A toolkit for achieving the common research agenda in interdisciplinary energy research projects

Abstract: Interdisciplinary research is especially relevant in the energy field where ambitious political targets for the energy transition require rapid advancements in technology and simultaneous developments in social norms and citizen engagement. Challenges related to interdisciplinary communication and the integration of findings across disciplines have been cited in past work to inhibit the execution of a common research agenda and the production of holistic research outputs. This paper offers specific tools and recommendations to overcome these challenges and facilitate an efficient collaboration. Specifically, a method for building a common project vocabulary and strategies for face-to-face group discussions are presented and tested. Recommendations regarding the usage and effectiveness of these strategies are based on the experiences of the SMARTEES Horizon 2020 interdisciplinary energy project. The toolkit includes reproduction code for analyzing a project's ecosystem of terms and a framework for planning and implementing effective structured discussions in group meetings.

Keywords: Interdisciplinary; Energy research; Group discussions; Terminology; Project ontology

1. Introduction

The energy transition and the underlying transformation of critical infrastructure imposes several challenges that are socio-technical in nature and require collaboration across disciplines (Hamborg et al., 2020). The complex task of decarbonizing our society and economy depends both on advancements in technological solutions as well as on continued and informed changes in society, including consumers' lifestyles, values and attitudes (Pellegrini-Masini et al., 2020). These advances need to consider the complex and multifaceted nature of this overall task and the intricacies of related sub-topics (e.g. increased energy efficiency of households or decarbonizing of the transport sector) (IRENA, 2017). Research projects that aim to contribute to these solutions often demand interdisciplinary teams including specialists from engineering, physical science, behavioral science, and humanities.

As documented in Sonetti et al. (2020), the European energy research agenda has moved progressively towards greater integration across disciplines, especially with respect to the integration of social science and humanities research within technical projects. Indeed, in November 2019 the European Commission hosted a seminar for "Making the best use of social science and humanities in the clean energy transition." A continued interest in integrating social sciences with technical disciplines in energy research was reaffirmed, apparently answering the call of Sovacool (2014) and Sovacool et al. (2015) to use social science to ensure that technical solutions enjoy improved market uptake and usefulness in realizing the energy transition. With the expectation of increased interdisciplinarity in future energy projects, laying out effective strategies for interdisciplinary collaboration becomes critical.

Cooperation of disciplines can take different forms and an overview of these forms and their definitions is provided in Choi and Pak (2006). Herein we focus on interdisciplinary research, which is specifically defined as the type of research that "analyses, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole" (Choi and Pak, 2006). Where other forms of cooperation across disciplines are considered we explicitly use the respective term when reporting these, such as multidisciplinary, transdisciplinary and cross-disciplinary.

Usually in an interdisciplinary research project a synthesis of two or more disciplines, leading to the establishment of a new level of discourse, is expected (Schuitema and Sintov, 2017). Particularly in the energy field, interdisciplinary research is often preferred due to the need to consider the entire energy system, including behavioral/social factors, materials/technology, engineering, policy, environmental issues, and system modelling (Winskel, 2018). An academic energy system perspective requires combining technological, physical and social sciences leading to a 'radical' form of interdisciplinarity, which spans many macro scientific disciplines (Petts et al., 2008). Additionally, many applied energy projects require 'transdisciplinary' efforts involving co-creation with non-academic policy, industry and technology specialists (Winskel, 2018). Thus, large-scale energy projects are often pushing the boundary of applied research practice, and are positioned to further expand and improve the field of interdisciplinary studies.

Success in interdisciplinary energy research hinges on elaborating a common research agenda that will serve as an overall guideline for joint work in the project (Schmidt and Weigt, 2015; Bark et al., 2016). Defining common research objectives and research questions while allowing each discipline to retain its distinctive approach are two major components of a common research agenda. In European energy research, this process is largely (perhaps hypothetically) completed by the official start of the project through the creation of the research proposal, which is a good sign for the structure of the funding process. However, the execution of this common agenda and the creation of interdisciplinary outputs is faced with numerous the challenges discussed below.

These challenges of interdisciplinary work are also well-documented (Sherif and Sherif, 1969; Klein, 1990). Common issues with interdisciplinary working groups include differing expectations of output, poorly understood roles of individuals and teams, juggling individual career interests with collective project goals, navigating different academic cultures and vocabularies, communication and comprehension, and valuing/using inputs of others (Mallaband, Wood, et al., 2017; Woiwode and Froese, 2020). Furthermore, even when the project is accomplished, evaluating its outcomes can be a difficult task due to variability in goals and key success indicators across disciplines (Bark et al., 2016). Most of these challenges arise due to the historical development of the academy and the rise of the divide between disciplines, where most current social science disciplines have developed out of philosophy and had the need to (over)differentiate from this common starting place (Riesch, 2014).

A core issue in interdisciplinary energy research lies in the role of quantitative and qualitative data methods in science. The meeting of these two research traditions within the scope of one project poses ‘‘unique challenges and possibilities of integration of qualitative and quantitative approaches’’ (Fetters and Molina-Azorin, 2017). For instance in the energy domain, the researchers of the SEPIA-project (Sustainable Energy Policy Integrated Assessment) reflect on the methodological challenges of combining quantitative and qualitative methods to foresee sustainable energy futures. The SEPIA authors note that the application of multi-method approaches in energy foresight research is challenging to implement and is time and resource-intensive, in part due to a lack of “a structured exchange of experiences, knowledge and mutual feedback” (Laes et al., 2013). In particular, complications for SEPIA arose in securing a deliberative consensus and organizing a process for translating narrative scenarios into quantitative model parameters. In addition, social science disciplines with strong qualitative or quantitative traditions often lay claim to certain methods of study design, data collection, and analysis as their own (Onwuegbuzie and Leech, 2005). This parochialism follows from an educational system that is usually differentiated by disciplines, forcing students to choose a discipline-specific set of mentors early on in their scientific careers. A collegiate study found that students from predominantly qualitative disciplines were disdainful of quantitative methods, and vice versa (Tobi and Kampen, 2018). These students believed they did not require knowledge outside their disciplines to further their careers; a belief that is in sharp contrast to the need for holistic solutions and concepts to build a sustainable energy system.

