Bridging the valley of death: A multi-staged multi-criteria decision support system for evaluating proposals for large-scale energy demonstration projects as public funding opportunities

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Keywords
multi-criteria decision support, demonstration projects, governmental support, funding

Abstract
There is an increasing pressure that enhanced and novel energy technologies are swiftly adopted by the market to ensure meeting the energy and climate targets. An important issue with such novel developments is their risk to be stuck in the 'valley of death', i.e. that their transition to the market is delayed or unsuccessful. Publicly supported demonstration projects could help to bridge the valley of death by reducing barriers to the adoption caused by missing information and perceived risks. A challenge for technology demonstrations in the industrial context is their often high investments that are required to prove their real-world benefits. Given the magnitude of such investments, it becomes crucial that public funding focuses on the most promising demonstration proposals. Structured evaluation processes can help to facilitate the identification of promising proposals and to improve the quality and transparency of decisions. This paper deals with a corresponding multi-staged multi-criteria decision support system (DSS) suggested to the German Federal Ministry for Economic Affairs and Energy. It deals with the evaluation of demonstration proposals across three stages: The first stage represents a filtering stage to identify those proposals relevant for further considerations. The second stage comprises a multi-criteria scoring method drawing on an evaluation against nineteen criteria. The final third stage serves to critically review the need for public funding of well-scored proposals. This contribution outlines the development of the DSS and its design and thus provides insights on proposal evaluating in energy research.

Introduction
Industrialized countries spend substantial budgets to support research for enhancing existing and developing new energy technologies (e.g. OECD/IEA 2017). The development state of these technologies can be described by technology readiness levels (TRL) (e.g. Mankins 2009): The lowest TRL 1 indicates that the basic principles of a technology have been observed while the highest TRL 9 points out the availability of proven systems. Public research funding traditionally tends to focus on TRL 1 to 6 or 7. With respect to the current target of reducing greenhouse gas emissions by at least 80 % until 2050 as compared to 1990 levels (European Commission 2011) and in view of the 1.5 degree Paris Agreement, the successful and broad utilization of efficient and climate friendly new energy technologies beyond TRL 6 gains significant importance. Yet, there remains a need to ensure a successful market transition of new developments after traditional research funding has ended as they run the risk of being stuck in the 'valley of death', i.e. they fail to be adopted by the market or this process simply takes long (Figure 1).

Bridging the valley of death for promising activities by public funding could help to accelerate the transition towards a low-carbon energy system. Yet for several reasons, thoroughly reviewing and identifying potential candidates for further funding can be considered as challenging for public institutions: First, industry-scale implementations require considerable resources for scale-ups and real-world adaptations while public budgets are limited and there are numerous funding opportunities. Thus, only the most promising projects can receive funds and these need to be identified. Second, market failures have to apply, i.e. there must be considerable financial risks and financing gaps to indicate public engagement. Third, public budgets must to be spent as effectively as possible. It also becomes increasingly important to transparently and comprehensively document the objectiveness of funding decisions. Finally, public engagements in the European Union (EU) have to comply with European legislation.

To help overcome these challenges and to facilitate the evaluation process, the aim of this contribution is to develop a decision support system (DSS) for evaluating proposals for large-scale energy demonstration projects as public funding opportunities. The approach has been elaborated as part of a research project on R&D of future energy technologies, funded by the German Federal Ministry for Economic Affairs and Energy (BMWi).

In the following, the approach for developing the DSS will be described first (section 2). Thereafter, the requirements and methods for the DSS itself will be discussed (section 3). This is followed by a presentation of the DSS and its respective stages (section 4), a discussion of the system and its implications for research funding (section 5) and final conclusions (section 6).

Methodological approach for developing the DSS

The process for developing the DSS had several phases (Figure 2). A preliminary problem definition phase initiated the development process. The impetus for this phase was an exchange between BMWi and the project team pinpointing the previously mentioned challenges that underlined the need for a DSS. Based on this exchange, a rough outline of the system was sketched and a formalised process was started.

A phase of information collection followed which concentrated on works related to the strategic planning of energy research activities in Germany (Vögele et al. 2007; Wietschel et al. 2010; Viebahn et al. 2017). Furthermore, a selection of approaches for proposal evaluation from different programmes and contexts in several countries were analysed (e.g. Horizon 2020 [European Commission 2017], Danish EUDP [ENS 2012], Austrian FFG approach [FFG 2016], EIT InnoEnergy [KIC InnoEnergy 2016]). The latter were mainly reviewed with regard to their evaluation criteria and mechanisms. A third element in the analysis focused on the legal framework for public funding in energy research in the EU. It focused particularly on definitions and financial ceilings for public funding activities.

