-edge research on different aspects around induced seismicity and hydraulic fracturing for unconventional gas extraction, and to engage in short question and answer discussion.

Specifically, attendees heard about:

- background to the concept of induced seismicity, its causes and how this compares to natural seismicity in the UK (presentations from Dr Brian Baptie, BGS and Dr James Verdon, University of Bristol);
- an overview of the UK regulatory position with regards to induced seismicity (presentation by Kelsey Tymms, Oil and Gas Authority);
- the recent hydraulic fracturing activities and associated induced seismicity at the Preston New Road site (presentation by Huw Clarke, Cuadrilla);
- the public's perception of the risks associated with hydraulic fracturing in the UK and that of Oklahoma and Colorado in the US (presentations from Dr Darrick Evensen, University of Edinburgh and Dr Liesel Ritchie, Oklahoma State University).

The general format was two or three 10-15-minute-long presentations followed by approximately 20 minutes of Q&A.

Part 2: The second half of the day was structured to facilitate knowledge exchange amongst all attendees by discussing research challenges relevant to induced seismicity and by working together through facilitated activities to collectively identify remaining knowledge gaps. Specifically, attendees were charged with

answering the question: “*What do we know, and what don’t we know about unconventional gas extraction and induced seismicity?*”

The afternoon activities aimed to bring attendees together to discuss:

- key research questions (issues) that remain challenging, unknown or uncertain (these topics might be within discipline and across discipline);
- where there is and where there isn’t consensus regarding these topics;
- topics not addressed in the initial UKUH Programme and, therefore, where current gaps in research knowledge could potentially be filled using the Challenge 1 flexible fund.

4. Facilitated activities

The facilitated activities comprised of a series of progressive tasks which aimed to achieve the aim of answering “*What do we know, and what don’t we know about unconventional gas extraction and induced seismicity?*”. Tasks 1-4 were designed to identify issues that attendees felt remain challenging, unknown or uncertain surrounding induced seismicity and hydraulic fracturing for unconventional gas extraction. Task 5 was designed to identify where the currently funded UKUH Challenges could address these unknowns and to identify any potential outstanding research gaps.

The results of the facilitated breakout sessions have been summarised in a series of mind maps, appended to this report (**Appendix A**).

Task 1: Directly following the morning presentations, participants were asked “*what are the biggest issues, uncertainties and unknowns, that you identify when thinking about induced seismicity?*”. Each participant was asked to record a maximum of three issues on separate post-it notes. These were then displayed on whiteboards for all participants to view and for the facilitators to group thematically during the lunch break. While clustering the post-its, some common topics were identified within the cluster, and each cluster was given a heading. The whiteboards with all post-its (issues) relating to each cluster were then spatially distributed in the workshop venue.

Task 2: Grouped into five ‘teams’¹ the participants were asked “*is there any obvious theme or cluster that is missing that should be added? Or that should be changed or renamed?*”. The teams were invited to, individually and working together, identify any additional important unknown or uncertain issues not yet captured within the clusters, and to rename the cluster headings, if necessary. Each group had an assigned Facilitator. Their role was to simply support group working by e.g. clarifying their task, supplying post-its/pens, aid fair discussion, keep discussions on topic, as well as to keep time and so on.

This process consolidated the clusters into eight agreed ‘themes’, which were:

- Risk
- Characteristics of induced events
- Communication
- Public perception
- Context
- Geological data / uncertainty
- Governance / regulation / policy

¹In advance of the event, the organisers arranged all participants into **five** teams, in which each team comprised of people with a range of background knowledge topics, including a mix of those from the social science and geoscience Challenges.

- Development of shale gas

Task 3: The teams then considered the eight themes, by circulating the room, ‘carousel style’ and considering: do you agree with the way that the issues (which we are calling ‘topics’ and ‘sub-topics’ on the post-its) within the cluster are arranged? Can any issues be grouped into common topics/sub-topics, or rephrased to be clearer? Is there anything that should be added? Are there any issues that are in direct conflict? Again, this task was facilitated.

Task 4: Participants were then asked to “consider the unknowns/uncertainties identified - do you agree with it? Or do you think this is known or resolved?”. They were supplied with sticky coloured dots which they were invited to, individually, indicate their level of agreement as follows:

- **Green** dot to signify endorsement or agreement; the participants feels that the issue (sub-topic or topic) is uncertain or unknown;
- **Red** dot to signify disagreement; the participant feels that the issue is not uncertain or unknown;
- **Orange** dot to signify that the participant is unsure about that issue.