Another risk is that the researchers from one discipline may not fully understand the contribution from other disciplines. For example, social science may be expected to help "sell" or increase the social acceptance of already developed technical solutions instead of cooperating in the full research process, including the development of the technical solution where alterations to the technology could be proposed to increase its success within social contexts. As Sovacool (2014) put it, "Social science related disciplines, methods, concepts, and topics remain underutilized, and perhaps underappreciated, in contemporary energy studies research." This means that a mutual respect and a willingness to learn from each other is an important starting point. This is confounded by the fact that interdisciplinary work can require extra time, which can stress project resources or the availability of personnel.

Despite the above-noted difficulties, interdisciplinary efforts in energy topics can improve the impact of research outputs (Pellegrino and Musy, 2017). Such efforts can "[…] accomplish a range of objectives: to answer complex questions, to address broad issues, to explore disciplinary and professional relations, to solve problems that are beyond the scope of any one discipline, to achieve unity of knowledge, whether on a limited or grand scale." (Klein, 1990)

Specific tactics and processes to help avoid the pitfalls of interdisciplinary work in energy research are so far scarce in the literature. Though some general best practices and recommendations for energy projects exist (Mallaband, Staddon, et al., 2017; Mallaband, Wood, et al., 2017; Pellegrino and Musy, 2017; Winskel, 2018). The need for more specific tactics and processes has been noted. For instance, Cooper (2017) underlined the "need to negotiate a new set of methods and/or strategies of interdisciplinary research," and argued that it is necessary to define common practices for integration of social and technical sciences in energy research. A recent project in environmental science proposed a focus on joint data management and co-authorship as proactive steps to ensure interdisciplinary cooperation (Henson et al., 2020). Another analysis in future studies focuses on the logistics, agendas, and participation of interdisciplinary face-to-face meetings and recommends general best practices in these dimensions (Bridle et al., 2013). More studies of this type are needed to guide emerging interdisciplinary working groups.

The aim of this paper is to help fill this gap with specific recommendations for strategies to overcome interdisciplinary barriers in energy research projects with the goal of realizing a common research agenda. We investigate several tools for improving interdisciplinary understanding and efficacy in communication, meetings and workshops, answering the noted need for 'how,' specifically, interdisciplinary energy research can be efficiently conducted (Pellegrino and Musy, 2017). First, specific recommendations and tools for building a common vocabulary in energy projects are given. Then, four structured activity strategies for face-to-face meeting are presented, tested, and analyzed. This offers an easily adopted toolkit to future interdisciplinary energy projects that can improve the efficiency of information exchange and help ensure that holistic research outputs are delivered.

This toolkit is illustrated and tested within the context of an interdisciplinary and transdisciplinary energy research project. The SMARTEES Horizon 2020 project, financed by the European Union, investigates five clusters of energy and mobility-related social innovation: holistic mobility plans, islands and renewable energy, district regeneration, mobility in superblocks, and energy efficiency against fuel poverty. Each of these clusters has both a technical, and social (usership) component. Thus, the SMARTEES project is by necessity interdisciplinary, including computer science, environmental science, urban planning, economics, psychology, and sociology represented. The SMARTEES project uses a combination of qualitative and quantitative methods. The project is ambitious in relation to how closely the different disciplines are expected to cooperate with the development of joint surveys, multi-method data analysis and agent-based models that are fed through qualitative data collections. The project structure reflects this, with heavy cross-involvement of groups within different work packages and project outputs (Pellegrini-Masini et al., 2019). One noticeable consequence of this intertwined structure is the need for frequent multi-lateral discussions and meetings to jointly solve problems concerning methods, analysis and data collection. In this experience, many of the challenges with realizing the common research agenda can ultimately be derived from difficulties in working with both types of data and methods without ending up with two parallel studies, one quantitative and one qualitative, and the associated difficulties with communication and the integration of methods and outputs. This is a key challenge of the SMARTEES project in producing a holistic product and validating an interdisciplinary effort. The developed toolkit is designed to meet this challenge.

In what follows, the background and motivation for each of the project tools is discussed. This discussion is illustrated by examples of how these tools were employed in the SMARTEES project, including a discussion of the tools' efficacy within the project. Specifically, Section 2 discusses the importance and strategies to building a common project vocabulary, which can help overcome communication problems. In Section 3, specific strategies for increasing the efficiency of face-to-face meetings are explored. The designers and leaders of four group discussion strategies reflect on the process and outcomes they experienced in SMARTEES. These experiences are compared to the experiences of the activity participants that were collected through a post-meeting internet survey. This exercise provides guidelines and ideas for the future use of structured activities as tools for improving interdisciplinary cooperation.

2. Building a common vocabulary

As suggested in Mennes (2018), interdisciplinary energy projects are frequently challenged by "problematically ambiguous terms," terms that have multiple meanings and for which it is not always clear which meaning is meant, generating communication problems. Communication issues relating to terminological ambiguity are well-documented in past research (File and Dugard, 1997; Bracken and Oughton, 2006; Marzano et al., 2006; Ranade et al., 2011). In a large-scale feedback collection from interdisciplinary European energy projects, Sonetti et al. (2020) noted "wide gaps in background, lexicon, theoretical and epistemological frameworks" as a major barrier to interdisciplinary efforts. It is troubling that the terminology barrier was also noted in an earlier meta-analysis of interdisciplinary research projects (Bruce et al., 2004), making it seem that little progress has been made towards viable solutions in the past decade.

One of the main sources of ambiguity in terms comes from discipline-specific jargon, especially in the case that a term is used by several disciplines but does not share the same meaning or convey the same concept across the disciplines. Such ambiguity in terminology not only complicates the communication within the project, but can also harm the project's results by leading to misinterpretation or incorrect application of the results from one part of the project to another. In order to alleviate these problems a procedure that can help identify and resolve these terms should be elaborated (Mennes, 2018).

