Using Scenarios for Interdisciplinary Energy Research
A Process Model

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Abstract: The transition towards renewable energies is not only a technical, but also an economic and social challenge. Without an economic perspective that takes into account risk and uncertainty, a technically feasible scenario can easily lead to financial losses. Likewise, a technically and economically feasible scenario which is not in line with public acceptance is difficult to implement and the diffusion of new technologies is hindered. It is therefore apparent that, for a holistic evaluation, new energy scenarios need to be considered from more than one perspective. The challenge in an interdisciplinary approach is to find a common analytical framework, which is a prerequisite to be able to integrate data and combine approaches from different disciplines into one holistic model. This paper suggests a process model for interdisciplinary collaboration and argues how within these, scenarios can be used as common frames of reference by taking a current interdisciplinary energy project as example. Finally, challenges and opportunities of the process model are discussed.

1 INTRODUCTION

Sustainable energy production is a global challenge. While the necessity of turning away from fossil fuels towards renewables is widely acknowledged and supported by the general public (Zoellner et al., 2008), specific energy projects have raised protests by (local) residents, especially large scale technologies and associated infrastructures (e.g., wind farms, transmission lines) (Wüstenhagen et al., 2007). While in the past, hindered diffusion and a lack of social acceptance also occurred, the scope, pace and organization of protest has dramatically changed (Marg et al., 2013), delaying projects and leaving residents unsatisfied with the development process (Gross, 2007). Among other reasons, this might be due to the fact that technology development predominantly considers technical, structural, or economic criteria, while social factors are often only integrated (if at all) at the very end of the research process (Zaunbrecher and Ziefle, 2016). A human-centered technology development process, also for energy technologies, thus needs to include social factors already in early phases. To achieve this, the interdisciplinary alignment of the adopted approaches is necessary. With interdisciplinarity, "a coordinated collaboration between researchers from at least two different disciplines, which can manifest itself in a simple exchange of ideas to the point of integration of methods, concepts and theories" is referred to (Hamann et al., 2016). It has been understood that a unidisciplinary perspective is not sufficient to understand global challenges like climate change or energy supply (Wilson, 2009), because these complex topics contain questions which cannot be answered by one discipline alone, but need the knowledge, methods and approaches of different disciplines. Nevertheless, up until now, no process model exists with specific guidelines how disciplines can collaborate to successfully achieve interdisciplinarity.

While the fact that interdisciplinarity as a key for understanding complex problems is increasingly acknowledged, and evolving into a general core academic competence (Boddington et al., 2016), the edu-

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cation at universities does not systematically incorporate interdisciplinarity as an inherent component of content-related questions across disciplines and it is rather treated as a stand-alone competence. Thus, specific research questions are mostly handled within the narrow limits of disciplines, and, if at all, possibly opened up for other disciplinary perspectives after the disciplinary approach is already finalized.

We argue that this shortcoming of academic education is due to the lack of a balanced methodological procedure, such as a process model, which allows to integrate the essential perspectives from the beginning of the problem-solving approach. In this paper, a conceptualization of interdisciplinary research is presented, in which scenarios play a key role for interdisciplinary collaboration. The model is designed to overcome barriers of interdisciplinary work such as diverse disciplinary perspectives, formed by different knowledge, socio-cultural upbringing, a different cognitive thinking, languages, methodologies, and code of practices (Lattuca, 2002; Hamann et al., 2016). The approach presented can be transferred to other interdisciplinary projects.

2 INTERDISCIPLINARY PROCESS MODEL

The process model (Figure 1) described in this chapter is exemplarily applied to the interdisciplinary energy project "KESS", in which researchers of the disciplines communication science and linguistics (=social perspective), mechanical and electrical engineering (=technical perspective), and economics are involved, exploring future energy supply for municipalities. In order to illustrate the interdisciplinary procedure, we first describe the process model in an abstract way and then elaborate on the specific energy scenarios used. The process model describes a continuum, from an "informal communication of ideas" to "formal collaboration" (Lattuca, 2002).

In stage one, the three perspectives (technical, economic, social) are marginally connected by the common research object "energy supply for municipalities". Each member approaches the topic from its own perspective, with its own methods. This also means that there are mostly unidisciplinary research questions, such as the interconnectivity between different technical parameters in the system from a technical perspective (Bexten et al., 2016b), or the perception of single components of the system from a social perspective (Zaunbrecher et al., 2017). For these studies, the research object (scenario) is loosely defined as a framework for the different perspectives. It is specified, e.g., which components the energy supply system contains, how many inhabitants the municipality has, and also how large the annual electricity consumption is and how large the share of renewables in the electricity supply of the municipality is.