Participants could apply as many green, red or orange dots as they wished, and the task aimed to establish, in a non-confrontational way, where there is consensus and disagreement around the topics that have been identified.

However, all participants were given just two **blue** dots each. The blue dots were to be used to identify which topics / sub-topics were considered the most important around induced seismicity, i.e. topics of most concern. This enabled the topics to be ranked in order of priority.

Task 5: Finally, in order to identify where the UKUH funded research will address the identified unknowns and any potential research gaps, the six Principal Investigators (PI), who lead the Challenge projects 2-5 were asked to indicate the issues identified during this exercise that their research project will address. Each PI wrote their Challenge number against the post-it (issue) or group of post-its (sub-topic or topic) that their research project has, or will, address.

This task identified where there are research or knowledge gaps which the UKUH Programme will not address, and which are deemed to be important (blue dots).

5. Outcomes: mind-maps of the issues identified within the eight key themes

The facilitated activity at the Integration Event identified unknown and uncertain issues. These were recorded on post-its and have been summarised in a series of mind-maps using ‘X-mind’ software. For clarity, this Section of the report uses consistent language to distinguish between a ‘theme’, ‘topic’ and ‘subtopic’ as illustrated in **Figure 1**, with ‘theme’ being designated as the main issue. Each ‘theme’ has several ‘topics’ associated with it and in turn a ‘topic’ may have one or more related ‘subtopics’.

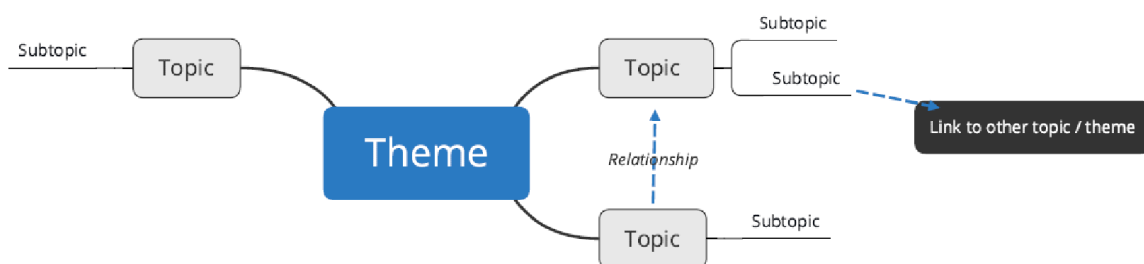


Figure 1: Illustration to explain terminology used to describe mind-map observations.

The mind-maps are considered to be a fair representation of the outcomes from the facilitated activity; some conditioning has been applied to consolidate issues and to remove duplicates simply for the purpose of clarity and to highlight key discussion points from the day. Specifically, the sub-topic or topics included in the mind-maps comprise information from post-its if one or more of the following criteria were met:

1. it had greater than five dots - regardless of colour (i.e. participants agree and/or disagree and/or are unsure about the issue)
2. it had one or more blue dot(s) (i.e. participants identified the issue to be a priority topic, and so one of key importance)
3. it had a Challenge research project assigned (i.e. the issue will be tackled within the UKUH Programme)

The following section comprises a summary of the key messages from each of the mind-maps. These messages are presented in no specific order of hierarchy but should be read alongside the corresponding mind-map.

6. Key messages from each theme

Theme 1: Development of shale gas

Four topics were identified within this theme, many of which were not related to induced seismicity. This perhaps indicates the challenge in dissociating or untangling other potential issues relating to shale gas development from those of induced seismicity.

Key messages include:

- ‘Benefits to wider society’ was endorsed by participants to be an uncertain issue with the highest number of green dots (4) compared with the other topics in this theme. The Challenge 5 PIs identified this to be an area that will be covered within their three research projects.
- The uncertainties around ‘scaling up’ regarding ‘how might the potential for induced seismicity be affected by development scenarios involving multiple well pads/ wells operating simultaneously or sequentially in an area’ received 6 green dots and this subtopic was also identified to be a priority issue (1 blue dot). As no Challenge project identified this as an area of research, this is considered to be a potential research gap. It is worth noting that within the ‘scaling up’ topic, the participants did not consider ‘shale gas and agriculture’ to be an uncertainty or unknown (6 red dots).
- ‘Environmental footprint’ received one blue dot, but this area of research will be addressed by the Challenge 4 project.