In the context of the SMARTEES project, a procedure for building common terminology was developed and tested as described below. The first step is a document analysis of the research proposal in order to identify the most frequently used cross-disciplinary terms. The research proposal is the document that lays out the common research agenda of the project at the project's outset. It contains contributions from all partners, and is thereby (in the best case) a truly interdisciplinary work, though this does not guarantee that the proposed research agenda requires the creation of interdisciplinary products or research outcomes. Nevertheless, the research proposal, or a similar documentation of a common research agenda, is likely the best place to start in an analysis of terminology.

The suggested document analysis technique is as follows. First, n-grams are pulled from the document. An n-gram is a grouping of words that contains n number of words. In this analysis $1 <= n <= 3$, meaning that the groups of words contain between one and three words. The n-grams are extracted from the research proposal based on two criteria, frequency and familiarity. For the frequency criteria n-grams are chosen if they satisfied the criteria: $e^2 <$ frequency $< e^4$, where 'e' is Euler's number ≈ 2.71. The frequency criteria gives the list of n-grams that are commonplace within the document, while also omitting many prepositions and articles, such as "the" or "a" that have frequency greater than e^4. Familiarity is a measure of how common the n-gram is within English vocabulary. Specifically, familiarity is defined by the number of "synsets" the n-gram is a member of in the Wordnet Ontology (University, 2010). A synset is defined by Wordnet as a "set of cognitive synonyms", and is thus a group of words that relate to a similar concept. More common words will be found in more synsets, while project defining words will generally be less familiar and more unique and thus present in fewer synsets. An n-gram was pulled from the research proposal if it met the following familiarity criteria: $0 <=$ familiarity $<$ mean familiarity, where "familiarity" is the familiarity measure for the current n-gram and "mean familiarity" is the average familiarity measure for all n-grams in the document. Looking specifically at unfamiliar n-grams focuses the analysis on project-specific terms, technical terms, or jargon words, and cuts out the many common phrases that would otherwise come out of such a document analysis. The code to reproduce this document analysis method is freely available at https://gitlab.com/doug.salt/stemma

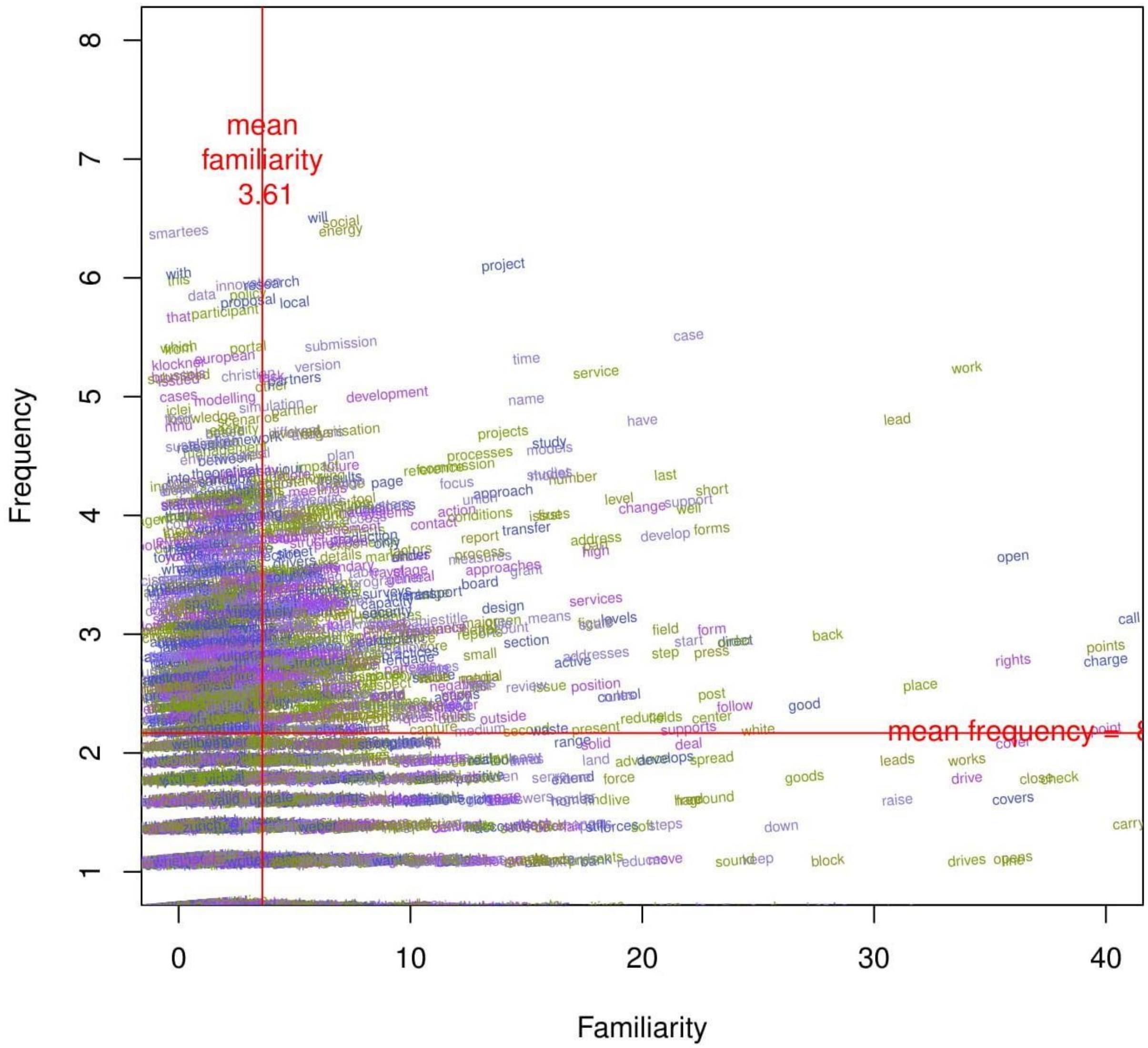

Figure 1: Unigrams from the SMARTEES research proposal

Figure 1 shows the results of the document analysis for unigrams, an n-gram where n equals one, for the SMARTEES research proposal. The lines in the figure give the mean familiarity (3.61) and mean frequency (2.2) across all unigrams in the document. The unigrams are shown in the figure, with the color of the words being arbitrarily assigned to make the words more legible. From the set of all unigrams in figure 1, a total of 491 unigrams are pulled out that satisfy both the frequency and familiarity criteria laid out in the preceding paragraph. These 491 are the starting set for further manual analysis of the terminology, giving a manageable set of terms. Specifically, unigrams are selected from this list of 491 to construct a list of 60 key terms that define the SMARTEES project. Selection is based on the relevance and uniqueness of the term to the SMARTEES project, and also on the potential for confusion in the interpretation of the term. The result is shown via word cloud in Figure 2. The word cloud is useful in its own right as a way to visualize the key points of the project; for the example of SMARTEES, the unigram word cloud contains references to the background, methodology, and objectives of the project, effectively encapsulating the project vision in one graphic.