The following system design phase included three successive workshops for problem framing, conceptual development and verification. These workshops were carried out as 3 to 6 hour workshops with members of German funding bodies: Next to a core team of at least five members attending all workshops, additional participants from funding organisations were especially involved in the problem-framing phase. A first workshop was both designed to gain a common problem understanding and to define the requirements to the DSS. A second methodological

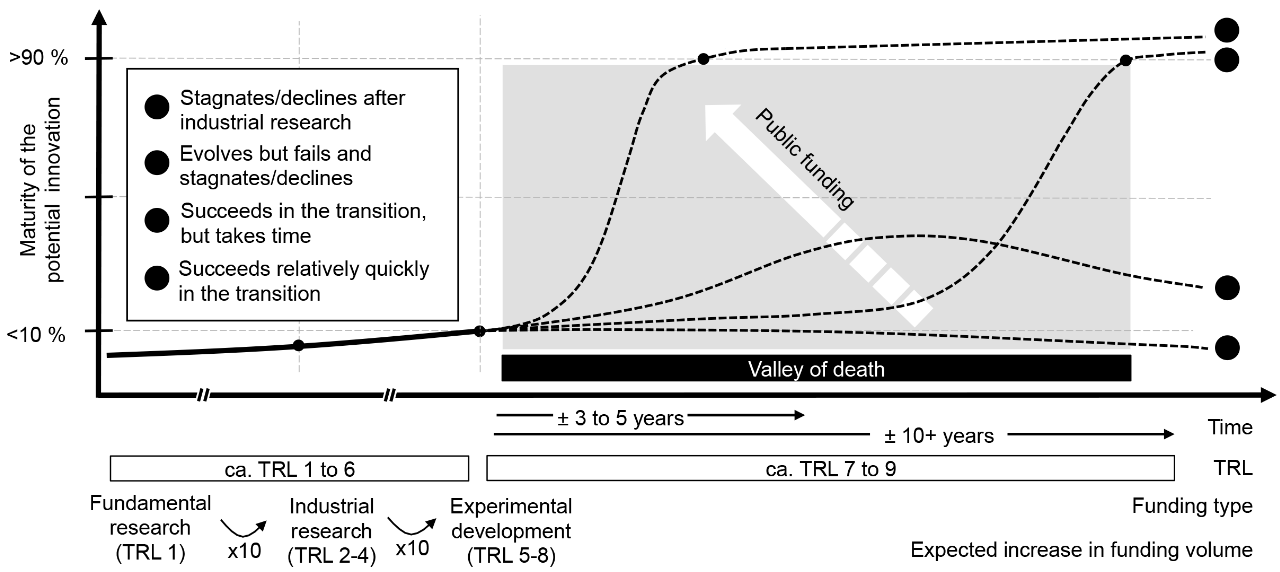

Figure 1. Conceptual illustration of the valley of death after typical project funding ends.

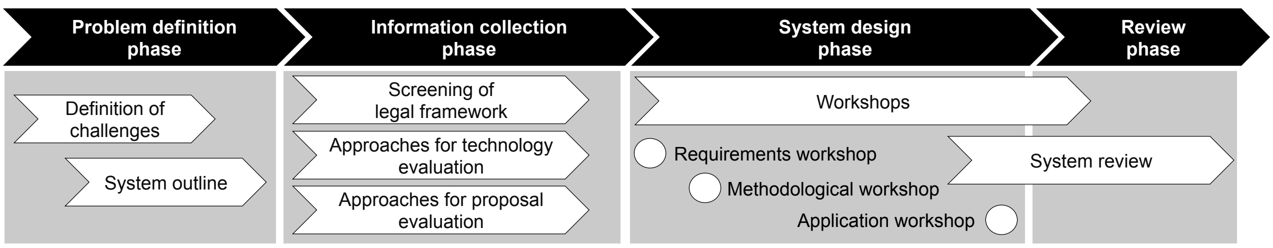

Figure 2. Overview of the methodological approach.