Theme 2: Characteristics of induced events

Four topics were identified within this theme, including ‘frequency of magnitude events’; ‘impact of numerous lower magnitude events’; ‘maximum magnitude’; and ‘induced versus triggered events’. In general, the facilitators observed that discussion around this theme was quite limited (i.e. dominated by leading voices and that fewer topics and sub-topics were identified). This may be because this is a highly technical area and may have engaged a lower number of participants, or that the level of agreement was high.

Key messages include:

- None of the topics within this theme received many green dots, however, the subtopic around the reliability of predictive models was endorsed by four green dots.
- Despite this, three out of four topics received blue dots (i.e. are priority issues). These three topics were ‘impact of numerous lower magnitude events’; ‘maximum magnitude’; and ‘induced versus triggered events’.

- Challenge 3 will address ‘induced versus triggered’. However, as no Challenge project identified ‘maximum magnitude’ or the ‘impact of numerous lower magnitude events’ to be an area of research within the UKUH Programme, these are potential research gaps. The latter links to the scaling up issues identified in Theme 1 (Development of Shale Gas).

Theme 3: Communication

Within this theme, participants identified the greatest number of topics (six) compared to the other seven themes, and attracted high levels of attention from the participants. Further, it was also noted during the facilitated activities that this discussions around this theme were particularly enthusiastic with high levels of engagement. However the conversations frequently drifted away from induced seismicity.

Key messages:

- The topic comprising ‘the use of common and simple language to describe complex and emotive subject’ received one of the largest number of endorsements (with 11 green dots).
- The topic of ‘how we can best communicate evidence at a local level’ received six blue dots, indicating that participants feel strongly that this is a priority issue relating to induced seismicity. As no Challenge project identified this as an area of research, this is considered to be a potential research gap within the UKUH Programme.

Theme 4: Context

The discussions in this theme mostly focused on comparisons of shale gas industry with other subsurface industries with regards to monitoring, management and regulation.

Key messages:

- Three topics were identified to be priority issues (blue dots): ‘Is what we have seen so far [in Lancashire] representative of what we will see elsewhere?’ (which also received the highest number of green dots, 13, compared to any other topic), ‘common/consistent language/terminology’ and ‘definition of conventional vs unconventional oil and gas’.
- The first of these topics, ‘is what we have seen so far [in Lancashire] representative of what we will see elsewhere?’ was identified as being addressed by Challenge 3 and the third, ‘definition of conventional vs unconventional oil and gas’ was identified by Challenge 5. However, none of the challenge projects identified ‘common/consistent language/terminology’ as an area of research, so this is considered to be a potential research gap of the UKUH Programme.

Theme 5: Geological data

Five topics were identified within the theme of geological data, and within this theme there were high levels of endorsement (green dots) and several issues of concern (blue dots); in fact, the theme itself was highlighted as an issue of most concern (one blue dot). It is worth noting that some of the topics and subtopics identified within the geological data theme have strong overlap with Theme 2, which is about the characteristics of induced seismicity.

Key messages:

- There were six issues of most concern (blue stickers) which included three topics (‘Trust’, ‘Ground shaking’, ‘Stress’, ‘How much more can we know about induced seismicity without further drilling?’) and

three subtopics ('Why do some hydraulic fracture wells produce lots of induced seismicity and others don't?'; 'What the seismicity says about pathways (closed or permeable faults)').

- The Challenge 2 PI indicated that his research project will address all topics and subtopics within this theme.
- Challenge 4 and 5 research projects will address 'ground shaking' and 'trust', respectively.
- The subtopic 'Why do some hydraulic fracture wells produce lots of induced seismicity and others don't?' was identified as being particularly important, receiving 10 green dots, and 3 blue dots. This issue was not identified to be addressed by any Challenge and thus remains a potential research gap for the UKUH Programme.
- The topic of 'how much more can we know about induced seismicity without further drilling' obtained one blue and one green dot, but also two red dots, and thus views may be mixed on this issue. This was not addressed by any Challenge and thus could be a potential research gap for the UKUH Programme, although additional drilling is outside the scope of the Programme.

Theme 6: Governance/ regulation/ politics and practicality of the Traffic Light System (TLS) implementation

This theme comprised the fewest number of topics (two), however, this should not be inferred to indicate poor quality of discussion - the ethnographer noted that discussion on this topic was rich and focused.

Only one of these topics was identified as being a priority issue ('TLS and review (political issue)', which received five blue dots). As no Challenge project identified as researching this issue, this topic could be a potential research gap for the UKUH Programme. However, commenting on the suitability of the TLS is specifically outside of the UKUH Programme.