Figure 2: Word cloud of 60 selected unigrams that define the SMARTEES ecosystem of terms

To assess the degree of interdisciplinary incongruity in terminology definitions feedback was collected from within the SMARTEES consortium. Seven words were selected from figure 2 that were deemed the most likely to have various definitions across disciplines. An example definition[1] was prepared for each of these seven words, and then an internal survey was sent out asking partners to first give their own definition of the word and then asking if they agreed with the supplied definition. Participants could respond “yes, I agree”, “I agree, but my definition is more exact”, “No, I disagree”, “I don’t understand the definition”, or “I would not use this definition in my research field”.

The internal survey has 14 respondents representing six different disciplines (social sciences, psychology, economics, computer science, environmental management, and agriculture). Summary responses to the terminology internal survey are given below in table 1. The responses suggest a ‘vocabulary gap’ whereby terms common in the project have differing definitions between researchers and disciplines. Interestingly, the more technical terms, such as “agent-based model” and “metadata” find higher agreement than the general terms “model”, and “empirical research”.

	Social Acceptance	**Agent-based models**	**Case-study**	**Empirical research**	**Metadata**	**Incentive Structure**	**Model**
Yes, I agree	14.3%	64.3%	84.6%	28.6%	71.4%	64.3%	21.4%
I agree, but my definition is more exact	14.3%	7.1%	15.5%		28.6%		28.6%
No, I disagree	14.3%	21.4%		50.0%		7.1%	35.7%
I don’t understand the definition	42.9%	7.1%		7.1%			
I would not use this definition in my research field	14.3%			14.3%		28.6%	14.3%

Table 1: Proportion of internal survey respondents agreeing with the supplied economics definition of the given term

The above-described exercise was instrumental in building awareness of the perils of interdisciplinary jargon in the SMARTEES project. There was some initial hope that a common glossary of key terms could be agreed upon and used in the project. However, given the number of key terms in Figure 2, and the level of dissension shown in Table 1, it was deemed unlikely that the group could agree on definitions for each term and then remember to

[1] A definition from the economics discipline was supplied to represent this discipline within the project and because the survey developer is an economist.

use the agreed upon definition in every case. Such a process would be excessively time consuming[2]. The document analysis and word mapping exercise illustrated the terminology challenge facing the consortium and made project personnel aware of this acute issue. Best practices, as shown in the recommendations below, were distributed to the consortium and the combination of awareness building and actionable recommendations allowed the consortium to avoid major issues related to terminology.

Terminology is strongly linked to research traditions, and there is a difference between qualitative and quantitative jargon. Both terms, “qualitative” and “quantitative,” are included in the list of 60 unigrams that define SMARTEES in figure 2. Other terms related to quantitative methodologies are on the list, for example “case-study”, “modelling” and “empirically”, which shows how such document analysis can emphasize key issues in realizing the common research agenda. In the case of SMARTEES this key issue is the merging of qualitative and quantitative research traditions. Based on the results of the document analysis, internal survey, and related literature, we suggest that future interdisciplinary energy projects introduce the recommendations below at the outset in order to improve the communication flow between all the project partners and stakeholders and build a project culture that fosters interdisciplinary understanding.

Recommendations for a common vocabulary:

1. Gain an overview of the project’s ecosystem of terms through document analysis and word webbing techniques. This strategy is used to focus on key terms or and make the group aware of the challenges of incongruent vocabulary. Present the word webs and document analysis to the consortium along with recommendations 2-7 early on in the project runtime.
2. Project personnel should add details to broad, semi-technical terms with additional qualifiers in both written and oral exchanges, e.g. “mathematical model”, or “theoretical model” instead of just “model”.
3. Project personnel should not assume that others understand the terms they use in the way that they understand them.
4. Define key terms in reports, either in a separate glossary, or within the sentence where the term appears.

[2] However, for the key term of the project, “social innovation”, we did attempt to agree on a collaborative definition through a structured workshop series, as discussed in Section 3.

5. Avoid discipline-specific jargon and acronyms where possible. When used, clearly define the term/acronym.
6. Increase contact and discussion between research and disciplinary groups (Marzano et al., 2006; Mallaband, Wood, et al., 2017). Initially unclear terms may become clear due to context clues or be hashed out during discussion.
7. Strive for a project culture where it is encouraged to ask for clarification of key terminology during discussions or presentations. This can be facilitated by project leaders behaving consistently and using statements like, “there are no stupid questions in interdisciplinary research.”

3. Structured group interactions

Not only are the words used in interdisciplinary interactions important, but the parameters, context and structure of these interactions can also affect the degree of success in executing the common research agenda. Interdisciplinary group interactions without structure can often suffer from time-use inefficiency, a lack of clear progress and objectives, tangential or non-critical issues taking up valuable time, and many participants becoming lost or not being able to participate in the process. The way in which interdisciplinary discussion and subsequent action take place is especially critical given its relevance in driving the scientific output. Scientific outputs can be a product of the interpersonal relations, and social constructive process undertaken alongside scientific inquiry (Bellotti et al., 2016). This is especially possible in the context of interdisciplinary projects, where the inputs from some fields may be seen as secondary, or not valued/used (Mallaband, Wood, et al., 2017). Thus, promoting effective interdisciplinary group interaction is critical not just for efficiency, but also to ensure a holistic research product that leverages the available perspectives and insights.