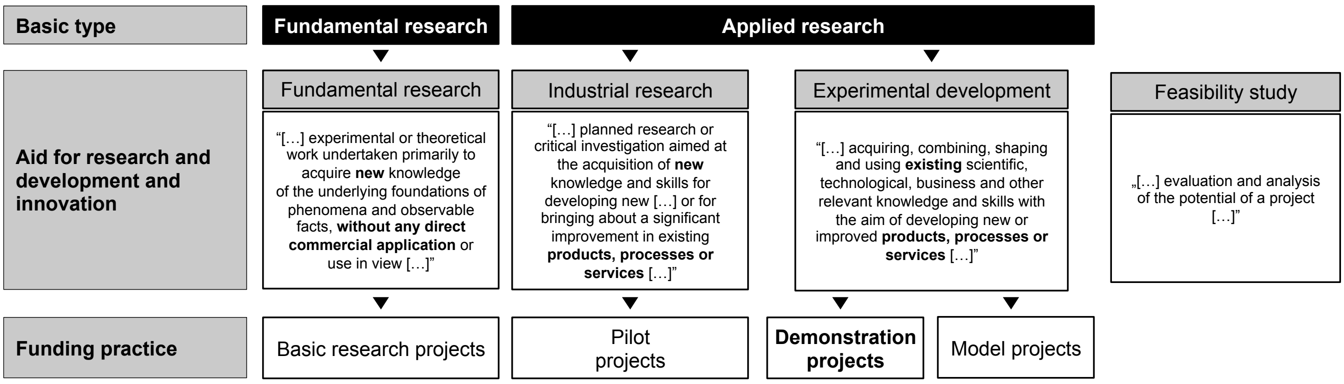

Figure 3. Terminology in the context of public research funding (citations on aid abbreviated from European Commission 2014).

workshop served to discuss an early system draft as well as evaluation criteria and their importance. A third application and verification workshop served to critically review the final draft. To ensure the validity of the approach, an internal system review was launched prior to the third workshop to critically review the draft and to challenge the assumptions made for the concept.

As the result of the process, three main outputs have been developed: A background document specifying the requirements to the DSS, a hands-on guideline for practical decision making at funding agencies, and a sample tool for illustrating the evaluation approach.

Requirements and methods for the DSS

TERMS AND DEFINITIONS RELATED TO ENERGY RESEARCH PROJECTS

In the context of national funding activities in the EU Member States, various terms and conditions from European legislation apply, especially from regulations on aid for research, development and innovation. In general, fundamental and applied research are distinguished as two basic types of research activities (Figure 3). The latter can be disaggregated further into industrial research and experimental development (European Commission 2014). In addition, feasibility studies are a specific category. Next to these types, the German energy research programme (BMWi 2011) refers to additional types of projects such as 'pilot projects' and 'demonstration projects' while a few public calls (e.g. BMWi 2017) also focus on funding 'model projects'. The lower part of Figure 3 provides a suggestion how these terms relate to fundamental and industrial research as well as to experimental development.

Despite a general understanding, there is a lack of specific definitions which makes it difficult to judge whether a project proposal falls into a specific category. For the purpose of the DSS, demonstration projects as in the focus of this contribution are considered as specifically characterized a) by broad transfer activities, b) by contributing to the enhancement of standards and approval procedures, c) by involving transfer partners in the project teams, d) by aiming for improvement of the acceptance levels of new technologies, e) by their uniqueness, f) by their localized character, g) by ensuring that within 5 years, the system will work and h) by plausibly describing a high likelihood that the project results will lead to cost-effective implementation after the project's conclusion.

PROPOSAL EVALUATION PROCESS IN GERMANY'S APPLIED ENERGY RESEARCH FUNDING

A specific outline of the administrative process for a successful proposal in German public energy research funding is provided in Figure 4. Mainly four groups of stakeholders are involved in the overall process: these are applicants, i.e. those developing and submitting project ideas, funding agencies or bodies, the Ministry and, if required, internal or external evaluators. The entire evaluation process covers different steps and has many interfaces with information transfers between these stakeholders. With regard to defining the requirements to the DSS, there is a need to acknowledge both the different groups as well as the interfaces between them.

REVIEW OF OTHER APPROACHES FOR PROPOSAL EVALUATION

The evaluation of project proposals is a core process of many funding organisations for applied research. While little verified knowledge is published on evaluation and selection processes in innovation agencies and within their programmes, an overview of the general situation is provided in Biegelbauer et al. (2016). Here, a brief look at a few energy and climate-related evaluation approaches is taken. Though publicly available information is generally scarce, call documents and submission guidelines yield some insights on criteria and on underlying evaluation mechanisms, as well.

Within the EU ETS, for example, the NER 300 programme for demonstration projects for CCS and innovative renewable energies was established. While project selection is mainly based on costs effectiveness, requirements to knowledge transfer from funded projects are also considered there. These include the technical set-up and performance, cost levels, project management, environmental impact, health and safety, and for CCS aspects related to site performance (European Commission 2010). Another example for a funding programme is the Danish Energy Technology Development and Demonstration Programme. In a 2012 call for proposals (ENS 2012), four main evaluation criteria including additional sub-aspects are described there: the "energy-related and technological perspective", the "economic perspective", "own contribution and incentivising effect" as well as "organisation, collaboration and knowledge transfer".