Theme 7: Public perception

Two topics were identified within this theme. The key messages from this theme include:

- Most subtopics within this theme received green dots, indicating a range of concerns (rather than a specific focus).
- Three subtopics were identified to be priority issues, namely: 'How can we have a more sophisticated understanding of community concerns' (two blue dots, 11 green dots, one red dots); 'Awareness of what seismic activity actually means in everyday life' (two blue dots, six green dots, two red dots); 'Public understanding of risk perception' (one blue dot and one green dot).
- The Challenge 5 Project teams indicated that their research projects will address all topics and subtopics within this theme; with Challenge 4 undertaking additional research into 'shaking' and the question of 'whether seismicity is the biggest threat to the local community and the environment?'. As such there are no outstanding research questions on this topic.

Theme 8: Risk

Three topics were identified within this theme, but these are interlinked (as indicated by arrows). Only one topic was identified to be a priority issue: 'setting the context (technical and perceived risks)'. Challenge 4 is addressing all topics in the risk theme within their research project and so there are no outstanding research questions identified in this topic.

7. Summary of outcomes

Table 1 summaries the priority research questions that participants identified as being uncertain or unknown and indicates where these issues are being addressed by Challenge projects within the UKUH Programme. In addition, each theme, presents the total number of green, red, and blue dots applied by participants, and so indicating where there is agreement or disagreement, and which issues are identified to be highest priority.

Table 1: Summary of the key issues around shale gas and induced seismicity that will be addressed by Challenges 2 - 5

Theme	Development of shale gas	Characteristics of induced events	Communication	Context	Geological data	Governance / regulation / policy	Public perception	Risk
Challenge 2	The viability of shale gas development				Geological data			Setting the context
Challenge 3		Induced v triggered	The use of common and simple language to describe complex and emotive subject	Is what we have seen so far [in Lancashire] representative of what we will see elsewhere?				Quantifying seismic risk
Challenge 4	Environmental footprint	Frequency of magnitude events			Ground shaking		Is seismicity really the biggest threat to the local community and the environment? It's not about magnitude – it's about the perception of damage (shaking) in my area.	Risk Setting the context Quantifying seismic risk
Challenge 5	Benefits to wider society		Deficit model in science	Definition of conventional vs unconventional oil and gas	Trust	On what basis are the regulators	Public perception	Scales of risk [national > individual]

Theme	Development of shale gas	Characteristics of induced events	Communication	Context	Geological data	Governance / regulation / policy	Public perception	Risk
						making decisions?		
Not addressed by Challenges	Scaling up (cumulative impacts)	Maximum magnitude Impact of numerous lower magnitude events	How we can best communicate evidence at a local level	Common/consistent language/terminology	Why do some hydraulic fracturing wells produce lots of induced seismicity and others don't? How much more can we know about induced seismicity without further drilling	TLS and review (political issue)		
Sum of blue dots	2	4	6	5	13	5	3	6
Sum of green dots	22	12	31	39	35	9	22	37
Sum of red dots	19	3	8	9	8	8	11	9

8. Outstanding research issues identified by the Integration Event

The research topics / subtopics identified by Integration Event participants that are not being addressed by Challenge projects (i.e. outstanding research gaps) are as follows (in order of priority as indicated by blue dots):

1. Reliable predictions around induced seismicity: Why do some hydraulic fracturing wells produce lots of induced seismicity and others don't? (3 blue dots, 10 green dots) and how can we reliably forecast maximum Magnitude of induced seismicity (2 blue dots + 4 green dots)
2. Is the Traffic Light System fit for purpose or should it be re-evaluated? (5 blue dots, 5 green dots, 1 red dot).
3. Scaling up: the potential effect of multiple shale gas sites on induced seismicity in an area (1 blue dot, 6 green dots) and potential cumulative impacts of numerous lower magnitude events (1 blue dot, 2 green dots, 1 red dot)
4. There is a need for common and consistent language and terminology around hydraulic fracturing and induced seismicity (1 blue, 5 green)

As the UKUH Programme is impartial and unbiased, research to directly address the Traffic Light System (i.e. is it fit for purpose) is out with its scope. The Programme is not intended to lobby for change in government policy, instead it is intended to present robust scientific evidence to key stakeholders. It is the ambition of the programme, however, that this scientific evidence base has the potential to lead to changes in best practice, regulations and / or government policy. Therefore, this is not considered to be a research gap.