Increased contact between project participants and opportunities for discussion are important to the interdisciplinary process (Marzano et al., 2006; Bridle et al., 2013; Mallaband, Wood, et al., 2017). Physical meetings are important events in a project that contribute to building a common vocabulary and executing a common research agenda (Kasvi et al., 2003). Features including the location, size, theme, background and career stage of participants can all influence the success of the interaction (Bridle et al., 2013). However, beyond the need for a unifying theme from Bridle et al. (2013), best practices regarding the organization, objectives, and specifics of group interactions in interdisciplinary energy projects are unclear. In this section, we attempt to fill this gap in the energy literature by making explicit recommendations for structuring group discussions based on the available literature, including insights from managerial science, the experiences within the SMARTEES project, and internal feedback from SMARTEES researchers.

In referring to the 'structure' of group interaction, we refer to the rules, conventions, objectives, and leadership elements of a group discussion. A structured discussion is juxtaposed to an open discussion, where no active leader exists, no ground rules of the interaction are laid forth (e.g. raising one's hand to speak) and no objectives or goals are made explicit. The broader managerial literature considers the structure of group interaction to be an important determinant of group efficacy. A meta-analysis of this literature recognizes the importance of task design and organizational context in the effectiveness of group work (Cohen and Bailey, 1997). In particular, the degree to which tasks within a project are interdependent invites innovation, but only in cases where common goals are well-defined and understood (Vegt and Janssen, 2003). This reaffirms the importance of developing a common research agenda. Furthermore, structure in group interaction can improve the quality of group decision-making and consensus building outcomes (Priem et al., 1995).

In the case of open discussion, interdisciplinary group interactions can often suffer from time-use inefficiency, a lack of clear progress, tangential or non-critical issues taking up valuable time, and some participants becoming marginalized. The SMARTEES consortium makes a conscious effort to include more structured interactions, and to substitute structured discussion for open discussions wherever possible. In this process, multiple structured interaction frameworks are developed and tested in project face-to-face meetings. The four strategies considered here are anonymous ranking, written feedback, group brainstorming, and sub-group interviews. The structured interactions have various goals, but each activity follows a defined array of best practices for group work. The basic guidelines for preparing structured interactions are adapted from Brame and Biel (2015) as follows:

1. There should be a responsible person arranging and shaping the discussion activity.
2. The leader defines clear objectives for the activity at the outset, explaining the overall purpose of the activity within the greater common research agenda.
3. The format of the activity is well defined and communicated at the onset, including any time constraints or rules to interaction.
4. The leader plays an active role during the activity, monitoring workflow or keeping the discussion related to the objectives.

In the sub-sections below, the process, outcomes, and objectives for each of the four strategies are presented and compared to the results from an anonymous internal feedback from discussion participants. First, for each strategy, the motivation for the activity, goal of the activity, a description of what took place, and reflections from the activity are described. The reflections are based on qualitative analysis of the experience with the discussion strategy from the discussion leaders, blended with feedback from discussants collected via a web tool that was circulated shortly after the activities. Overall, we have about a 50% response rate for feedback requested from discussants. The feedback from the activity participants is taken as illustrative and descriptive and is not meant to constitute statistical evidence in support of one exercise or another.

3.1. Strategy 1: Anonymous ranking exercise

Motivation. Both strategies 1 and 2 relate to an effort at building a common vocabulary. Namely, the SMARTEES consortium attempts to collaboratively build and agree on a project definition of the term "social innovation," a term that is key to the project identity but not well enough defined. In order to improve internal communication and reach a mutual understanding of the common research agenda an agreed upon definition of this key term is needed.

Goal. The goal of the SMARTEES anonymous ranking exercise is to create initial data on the project definition of social innovation. These data can then be used to develop a first project definition of social innovation, analyze the important elements of such a definition and identify elements where the consortium agreed or disagreed.

Description. A 10-minute primer presentation introduced the concept of social innovation and showed the results of an internal survey about existing or proposed definitions of social innovation that was completed before the physical meeting. The primer presentation was followed by a stage of group work for 30 minutes. Workshop participants sat in groups of four or five people and each group developed their own project definition of social innovation. The four groups developed four rather different definitions of social innovation even after all seeing the same list of previously proposed definitions in the primer presentation. Each group then briefly presented their definition and explained why they believed it should be the project definition. The workshop participants were able to anonymously rate each definition using the Sli.do website on a 5-star scale[3]. The presentation and rating stage was allocated 10-minutes. A final 10-minutes of time was allocated for open group discussion

[3] For a full documentation of the process and outcome from this structured activity please see (Cohen and Kollmann, 2020).

Reflections. One consideration that arose from this process is the timing of sub-group tasks. During the activity, 30-minutes was generally discussed as being too short of a timeframe to develop a product that could be agreed upon within each sub-group. In the future, we recommend more time be provided to product development in the sub-group phase. However, face-to-face time is precious in research projects. Thereby, future projects should give sufficient time for sub-group tasks, and balance this time requirement with the other goals of the workshop/meeting. The time requirement for sub-group work makes this strategy costly, in terms of time investment; a way around this would be to assign certain individuals to create products before the meeting and then move directly to presenting and voting on these products in the group meeting.

One element that worked well was the anonymous form of the feedback. In open discussion, many group members can be timid to voice dissent leading to sub-optimal outcomes (Priem et al., 1995). The anonymous feedback mechanism alleviated this issue and ensured that all participants had equal weight in rating each other's products (one vote per person), as opposed to the social dynamic where the loudest's, the leader's, or de-facto leader's opinions have higher weight in the group decision.

This activity received an average rating of 3.4/5 with respect to how useful participants found it, while two of the nine discussants found this activity to be unnecessary and would have preferred an open discussion. In the anonymous comments, one respondent explained their poor rating as relating to the content and objective of the activity and less to the activity itself.

> "The activity I gave the lowest rating to is one I personally struggle most to engage with constructively, as I see little benefit in (or even hope of) reaching a consensus on the definition of 'Social Innovation' in the SMARTEES project."

Interestingly, this shows that there are individuals in collaborative projects who do not see the value in having common definitions. However, six of the nine discussants found the activity productive and a good primer for discussions.

3.2. Strategy 2: A written feedback exercise

Motivation. A written feedback exercise was developed and undertaken with the objective of the consortium agreeing on a final common definition of the term "social innovation". The goal of such an exercise was to efficiently collect 'votes' on the proposed project definition of the term and to solicit specific feedback on disagreements with the proposed definition. This exercise came in the wake of previous group discussions, where definitions were proposed, as described under Strategy 1, above.