This first stage cannot be referred to as truly interdisciplinary, as the perspectives and their methods or parameters are not interlinked yet. Rather, it presents a case of multidisciplinarity, in the sense that "every component of [the] research problem calls for a different science" (Krohn, 2010). This initial stage is, however, no less valuable, because each discipline first needs to acquire an understanding of relevant issues from its own perspective as a solid basis for later cooperation, as disciplinarity is "considered [one of] the most important factors for successful interdisciplinary collaboration" (Hamann et al., 2016).

The second stage, the "multidisciplinary approach with exchange", is similar to the first stage: all disciplines still approach the topic from their own perspective and with their own methods. Additionally, however, exchange between the three perspectives has started. At this time, requirements of the different perspectives regarding information or specifications from other disciplines should also be shared. Methods, approaches and terminology are communicated to create a mutual understanding for the disciplinary approaches (Armstrong and Jackson-Smith, 2013). This is necessary to prevent misunderstandings between disciplinary perspectives and a lack of understanding for possible contributions from other disciplines as well as for intersections between the disciplines (Hamann et al., 2016). The communicative basis which is founded in this stage is essential for the definition of scenarios in the subsequent steps.

Stage three is the first one in which interdisciplinarity is visible in the working process, and in publications arising from the collaboration in this stage. Bilateral teams are formed which approach a common topic, align their scientific approaches, combine methods and work on research questions which cannot be answered by one perspective alone, but need the knowledge and the methods of several perspectives. In the project at hand, these were questions of socio-economic, socio-technical and techno-economic nature (Zaunbrecher et al., 2016). During this phase, central benefits of interdisciplinary collaboration become visible, such as the widening of the horizon of the researchers involved, the combination of knowledge, and the innovative potential (Hamann et al., 2016). This is also the stage in which common scenarios start to play a key role. They define the boundaries and application fields as well as obligatory and optional components and form the basis for stages

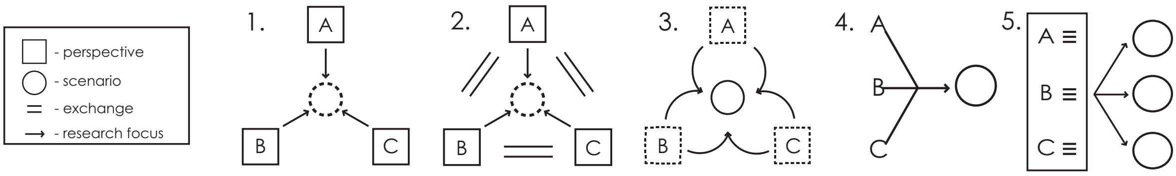

Figure 1: Process Model for Interdisciplinary Collaboration.

four and five (specific scenarios used in the exemplary project are presented in Section 3). The scenarios become necessary in this stage because the data acquired through the different methods applied need to be integrable. For this, a common basis is needed, which refers, e.g., to the level of detail in which a technology is analyzed.

In stage four, elaborated communication across the three perspectives and mature interdisciplinarity is achieved. The research topic is approached with a multi-method methodology, combining viewpoints, methods and approaches from all perspectives. Stage four is thus an advancement to stage three by combining not only two, but all perspectives involved. It is furthermore the prerequisite to stage five, in which an integrated, interdisciplinary index is created for the holistic assessment of energy supply scenarios. This requires the data of all perspectives to be comparable and integrable, for which the basis was formed in stage three by defining specific scenarios.

3 DEFINITION AND INTEGRATION OF ENERGY SCENARIOS

From stage three onwards, specific scenarios were used to coordinate interdisciplinary research and to facilitate the integration of results from different perspectives. In the stages before, the scenario was loosely defined to provide a framework for research.

In our exemplary case, this referred to the following conditions: The municipality to be supplied with energy has 10,000 inhabitants, thus the annual power consumption is expected to be 20 GWh. The annual power consumption should be covered integrally by locally produced electricity from renewable energy sources (wind power, photovoltaics (PV)), i.e. 20 GWh of “green” electricity should be produced in one year. The municipality should be connected to the grid (no isolated, autarkic solution), so it can rely on electricity supply from the grid at all times, and “black-outs” are avoided when no electricity can be produced from renewables and no stored electricity is available. Also, this means that at times when there is more locally produced electricity than could be used or stored, it can be fed into the grid. Additionally, battery and hydrogen storage are specified as electricity storage possibilities.