9. Evaluation of the event: reflections from event delivery team and attendees

Each of the three objectives of the Integration Event are considered in turn to establish whether the objective was achieved, what worked well, and what worked less well and therefore where future events can be improved. Reflections from the facilitation team, the ethnographer, and feedback from participants following the event are drawn on to inform the evaluation.

Objective 1: To introduce the UKUH Programme members to the integration programme, giving them the opportunity to shape the topics and formats of future Integration Events.

Attendees were introduced to the Integration Events programme and were invited to engage with Challenge 1 team at the event about future topics for Integration Events. Further, feedback obtained via a post event survey allowed participants to shape the format of future events by sharing what worked well and what worked less well. This feedback is discussed later in this section. In this sense, this objective was achieved.

Objective 2: To bring UKUH researchers together to share information about current knowledge on a topic of shared relevance based on UKUH research and activities to date, and to encourage the exchange of perspectives, knowledge, understanding, and experiences amongst UKUH researchers.

This objective is broken down into several components:

- a) To bring UKUH researchers together: The Integration Event brought together 46 representatives from the research Programme. Attendees were primarily from academia, often identifying as either social scientists (Challenge 5) or geoscientists (Challenges 2, 3, 4). 43% of the total UKUH Programme members

were able to attend, including all seven PIs, therefore, the event did bring together the UKUH team. However, feedback from participants following the event highlights that there might be budgeting issues around attending future Integration Events, since Challenge 1 does not support travel and subsistence for UKUH Programme members, and the events were not costed in the Challenge projects.

Verdict: Objective achieved.

b) To share information about current knowledge on a topic of shared relevance based on UKUH research and activities to date: The first part of the day was structured around knowledge transfer through traditional forms of communication - presentations and Q&A. While feedback from attendees following the event suggests that the morning sessions were useful, speakers tended to speak to their discipline, and therefore, it is difficult to gauge whether knowledge transfer occurred between social and geoscience researchers (rather than just within their discipline groups). Observations by the ethnographer suggest that the talks of most interest to all participants were those that 'set the scene' regarding the policy and activity landscape. Fewer, longer, presentations with extended Q&A might work better for future events, and speakers need to be supported to be able to speak across the disciplines within the room. The Challenge 1 team need to carefully craft the agenda of future Integration Events accordingly. Further, all speakers must use the microphones when presenting at future events.

Verdict: Objective partially achieved.

c) To encourage the exchange of perspectives, knowledge, understanding, and experiences: Exchange of knowledge occurred throughout the day. This was primarily achieved during the facilitated activities although refreshment breaks were also important spaces for knowledge exchange. Geoscientists were observed more commonly sharing their knowledge with large groups of non-geoscientists during informal breaks, whereas social scientists tended to volunteer information more frequently during the facilitation activity. That said, knowledge exchange was not evenly distributed between the participants; it was more common to see social scientists seeking geoscience information than vice versa. The facilitated activities created space for exchange of perspectives and understanding. In particular, the mapping of issues and the use of the green and red dots on the post-it notes allowed for a recognition of the diversity of perspectives amongst participants and demonstrated how priorities varied between different groups, thereby creating space where dialogue and knowledge exchange could occur.

Verdict: Objective partially achieved.

Objective 3: To map the range and breadth of issues and challenges relevant to the topic of the Integration Event and, if possible, to identify where current knowledge is well established, where there are knowledge gaps, where these gaps will be addressed by the UKUH Programme, and where future work (potentially supported by Challenge 1 flexible funds) should focus.

Overall, the Integration Event was very successful in identifying key areas of concern around the focus of induced seismicity that are either currently being explored by the Challenge areas or are potential areas for further study. The facilitated activities identified where there is consensus, where there is disagreement, and issues of greatest importance. Allowing participants to identify issues of greatest priority amongst the themes, topics and sub-topics generated a useful framework for identifying gaps in the current UKUH programme.

However, some limitations do apply to the interpretation of those results. Firstly, for future events there is room to simplify the facilitated task or to structure the process so as to enhance clarity of purpose, as there was some indication of perceived lack of focus and some indication of disengagement as the task progressed (e.g. not putting dots on issues, or retreating into conversation with persons from within their

discipline but outside of the task group). Secondly, it is interesting to note that there was an overall skew toward social science issues during the early tasks, however, when it came to identifying priority topics, geoscience themes / topics and sub-topics were dominant. This might reflect the prevalence of geoscientists at the event, rather than the joint perspectives across the social and geoscience community. It was noted by the ethnographer that the number of geoscientists dominated over social scientists and 'others' in the room. Finally, we cannot be sure of the approach that individuals used to prioritise themes / topics / sub-topics. For example, if a participant knew that a particular issue that they deemed to be high priority was being addressed by UKUH (or other) research projects, did they prioritise a different issue instead? That said, the event was designed such that participants had multiple opportunities to influence or question the issues and topics identified by the facilitated task.