Goal. The final goal was to generate a project definition of social innovation that enjoys wide support of the consortium as a whole. The written feedback exercise allows for documentation of the consortium's support for the proposed definition and areas of remaining disagreement with the proposed definition along with specific suggestions for amendments.

Description. To begin the written feedback exercise, a 10-minute presentation on thought provoking points, such as breaking down potential definitions into constituent parts (e.g. problem statement, direct and indirect objects, etc.), regarding the definition of social innovation was held. After which, each participant was provided with a one-page paper handout. The handout had a place for the name of the participant with the "optional" tag, in case the participant wanted their response to remain anonymous. The handout then provided the proposed definition of social innovation and asked if the respondent agreed or disagreed with the definition, with an "unsure" option also provided. If the respondent disagreed or was unsure of the definition, they were instructed to write down specific issues that they saw with the suggested definition and to propose specific amendments to the definition that would rectify the problem.

Participants had 10 minutes following the presentation to complete the form. Participants were encouraged to interact in ad hoc groups with those around them to discuss relevant issues as they wrote down their personal feedback. Many participants quickly finished the task as they had previously thought about the topic or were fully in support of the proposed definition. The activity leader stayed engaged with the exercise by walking through the room and offering support or engaging in discussions. About one third of the participants actively discussed with the activity leader or those around them regarding specific points of the topic. No confusion about the purpose or instructions for the task was encountered; however, some participants needed additional coaxing to actually write down their comments and suggestions instead of relaying them only verbally to the activity leader.

Reflections. The written feedback exercise was well received by the participants and effective. The goal was achieved, as the results were used to finalize the definition of social innovation for the project.

Based on the outcome and the process we find that written feedback can be a good tool for interdisciplinary cooperation. For one, it is inclusive and allows each person to give their own feedback while still allowing for cross-disciplinary discussions within one’s proximity. Secondly, it forces participants to consider a question of limited scope (i.e. the question written down on the page), and to give specific answers to that question. On the other side, the written feedback tool is best used in circumstances where a limited scope is being addressed and specific feedback is requested. Using this tool for a broader scope would likely result in more confusion and lost time as participants would then be required to craft long and complex responses.

This activity received an average rating of 3.9/5 with respect to how useful participants found it, while one of the nine discussants found this activity to be unnecessary and would have preferred an open discussion. Only two of the respondents found that the objectives were well defined; a surprising point, given the pre-meeting emphasis that was given to defining activity objectives. This could be due to the fact that the objectives were only provided verbally, a takeaway from this is to ensure that objectives are visible to participants during the whole of the activity, for instance in a presentation or a handout.

3.3. Strategy 3: Structured brainstorming

Motivation. Group brainstorming sessions are likely the most common strategy currently used at meetings and workshops and therefore it is worthwhile to consider their structure and efficacy here.

Multiple structured brainstorming sessions were held during SMARTEES’ project meetings. The brainstorming sessions were motivated by a need to understand the full breadth of ideas and ambitions for a project output, similar to the motivation behind the word web in figure 2. From the broad pool of possibilities, the activity leaders were then able to pull out common threads of ideas to implement in the output. These sessions were positioned early on in the processes for creating their respective outputs, as they should be given the more general nature of their outputs.

Goal. While the specific topics of the brainstorming sessions varied, the goal in all cases was to generate a list of ideas that could be sorted through later and used to produce specific outputs.

Description. Structured brainstorming activities began with an introduction to the problem at hand that lasted between 5-10 minutes. The activity leaders made clear statements as to the objectives of each brainstorming session. For example, in one case, the issue at hand was the development of a webinar series to showcase the project results; the statement of objectives in this case was to come up with ideas for the format, content, and target audience for possible webinars.

After the objectives of the exercise were made clear, the leader broke the group into sub-groups. This was an important step where the leader ensured that these groups are interdisciplinary and mixed across types of stakeholders, genders, age, and institution (Brame and Biel, 2015). The sub-groups then discussed the objective(s) at hand to generate ideas for about 30 minutes. The leaders kept engaged during this stage to answer questions and to ensure that the discussions stayed on topic. After the sub-group brainstorming, the leaders assembled the findings by publicly going through each group and asking them to summarize their main points.

Reflections. Sub-group brainstorming is a common strategy employed in workshops. As such, it was noticeably more comfortable and easier to explain to the group at the start of the exercise. While these exercises can be easy to organize and can give broad inputs into the research process, they can have the downside of being overly general, as noted by the quoted survey participant below.

> "It seems to me that asking too general questions to all the group blurs the objectives of the exercise and provides less relevant/accurate results in the discussion (hard to see what an interdisciplinary group provides when the answers are not structured)."

This leads to the suggestion that brainstorming exercises can be similar to presentations and open discussions in their usefulness, from another survey participant quote.

> "Brainstorming exercises are sometimes useful but I prefer presentations and open discussions."

Another critical aspect that emerged from the multiple SMARTEES instances of this activity was the importance of sub-group diversity. This should help to generate diverse ideas and ensures that more encounters take place across disciplines, which helps to increase the number of such encounters as suggested by Bridle et al. (2013). Thus, the default option of allowing groups to be formed from those who initially chose to sit near each other is strongly discouraged.

This activity received an average rating of 3.7/5 with respect to how useful participants found it, and one of the seven discussants found this activity to be unnecessary and would have preferred an open discussion. The lower number of discussants for this activity reflects a higher number of participants who noted that they did not recall the specifics of these activities. This may suggest that brainstorming activities are less memorable than other strategies due to their frequent use at workshops. Furthermore, we found that only two of seven discussants found the brainstorming activities to be productive and well-defined, while five of the seven found that they lead to good discussions.

The feedback from our participants fits together with the other reflections to suggest a generalizable point about brainstorming activities: they can be useful to incite discussion but are less useful to target discrete objectives and move the common research agenda forward. As such, we would recommend to use this strategy sparingly and substitute it with some of the more innovative strategies, such as the other three presented in this paper.