For the renewable sources, a reference year in the region of Aachen, a mid-sized city in Western Germany, is chosen to provide data for solar radiation and wind speeds. For solar power, installation on rooftops was assumed rather than a solar park. Furthermore, the types of components used (wind turbines, solar panels, battery storage, hydrogen storage) are technically specified (Bexten et al., 2016a).

3.1 Disciplinary Parameters and Scenario Requirements

Apart from the reference framework described above, each perspective had specific requirements for the definition of the scenarios.

Technical: From a technical point of view, the scenarios are used to quantify the impact of the specified dispatchable energy conversion and storage components on the electrical self-sufficiency of the municipal energy supply system. In addition, the resulting operational demands on the dispatchable components are analyzed. These investigations require information on the time-dependent dispatch and performance of the individual system components within the scenarios. To be able to provide this data, detailed technical component models, incorporating part-load characteristics and operational flexibility parameters, have to be integrated into an overall model of a municipal energy supply system and a corresponding operational strategy has to be defined. This approach subsequently enables the simulation of the energy supply system operation within a predefined scenario.
In addition to the evaluation from a technical perspective, selected simulation results also function as basic input parameters for the scenario analysis from an economic and social perspective.

Economic: Scenarios are required for the economic assessment to estimate costs and risk of different asset portfolios. Besides the pure amount of costs, this also helps to decide between a framework in absolute or in relative values. It turns out that a framework based on levelized costs of electricity supply and storage would be favorable since it makes a comparison of assets with different life expectancies as well as different operational strategies easier. The second aspect is the investment risk, which should also be considered in an economic evaluation. Scenarios based on different asset portfolios were used to illustrate the trade-off between profitability and risk (Madlener, 2012). They can help to estimate how much stronger the impact of a bias in the estimates is (such as for the amount of wind or the electricity exchange prices) in scenarios which focus on only one technology in comparison to those which are more versatile. The results can later also be analyzed from a social perspective.

Social: From a social perspective, research questions for which the scenarios were required included social acceptance and attitude towards the combination of components and possible trade-offs. For this, it was necessary to have specific technical information, most importantly with regard the number and size of the components as well as technical consequences for specific combinations (e.g., the degree of self-sufficiency, defined as periods where the municipality used their own, locally produced electricity from renewables), as it was hypothesized that these parameters were relevant for acceptance. Additionally, the scenarios should be defined in a social context in order to be understandable for laypeople. At the same time, they should provide a level of complexity which allowed to vary certain parameters (e.g., electricity mix and types of energy storage). Finally, the total number of final scenarios should be manageable within a single survey, so that a comparison between all scenarios by a participant would be possible.

3.2 Final Scenarios

The final scenarios (Table 1) were based on the "lowest common denominator" of the requirements from the three perspectives: the definition of the electricity mix (based on PV and wind power) and the type of storage technologies. The electricity mix was defined in shares, which were mostly influenced by technical and social considerations: The shares should correspond to an integer number of the same type of wind turbines to make the scenario feasible (e.g., not 3.5 wind turbines), but at the same time, they should be substantially different between the scenarios (e.g., not 33% vs. 35%), so that the differences are relevant to laypersons. According to these requirements, shares of around 30/70 and 50/50 were chosen. The electricity storage type was operationalized by the differentiation between different storage strategies. It was refrained from including, e.g., different types of batteries or hydrogen storage options, as there were considered too detailed information for laypersons. The combination of these two factors resulted in 12 scenarios (Table 1) which are used in subsequent stages for interdisciplinary research approaches.

3.3 Integration of Scenarios in Disciplinary and Interdisciplinary Research

The scenarios defined in Table 1 were used in disciplinary and interdisciplinary research approaches.

Technical: In a first step, the described scenarios were used as input parameters for the simulation of the municipal energy supply system operation. The subsequent analysis of the simulation results mainly focused on the impact of the different dispatchable components on the system self-sufficiency utilizing various technical evaluation parameters. The results were, in turn, used in the studies on the social acceptability of scenarios. In addition, the flexibility demand on the individual dispatchable components (e.g. no. of start-ups, load gradients) was evaluated (Bexten et al., 2017). In a next step, the scope of the scenarios and the associated simulations will be extended to the municipal heat demand and the potential to provide the required heat with the dispatchable system components. The influence of different energy supply system operational strategies, incorporating economic parameters, will be in the focus of further research.

Economic: To enable potential decision makers to evaluate the trade-off between risk and value, a pre-simulator was programmed. As input to this simulator, the parameters and limitations from the technical perspective had be taken into account. While less precise than the technical simulation, this pre-simulator allows for a quick overview about the economic viability and risks of different technical portfolios, which can subsequently be addressed from a social perspective. The outcomes can help to keep risk at a socially acceptable level without losing too much of the economic value.