Verdict: Objective largely achieved.

Was the process fair?

As previously mentioned, the consistency of knowledge exchange and the quality of outputs from the facilitated activities were dependent on the dynamics of the group and the performance of the facilitator. The most successful groups were ones where the group had a mix of disciplines and seniority, with one or two members leading from within the group in such a manner that all group members were supported to participate. The facilitator has a key role here too, and some confusion about the role led to varied performance of the groups or the themes.

Thus, while the process was deemed to be fair, there are important issues to be managed for future events.

Reflections from attendees.

All attendees were given the opportunity to provide anonymous feedback via an online survey. 28% of participants responded and most of the respondents considered the event to be a success with only 12% unsure of its success. Attendees felt that the event was well managed and there was a good balance of technical and social science presentations and a good range of speakers. To summarise the feedback with regards to improvements, the overall message was around the need to simplify the breakout sessions. There was also an additional comment to remind the facilitators to make it clear that 'getting the public on side' is not the role of the UH programme and that the participants (attendees) should not lose sight of the aim of the programme, which is to provide independent scientific evidence accessible to and can inform all stakeholders whether they are 'pro' or 'anti' shale gas development in the UK.

10. Conclusion

The inaugural UKUH Integration Event workshop was designed to encourage the exchange of knowledge and perspectives around induced seismicity caused by hydraulic fracturing for shale gas extraction, with the objective to collectively identify potential research gaps within the deliverables of the UKUH Programme. The Integration Event successfully achieved its objective, whilst simultaneously identifying several ways that the workshop's design could be improved for future Integration Events. During the afternoon breakout session, several questions which represent gaps in the current UKUH Programme were identified by the various participants, key of which have been identified as:

1. Reliable predictions around induced seismicity: Why do some hydraulic fracturing wells produce lots of induced seismicity and others don't, and how can we reliably forecast maximum Magnitude of induced seismicity?
2. Scaling up: what are the potential effects of multiple shale gas sites on induced seismicity in an area and the potential cumulative impacts of numerous lower magnitude events?

3. How do we address the need for common and consistent language and terminology around hydraulic fracturing and induced seismicity?

Research into these potential gaps will become the focus for the flexible fund projects, which are overseen as part of Challenge 1. In addition, the area for further research related to the reliability of predictions around induced seismicity, which was identified as a priority research area during the Integration Event, is in line with the findings of the recently published OGA report on predicting the seismic risk from hydraulic fracturing in the UK.

Acknowledgements

The research councils NERC and ESRC have funded this review through the Unconventional Hydrocarbons in the UK Energy System: Environmental and socio-economic impacts and processes Programme. The aims of this research Programme are to provide an updated independent scientific evidence base to understand potential environmental and socio-economic impacts of unconventional hydrocarbon development.

About the Programme

The overarching objective of the research programme is to improve significantly the scientific evidence base on shale gas as a potential energy resource for the UK.

More information can be found at www.ukuh.org

Contact Details

If you have any comments or questions, in the first instance please contact:

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Appendix A

Mind-maps based on facilitated activities

Theme 1: Development of Shale Gas

Theme 2: Characteristics of induced events

Theme 3: Communication

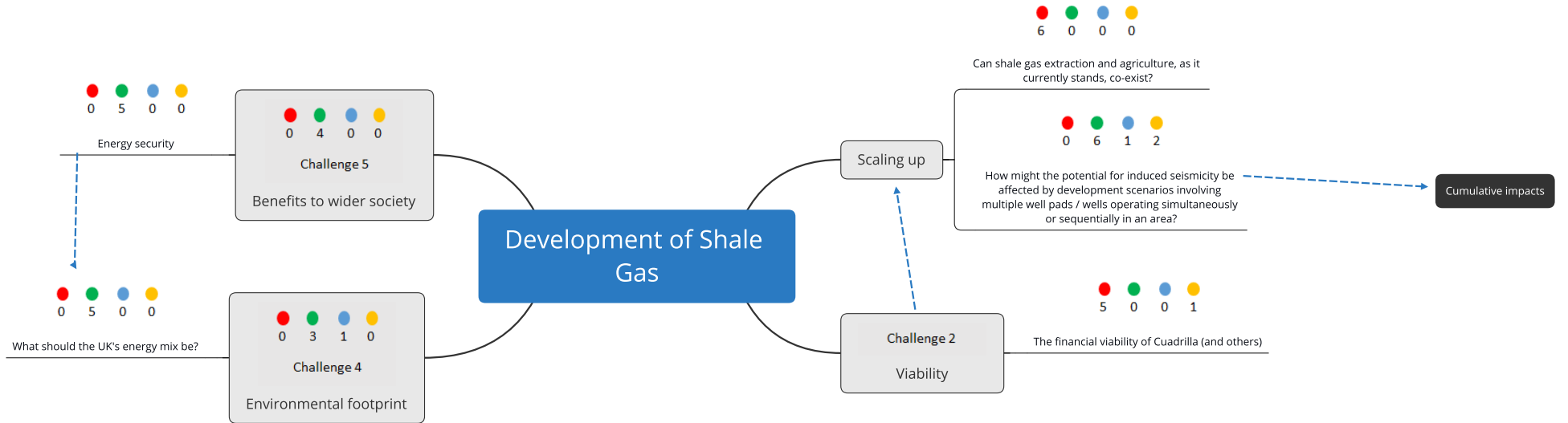
Theme 4: Context

Theme 5: Geological data

Theme 6: Governance / regulation / policy

Theme 7: Public perception

Theme 8: Risk



Characteristics of induced events

Challenge 4
Frequency of magnitude events

0	1	0	0
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Impact of numerous lower magnitude events

1	2	1	0
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Scaling up / development of shale gas