3.4. Strategy 4: Cross-disciplinary group interviews

Motivation. Cross-disciplinary group interviews have a dual motivation. The first is to directly promote more interaction and understanding across disciplines and stakeholder groups. The second is to create interdisciplinary content.

For example, in SMARTEES, the purpose of one interview session was to create research questions that could be answered by an agent-based modelling approach. While agent-based modelling can hardly be said to be ‘new’, it is surprisingly unfamiliar to many in the social sciences and in policy circles (Polhill et al., 2019). As detailed in the description below, key parts of a documentation protocol (Grimm et al., 2020) for agent-based models were used to structure discussions with a view to enabling those unfamiliar with agent-based modelling to see the perspective of modelers.

Goal. While the first motivation of promoting discussion across stakeholders and disciplines is a valid goal in itself, the best practices of interdisciplinary research suggest that activities have a realizable and clear objective. In this regard, the goal of cross-disciplinary discussions is to create an end product, in the form of listed questions, topics, or areas of further reflection, that take account of the cross-disciplinary format.

Description. In the SMARTEES project there were two instances of cross-disciplinary group interviews. In both cases, the group was broken up into subgroups with ‘specialist’ representatives required in each group. For example, at one event in SMARTEES, each subgroup contained an urban planner and city representative, while at the other event, each group contained an agent-based modelling expert. These ‘specialists’ were then interviewed by the other members of each subgroup with a specific goal in mind. In the case of the agent-based modeler interviews, the goal was to elicit research questions related to one type of social innovation (holistic mobility plans, islands and renewable energy, district regeneration, mobility in superblocks, and energy efficiency against fuel poverty), that could be answered through agent-based models. This required that the subgroup question the specialist as to how they would go about understanding and implementing models related to particular research questions. If the method was deemed relevant and feasible, then this research question could be written down as a potential question for the agent-based modelling part of the project.

The agent-based modeler interviews were structured around a protocol for documenting agent-based models in academic literature (Grimm et al., 2006, 2010, 2020), which has been argued to also be useful as a means for structuring workflows for building agent-based models (Grimm et al., 2010). The protocol, known as 'Overview, Design concepts, and Details' or 'ODD' for short, provides a series of headings under which models are described in a manner that is complete (in the sense that theoretically, one could implement the model from the description) and readable (concepts are presented in a logical order). A typical ODD can run for several pages, and it would be inappropriate to expect participants to complete such a document. However, certain key headings (purpose; entities, state variables and scales; process overview and scheduling; observation; input data) provide the basis for a skeleton model. Outside of the agent-based modelling context, the key would be to structure discussions around any standards or protocols that reflect a specialist's ontological perspective to encourage participants to begin to understand their worldview.

In each case, the group leader remained engaged with the discussions by walking around and helping to clear up any misunderstanding. After ten minutes with each subgroup, the specialist moved on to the next sub-group, and thus the interview was repeated with multiple specialists. This was an important extension for gaining a robust view of another discipline as specialists represent their perspectives differently, and thus only by speaking with multiple specialists can participants gain a more complete understanding of the specialists' viewpoint. To end the exercise the group leader asked each subgroup to summarize what they learned from the specialists in two minutes or less. Along with the oral summaries, each subgroup submitted the requested output in written form to the leader, which was later compiled.

Reflections. Overall, this exercise was well-received and produced usable intermediate outputs for the project. Perhaps more helpful than the output was the increase in communication across stakeholders and disciplines that was incited by these activities. In particular, these activities gave the interviewed specialists the chance to have their full say and explain their perspective in detail, while this may not have been feasible in a general forum due to the number of specialists and time constraints. Also, using subgroups gave less vocal project personnel the chance to ask questions of the specialists, and less vocal specialists the chance to represent their perspective.

Due to the focus on specialists within a given field or stakeholder group, this exercise best fits to situations where one perspective needs to be explored in depth. For example, in SMARTEES, agent-based modelling is used to consider the application of social innovations to certain municipalities. Thus, both an understanding of the challenges and motivators faced by city officials and the abilities of agent-based modelers are of key importance. Modelers and city officials thus served as the specialists in two separate iterations of this activity.

This activity received an average rating of 4.3/5 with respect to how useful participants found it. Only one of the ten discussants found this activity to be unnecessary and would have preferred an open discussion. One commenter specifically mentioned the cross-discipline interviews as the most productive activities.

> "I think the diversity of exercise facilitation techniques was stimulating. Looking back to the different activities led during SMARTEES project meetings, it seems that the most productive ones were when differentiating the type of partners by discipline and/or role in the activity. [Partner A and B's] activities were both a good example in that regard (type of partner x interviews type of partner y)"

Still only 40% of discussants found that the objectives to these activities were well defined, a clear trend that suggests further steps are needed to clarify the objectives of structured group activities.

3.5. Recommendations for structured discussion strategies

This section related the methods of, and experiences with, four specific strategies for structuring face-to-face group meetings and workshops in multidisciplinary energy projects to improve efficiency and execute the common research agenda. These are anonymous ranking, written feedback, structured brainstorming and cross-disciplinary interviews. As a general reflection, the SMARTEES project personnel enjoyed the variety and innovative use of various group methods, as opposed to only having presentations and open group discussions, as shown by the following three quotes from survey respondents.

> "It was a structured way of working and led to interesting discussions."

> “[The activities] were well-organized, and opened up necessary areas of discussion for one or more members of the project team that needed the attention and constructive engagement of everyone.”
>
> “[The activities] were well organized and made good use of the time available.”

The post-activity feedback suggests that the most preferred exercise was the cross-disciplinary group interview, while the least preferred was the anonymous ranking exercise. One area of possible improvement in all the activities is in the explication of clear objectives for the activity. This is known to be an important aspect of group work (Brame and Biel, 2015), but, even in the best case of the four tested strategies, only 44% of post-activity survey respondents found that the objectives were well defined. This suggests further explicit steps for specifying the activities’ objectives, namely that they be visible to participants during the runtime of the activity.