Additional information on evaluation mechanisms can be found in other funding schemes. Within the EU's Innovation and Research Programme Horizon 2020, for example, award

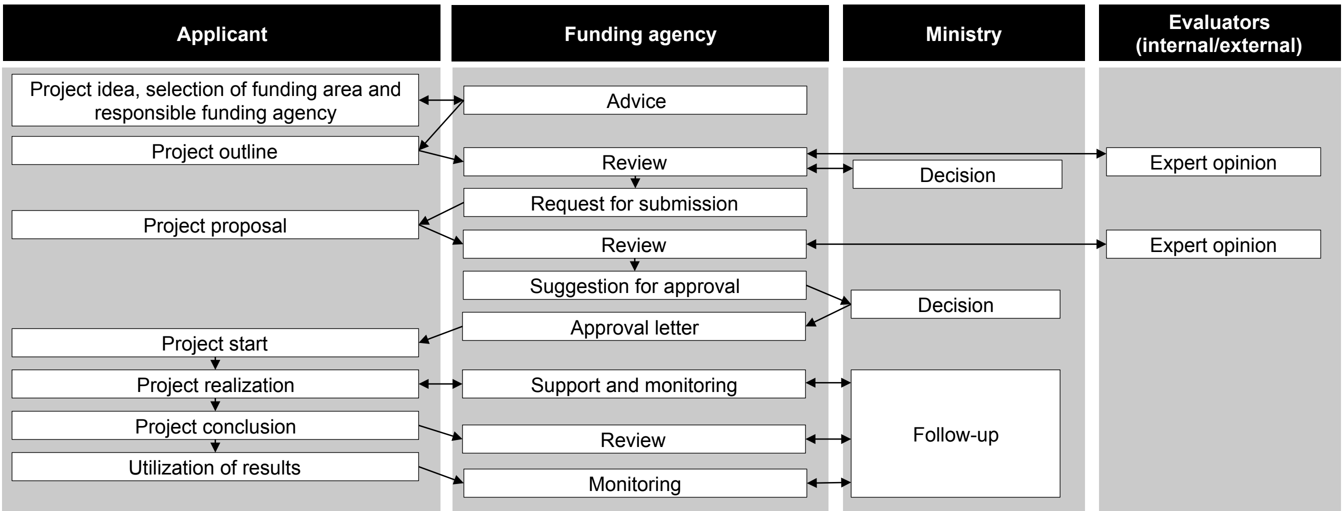

Figure 4. Administrative process for a successful proposal in Germany public energy research funding with amendments based on BMWi (2011).

criteria for research grants within the funding area "Secure, clean and efficient energy" include their "excellence", "impact" and the "quality and efficiency of the implementation". For full proposals and unless otherwise specified, these criteria will have equal weights. Each criterion is scored on a 0 to 5 level and a minimum of 3 per criterion and of 10 for the overall evaluation is required for funding (European Commission 2017). Another example with further breakdowns of criteria and weights is for example found in a call by KIC InnoEnergy (KIC InnoEnergy 2016). Here, five main criteria as well as two to five additional sub-criteria per main criterion are laid out. Weights are also attributed on the level of sub-criteria. Another more detailed, yet non-energy focused approach is described in a guideline by the Austrian Research Promotion Agency (FFG 2016). Here, four main criteria with minimum thresholds and sub-criteria with different achievable scores are used. In addition, a list of sub-items and examples is provided for further detailing of some of the criteria.

With regard to suggesting a DSS for proposal evaluation in energy research, the range of different criteria used for project evaluation in these funding programmes suggests that proposals evaluation requires a multi-dimensional approach. Where further information on the process mechanisms are given, it seems that weights and thresholds are also common practice. Moreover, it can be noted that the methods for the evaluation are usually relatively simple and straightforward scoring models.

CONCLUSIONS AS GENERAL REQUIREMENTS FOR A DSS

Based on the review of legal documents, existing evaluation approaches as well as the results from the first workshop, the following requirements to the DSS were compiled and used as a guideline to develop the DSS:

- *Definitions*: While legal European documents set the framework for public funding, terms like 'demonstration projects' or 'model projects' are insufficiently defined. Therefore, the DSS should include a suggestion for determining the type of proposal at hand.
- *Operationalisation:* To ensure that all proposal evaluations are based on the same premises, the DSS should also provide operationalisations, especially when very general terms and concepts (e.g. 'excellence', 'innovation') are used.
- *Universality:* Given that many technological areas could be covered by project proposals, the DSS should be universally applicable and not be tailor-made to certain energy technologies.
- *Simplicity:* Various and varying stakeholders are involved in the evaluation who are not necessarily proficient day-to-day users of the DSS (e.g. experts on dedicated topics or personnel only occasionally involved in evaluations). The DSS should therefore be an intuitive non-expert system.
- *Real support:* The DSS should assist public funding bodies, but it should not be designed as a simple scoring mechanism or algorithm replacing knowledge and experience. Otherwise, it might run the risk of not being accepted by future users which want to bring in their expertise on the one hand. On the other hand, a 'mechanistic' view on proposals might not allow to properly cover the full context of the proposal.
- *Linked to TRL:* Given that TRL are well established in project funding, the DSS should also link to them.
- *Documentation:* Due to an increasing need for transparent documentation of decisions in public funding, the use of the DSS should also allow documenting decisions.
- *Funding ceilings:* Legal documents set ceilings for public funding without a notification process, but a minimum funding is needed to incentivise submissions. The DSS should help to consider this.
- *Compensation:* Proposals may vary in their performances. The DSS should ensure that good scores in some areas do not compensate for bad scores in other areas. This means that proposals should achieve minimum quality levels with regard to all evaluated criteria.

SELECTION OF A MCDA METHOD FOR PROPOSAL EVALUATION

Due to the multi-criteria nature of many decision situations, a large number of methodological approaches have been developed since the 1960s to support decision-makers in evaluating and selecting alternatives (such as project proposals) by formalised explicit models (Zhang et al. 2009). For such models, it is necessary to operationalise the relevant target criteria, to determine the benefits of an alternative course of action and to resolve existing target conflicts (Klein and Scholl 2011).

Many methods of Multi-Criteria Decision Aid (MCDA) have been developed to support decision-makers by allowing to concurrently and transparently analyse several goals. The selection of a specific method is usually based on the problem to be solved (Zimmermann and Gutsche 1991). Within MCDA, two main families of methods can be distinguished: Methods attributed to Multi-Objective Decision-Making (MODM) allow determining optimal alternatives which are implicitly described by mathematical objective functions and constraints. The second family, methods of Multi-Attribute Decision-Making (MADM) allow to evaluate a set of explicitly given alternatives, as is the case with proposals.

Various aspects (Figure 5) next to the general requirements described above determine the selection of the evaluation method for the DSS:

- *User group*: Depending on the group of users, methods of varying complexity can be considered. As pointed out in the general requirements, the DSS should be suitable for non-expert users.
- *Perspective:* Though the DSS should transparently document decisions, it is primarily intended as an operational instrument for funding bodies and similar institutions and thus should adopt their perspective on proposals.
- *Decision-makers:* Individuals or groups can make decisions. For ensuring the simplicity of the DSS, the use of a method for an individual or a group treated as an individual seems most appropriate.
- *Alternatives:* Alternatives can be implicitly or explicitly described and proposals are the latter. Yet it should be noted that in case of funding programs without fixed deadlines, a direct comparison of proposals is not necessarily possible. An appropriate method should thus also allow to analyse individual proposals.
- *Problem statement:* Different types of problems are distinguished in MCDA theory (e.g. Belton and Stewart 2002). In the case of the DSS, the so-called description problem (i.e. a simple description of performance parameters without aggregation) but also the ranking problem (i.e. a ranking of the best to the worst proposal) as well as a sorting problem (i.e. a classification into groups such as excellent, adequate and insufficient proposals) could be relevant.
- *Type of information:* With regard to proposals, at least some of the data might be quantitative and, as illustrated above, many methods use weights to differentiate the importance of criteria. This suggests using a method that is able to process cardinal information.
- *Uncertainties*: Real-world decision problems are always fraught with uncertainty, due to non-quantifiable, incomplete or unavailable information or ignorance (e.g. Chen et al. 1992). Though there are many methods to deal with uncertain information, the need for simplicity suggests avoiding the explicit consideration of uncertainties.
- *Weights:* An important component of a multi-criteria procedure are the weights of decision criteria. The review of programmes indicates individually tailored weights which depend on the programme. A suitable method should allow selecting individual weights.

METHODS FOR MULTI-CRITERIA DECISION SUPPORT

Methods for multi-criteria decision support need to be reviewed against these requirements. As proposals correspond to explicitly defined alternatives, only the MADM methods apply. They can be further structured by the type of information about the alternatives (i.e. what information is available about the alternatives) and then by the quality of information (i.e. which type of information is used to reflect the decision-maker's preference). With regard to the latter, cases with no information, information on alternatives as a whole or information on their individual attributes can be distinguished (Figure 6).