Maximum magnitude

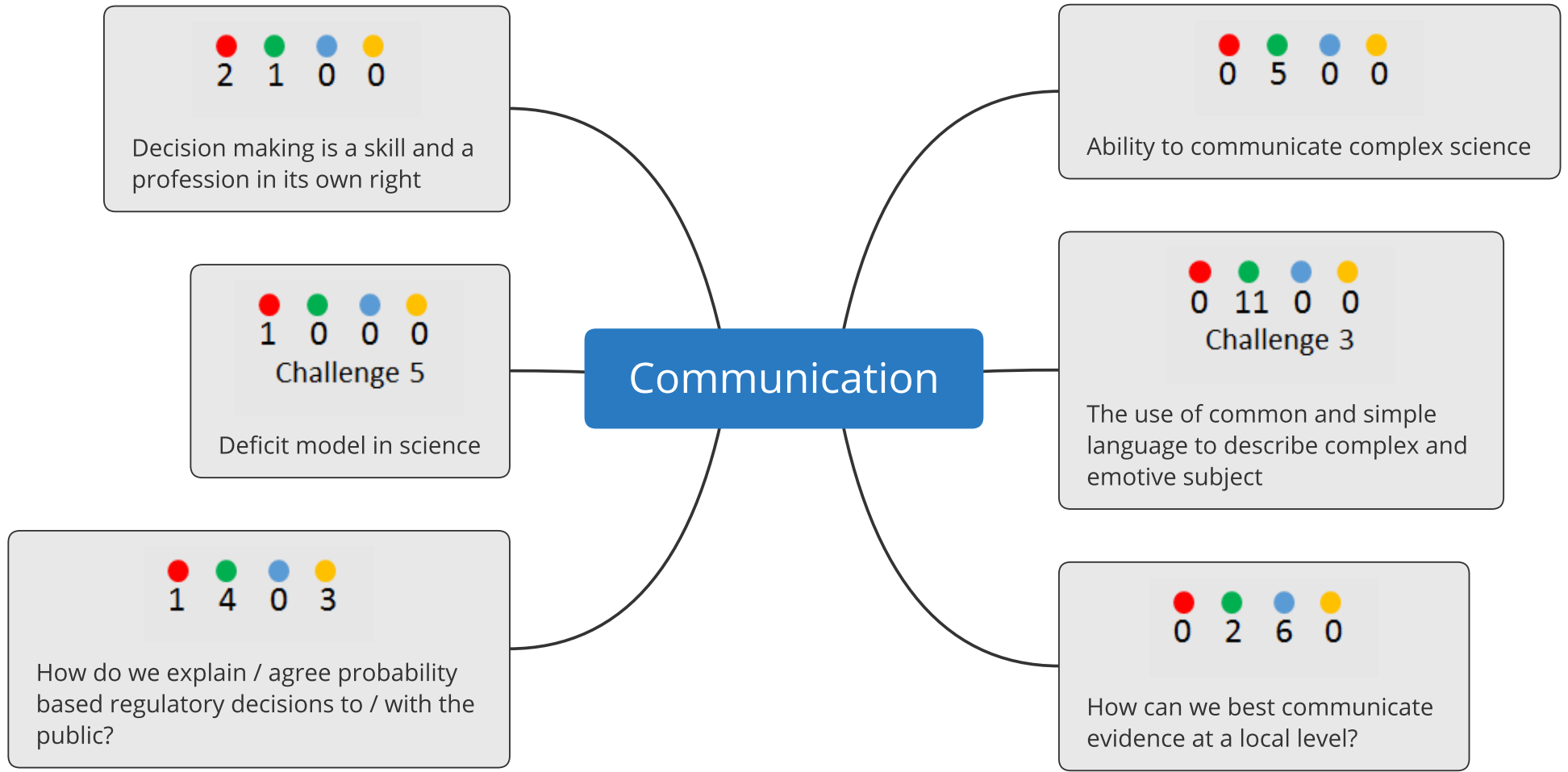
0	0	2	0
---	---	---	---

Challenge 3
Induced vs triggered

0	0	1	0
---	---	---	---

1 4 0 0

How robust / reliable are predictive models of Mmax and induced ground motion?



2 1 0 0

Decision making is a skill and a profession in its own right

1 0 0 0

Challenge 5

Deficit model in science

1 4 0 3

How do we explain / agree probability based regulatory decisions to / with the public?

0 5 0 0

Ability to communicate complex science

0 11 0 0

Challenge 3

The use of common and simple language to describe complex and emotive subject

0 2 6 0

How can we best communicate evidence at a local level?

Communication

● ● ● ●
1 0 0 0

Challenge 3

Why have a TLS for shale gas, but no other subsurface industry?

Comparison and ethics

● ● ● ●
0 5 1 0

common / consistent language / terminology

● ● ● ●
3 0 1 0

Challenge 5

definition of conventional vs unconventional oil and gas

Context

● ● ● ●
0 13 1 0

Challenge 3

Is what we have seen so far [in Lancashire] representative of what we will see elsewhere?

● ● ● ●
0 5 0 0

How do we compare seismic risk with other risks?

0 10 3 0

Why do some hydraulic fracture wells produce lots of induced seismicity and others don't?

0 2 1 0

What the seismicity says about pathways (closed or permeable faults)?

0 4 0 0

Faults / Fractures

Uncertainty in subsurface stress and how this may vary spatially across an area of exploration interest

Maximum horizontal stress regime

Heterogeneity of subsurface rocks and structures

How long will it take for a subsurface stress state to return to normal after hydraulic fracturing has ceased?

High regional stress anisotropy should make it more difficult to induce events, but make bigger events when it happens

1 3 2 0

Stress

How are ground motions modulated by local geology / shallow subsurface characteristics?

Improved characterisation of the shallow subsurface to better constrain ground motion prediction models

Which ground motion models are fit for purpose?

Uncertainties re: long term impact of accumulation of induced seismicity (in US/UK or elsewhere)

0 5 4 0

Challenge 4

Ground shaking

0 0 1 0

Challenge 2

Geological data

2 1 1 0

How much more can we know about induced seismicity without further drilling?

0 5 0 0

Transparency / translation of data and its uncertainty

1 0 1 0

Challenge 5

Trust

Characteristics of induced events

Governance /
regulation / politics
and practicality of TLS
implementation

1 5 5 0

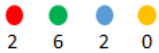
TLS and review (political issue)

Is the TLS the most appropriate way to regulate induced seismicity from shale gas extraction?

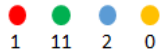
Challenge 5

Regulator - capacity and scope

On what basis are regulators making decisions?



Awareness of what seismic activity actually means in everyday life



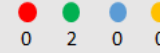
How can we have a more sophisticated understanding of community concerns?

Understanding of 1.5

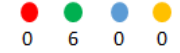
Challenge 5

Public Perception

Communications



Risks of 1.5



How is the public reaction to, or perception of seismicity, as an issue likely to be affected as the shale gas industry scales up from individual to multiple well sites?

Challenge 4

Is seismicity really the biggest threat to the local community and environment?

Challenge 4

It's not about magnitude - it's about the perception of damage (shaking) in my area



Public understanding of risk perception