A second consideration is the circumstance under which a given strategy makes sense. An obvious criterion arising from comparing the four activities tested above is the stage in the research process and the required specificity of the outputs of the activity. Brainstorming is best-suited to use early on in the research process for generating general ideas, while the written feedback exercise is ideal for gleaning specific inputs to a well-defined question. Along with this dimension, we can consider activities that actively push forward the interdisciplinary understanding and interactions within the group, and those that do not. In this aspect, the written feedback exercise is weaker as it does not explicitly invite exchanges between disciplines, but instead gives feedback mostly to the activity leader. In contrast, the cross-disciplinary group interviews are specifically designed to create a deeper understanding of a targeted perspective or discipline.

To describe these two critical dimensions of group discussion strategies we offer figure 3, which shows where the four tested strategies lie relative to each other in these dimensions. Strategies that invite interdisciplinary discussion in subgroups, framed with specific objectives, satisfy the goal of promoting interdisciplinary exchange, which will help to create common vocabulary and move forward the research agenda for the. The only strategy of the four tested to achieve high levels of interdisciplinary interaction while still allowing for specific outputs and objectives is cross-discipline group interviews, perhaps explaining the high scores this strategy received in the post-activity survey.

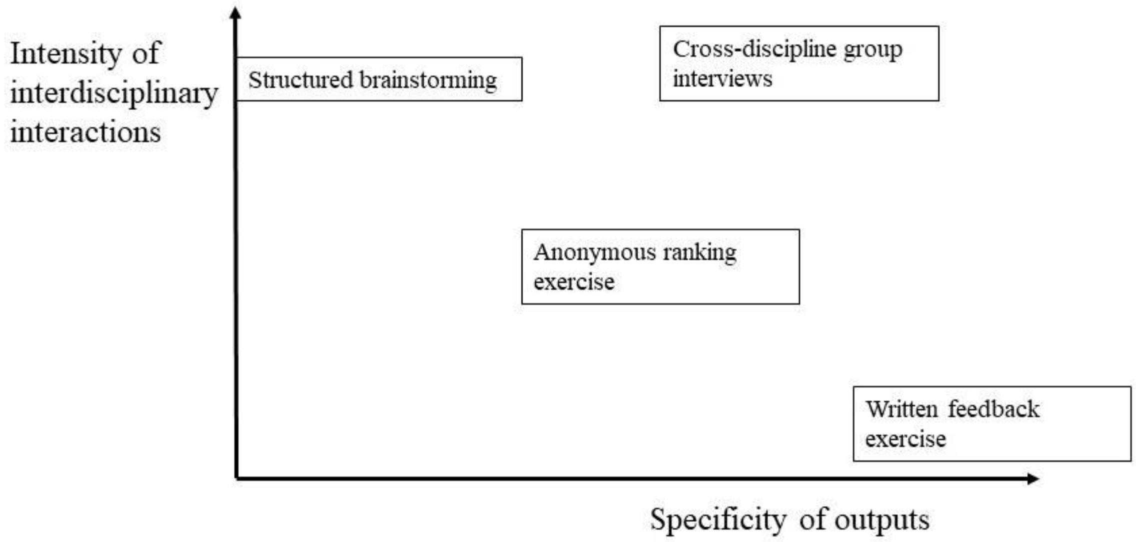

Figure 3: A framework for selecting and creating group discussion strategies

Based on the experiences related above, and a review of the literature regarding structured activities, we offer the following explicit recommendations to future interdisciplinary energy projects.

<u>Recommendations for structured group activities:</u>

1. Use structured activities in face-to-face meetings and workshops in place of some open discussions or presentations. However, keep in mind that structured activities take slightly more time to set up than a standard discussion or presentation. The efficiency gains from structured activities should be balanced with the time requirements considering the outputs required from the encounter and the degree of cross-discipline exchange desired (as in Figure 3).
2. The leader should define clear objectives for the activity and these objectives should be visible to the participants throughout the activity's duration.
3. Choose the format of the activity based on the two dimensions in Figure 3, the intensity of interdisciplinary interaction desired, and the specificity of the objectives and outputs required. All else equal, formats with higher levels of interdisciplinary interaction are preferred.
4. When an activity requires subgroups, take the extra time to ensure that each subgroup is diverse in terms of the disciplines, perspectives, genders, and age groups represented. This should be reflected in the set-up of the meeting room so that subgroup discussions are enabled.

4. Conclusions

The energy research agenda is moving ponderously, but continuously, towards a more interdisciplinary and integrated format (Sonetti et al., 2020). Due in part to the fact that interdisciplinary approaches allow for more complete answers to pressing societal questions that are complex and multifaceted in nature (Sovacool et al., 2015). However, interdisciplinary projects face many challenges related to cross-disciplinary understanding, work flow, and the format of research outputs that can inhibit the execution of the common research agenda (Sherif and Sherif, 1969; Klein, 1990; Riesch, 2014; Bark et al., 2016; Mallaband, Staddon, et al., 2017; Mallaband, Wood, et al., 2017; Winskel, 2018). The energy research community lacks specific strategies to overcome these barriers and ensure effective and efficient integration of inputs from different disciplines. This paper begins to fill this gap by offering implementable strategies that aim to support the efficient execution of the common research agenda and the delivery of holistic research products to policymakers and stakeholders in the energy system. The suggested methods for building a common vocabulary and four specific strategies for improving the efficacy of face-to-face group discussions are illustrated and tested within the context of the SMARTEES interdisciplinary energy research project.

We find that the best practices can help alleviate challenges in interdisciplinary energy research. With respect to the common terminology, the central takeaway is to use tools that illustrate the diversity of terminology within the project to help build a project culture that recognizes word choice as an issue, whereby disciplinary jargon becomes less acceptable while using plain language and asking for clarifications becomes more acceptable. Especially the divide between quantitative and qualitative research traditions creates complications in the articulation of joint methods and holistic research outputs. This issue is only partially resolved by drafting a common research agenda, as the execution of this agenda faces numerous challenges that are documented in the related literature. We suggest the elicitation of a common project vocabulary, as shown in section 2, along with increased structured interdisciplinary interactions can counter these challenges. The presented strategies for structured group discussions can improve the efficiency of face-to-face meetings and help move the research agenda forward, but the listed best practices in using and implementing these strategies should be used to avoid wasted time and confusion.

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