In the case of proposals, information on individual attributes is available. Corresponding methods are further disaggregated by whether nominal (disjunctive vs. conjunctive procedure),

Aspect	Structure			
User group	Expert user group		Non-expert user group	
Perspective	Applicant	Funding agency	Public	Others
Decision maker	Single decision maker or implicit group		Explicit group decision	
Alternatives	Unlimited or implicitly defined number		Limited or explicitly defined number	
Problem statement	Choice	Sorting	Ranking	Description
Type of information	Nominal information	Ordinal information	Cardinal information	
Uncertainties	None or implicit consideration		Explicit consideration	
Weighing	Equal weights		Individual weights	

Figure 5. Morphological box to describe the setup for the DSS (relevant aspects in grey).

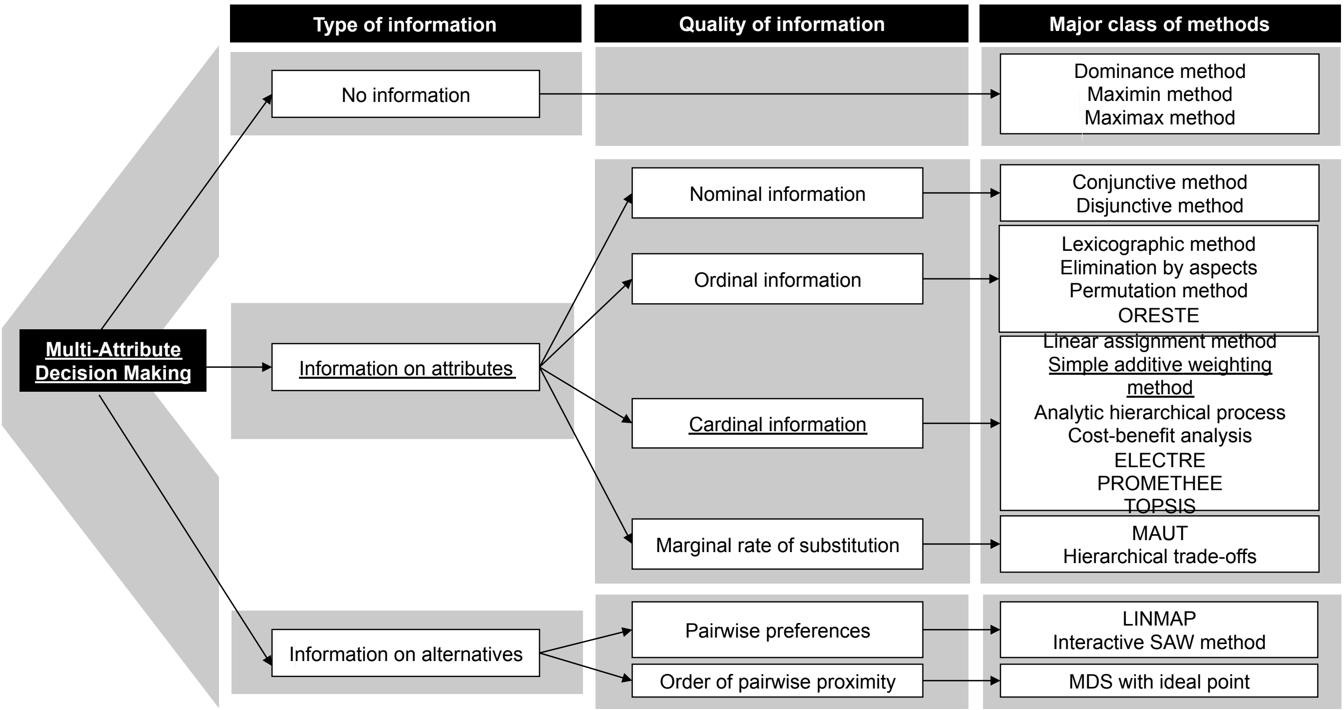

Figure 6. Overview of MADM methods (with modifications based on Götze 2008; Hwang and Yoon 1981).

ordinal (e.g. Lexicographical method, Permutation method) or cardinal information (e.g. Analytical hierarchy process, ELECTRE, PROMETHEE, Cost-benefit analysis) is used or whether rates of substitution apply (e.g. MAUT, Hierarchical trade-offs) (Götze 2008; Hwang and Yoon 1981). For the latter two types, weights can be attributed and thus a specific importance can be assigned to the attributes of the alternatives. As compensation, i.e. substitution, is excluded by the requirements, a method from the group of cardinal approaches seems well suited. Due to its simplicity, the simple additive weighting method seems a good candidate for the DSS and has also been used in the previously described evaluation approaches.

Description of the DSS

The approach for the DSS comprises three stages of analysis (Figure 7), whereby project proposals can be excluded from funding at each stage.

FILTERING STAGE

Review of fulfilling the formal criteria

The aim of this first step is to ensure compliance of the submitted documents with the formal requirements to a proposal. It contains, for instance, a check whether all required documents have been completed and submitted on time and, for instance, a comparison of the consortium's composition to the requirements of the call.