Social: In the initial, exploratory socio-technical analyses (cf. Step three, Section 2) the scenarios were used in discussions with laypersons by integrating them in an interactive scenario builder (Figure 2). It was used by participants to create their own, favored scenarios and served as an anchor in the discussion to remind participants of the different components and help them imagine the situation in the municipality. Using the specific scenarios, acceptance-relevant factors for single components (e.g, hydrogen storage) as well as combinations of components were identified, and also factors defining trade-offs between scenarios. Further research will include quantitative analyses of the scenarios with regard to social acceptance.

Table 1: Energy supply scenarios.

Scenario	Electricity mix	No. of wind turbines	No. of PV modules	Storage
A1	73% wind, 27% PV	3	1025	no storage
A2	73% wind, 27% PV	3	1025	battery storage
A3	73% wind, 27% PV	3	1025	hydrogen storage
A4	73% wind, 27% PV	3	1025	hydrogen + battery storage
B1	49% wind, 51% PV	2	1960	no storage
B2	49% wind, 51% PV	2	1960	battery storage
B3	49% wind, 51% PV	2	1960	hydrogen storage
B4	49% wind, 51% PV	2	1960	hydrogen + battery storage
C1	24% wind, 76% PV	1	2695	no storage
C2	24% wind, 76% PV	1	2695	battery storage
C3	24% wind, 76% PV	1	2695	hydrogen storage
C4	24% wind, 76% PV	1	2695	hydrogen + battery storage

The results can then be re-integrated into the technical as well as economic modeling, approaching the last step of the research model.

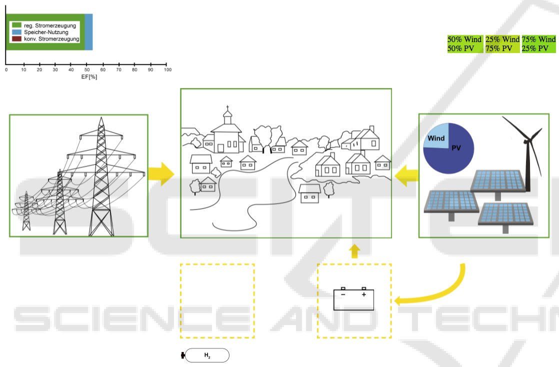

Figure 2: Scenario builder for social acceptance studies.

4 DISCUSSION

The process model presented requires the different perspectives to settle on compromises, often at the expense of detail, to be able to integrate the different perspectives (for example when negotiating the scenarios). It could thus be argued that the model results in a lack of depth of the analyses (Hamann et al., 2016). To avoid this, a continued disciplinary approach next to the interdisciplinary analyses is necessary. This means that while input parameters for the interdisciplinary analyses might not cover in depth the research question of a single discipline, this can well be achieved by taking the interdisciplinarily agreed upon scenarios as starting point for more detailed disciplinary analyses - next to analyses on a level which can be integrated with other disciplines.

While the process model was successfully applied to the KESS research project, there might be projects and constellations of perspectives for which the application is more challenging. The KESS project, e.g., involved researchers of the same university, which means that the frequently reported organizational barriers in interdisciplinary projects were possibly lower than in projects with researchers of different organizations (Cummings and Kiesler, 2005). Despite the great value of the process model for the project work, it remains an open question what exactly influences the success of interdisciplinary research, whether it is the project itself (content), the perspectives involved (disciplines) or the specific researchers involved (personalities). Success or failure of an interdisciplinary project should thus not be attributed to a process model (or lack thereof) alone. However, independent of other factors enabling interdisciplinary success (Calero Valdez et al., 2012), a process model such as the one described is a decisive enabler of interdisciplinary work. Still, future research should address the applicability of the model to other interdisciplinary projects and the personality of team members to be able to steer team communication.

For responsible university education, it could be promising to form novel modules in different faculties, in which interdisciplinary methods are interlinked with content related questions to teach multiperspective problem solving.

5 CONCLUSIONS

For complex problems of worldwide relevance, such as energy supply, integrated, interdisciplinary approaches are inevitable. The step-wise model presented in this paper answers the need for specific, content-driven guidelines for interdisciplinary research and exemplifies how specific scenarios can be used as key elements, from which socio-technical, socio-economic and techno-economic approaches can be developed. While the model is generally applicable to other research projects, it should not be taken as a guarantee for successful interdisciplinary research, as this is dependent on multiple factors.

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