Review of innovative parts

This step is dedicated to identifying the parts of the proposal that are relevant for funding. The key issue here is how to break down the proposal and how to determine in how far its parts are innovative and therefore eligible for funding. The DDS suggests to start by systematically subdividing the overall project by its essential 'contents', e.g. a) along the working plan, b) by work packages, c) by sub-parts of the real-world installation, d) by technical process steps or e) by services. A subsequent identification of the 'contents' which are relevant for the research activities is based on a review using the TRL for support. Here the DSS forsees that a set of questions is answered for each 'content'. Based on the answers, a TRL is attributed to each 'content'. Due to the close-to-market nature of demonstration projects, only the high TRL beyond 7 are in the focus of these questions. 'Content' is not considered as eligible for funding if it already belongs to TRL 9 unless it is indispensable for the implementation of other innovative parts. The determination of the relevant surplus costs follows the same approach: It is also based on reviewing the individual 'contents' and asking to what degree they are relevant for realizing the innovative parts of the proposal.

Evaluation of the demonstration character

The third step intends to verify whether the submitted proposal has the relevant characteristics of a demonstration project. To do so, two tasks must be carried out: First, it is required to verify when the proposal corresponds to an experimental development according to the legal framework of the EU. For this purpose, a list of supporting questions, closely following the legal texts, needs to be answered. Second, specific characteristics of a 'demonstration project' must be met. Table 1 shows an excerpt of this list including supporting items. The full list covers all aspects enumerated earlier.

Review of existing market failures

Market failures are essential for public funding. They are supposed to exist if the implementation of the research-relevant content of the proposal is expected to be so unattractive from an economic point of view that it would not be realized without funding. Alternatively, economic risks may also prevent investments in innovative approaches, e.g. if they might endanger the existence of the beneficiary in the event of a warranty claim. Again, a list of questions has to be answered here.

Review of the strategic-programmatic relevance

A final important step concerns how a proposal fits into the funding scheme. A set of questions helps to check, for example, whether the proposal makes an adequate contribution to the scheme, whether it closes gaps in the existing funding portfolio and whether it does not endanger the balance of the funding portfolio (e.g. by binding too large sums).

EVALUATION STAGE

If a proposal has successfully passed the filtering stage, a detailed assessment is made at the evaluation stage. Here the simple additive weighting model is used to cover six main areas. Three of the main areas ('Contribution to the fulfilment of energy and climate policy requirements', 'Strengthening and securing the competitiveness of German companies', 'Securing and expanding technological development') reflect the objectives of national energy research policy in accordance with the current German Federal Energy Research Programme (BMWi 2011). The three remaining areas cover the inherent characteristics of the suggested project ('Suitability of applicants', 'Qual-

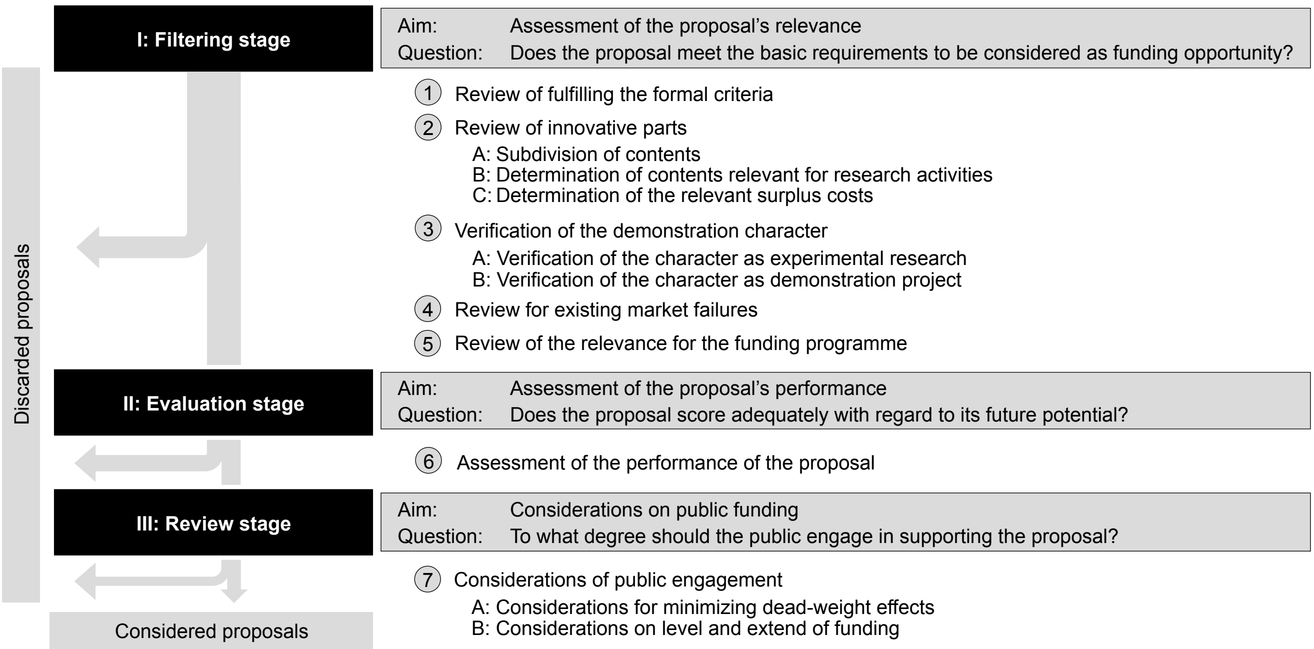

Figure 7. Overview of general setup of the DSS including its stages and sub-items.

Table 1. Excerpt from the guideline for ensuring the proposal's demonstration character.

Aim: To verify whether the proposal meets the main characteristics of a demonstration project
Does the project foresee broad transfer activities regarding its innovative parts? e.g. • Will a transfer concept be developed and implemented? • Is a series of regular events foreseen for accompanying/presenting the project? • Does the proposal contain reporting activities to the public or relevant market participants that considerably exceed the transfer activities of traditional applied research activities (e.g. a structured press campaign, participations in trade fairs, social-media presence, regular report in applied journals, patents, other publications?) • Is it possible to visit the demonstrator? • Does the measure promise to have a broad impact or is its impact limited to the specific case at hand? • Can the relevant information be available at the beginning of a work package based on previous WPs? • Is there a realistic opportunity that the findings can in principle be transferred to other companies or users?
Does the project contribute to enhancing or validating norms, standards and approval procedures? *e.g.* • Will the knowledge and results gained in the project support the creation of norms, standards or does it help to establish approval procedures (e.g. by a participation of the funded organisations in corresponding committees)? • Will concerned bodies, e.g. technical inspection bodies or standardization organisations, be involved to establish or enhance technical preliminaries for realising the project?
Can at least one of the participating organisations show its experiences/competences in knowledge transfer and is it involved in this task during the project? *e.g. …*

Figure 8. Overview of the six main and nineteen sub-criteria of the evaluation stage.

Table 2. Sample excerpt from the guideline for the criterion 'quality and efficiency of the work plan'.

Criterion 15: Quality and efficiency of the work plan	
Definition	Traceability and quality of the procedure for achieving the project's objectives at the overall project and sub-project level
Premises	The higher the quality and efficiency of the working plan, the more attractive the project is
Main area	Quality of the project
Perspective	View of the subsidy provider
Does the working plan follow a logical and purposeful structure that seems to make the project feasible? *e.g.* • Are the sub-steps presented in the working plan built on another logically? • Can the relevant information be available at the beginning of a work package based on previous WPs?	
Does the work plan follow a plausible temporal structure? *e.g.* • Is the duration of the individual work phases adequately defined according to the content? • Were buffers also included to allow unforeseen delays?	
Are all phases of the working plan really relevant to the project? *e.g.* • Are there any doubled topics or duplicates that can be avoided? • Are there any synergy effects that were not taken into consideration? …	
Is the methodology for the different phases of the work plan plausible and does it contribute to achieve the targets? *e.g.*	

ity of the project', 'Risk of the project'). Each main area consists of further sub-criteria that can be evaluated individually, leading to a total of 19 sub-criteria (Figure 8).

Each sub-criterion deals with specific aspects of the proposal. The sub-criterion 'Quality and effectiveness of the work plan', for example, falls under the main area 'Quality of the project'. For this criterion as well as for any other, a list of supporting questions is provided to facilitate the evaluation. With regard to the 'Quality and efficiency of the working plan', for example, it is discussed whether the plan follows a logical and goal-oriented structure and whether its timing is plausible. An excerpt from the guideline for this criterion is given in Table 2.

Based on the answers to such individual questions, an aggregated score is awarded to each criterion on a scale from 0 (criterion not fulfilled at all) to 5 (criterion fulfilled to a very high extent). Each main area and each sub-criterion can be attributed a weight to change their relevance. The evaluation of the weighted criteria is then aggregated into an overall score. Threshold values can also be selected both on the level of individual sub-criteria as well as for the main areas. If these thresholds are not met, the proposal will not be considered further.

Figure 9 shows an excerpt from a simple Excel tool used to illustrate the scoring model in the evaluation stage. Its upper part shows the set of criteria, their weights and minimum thresholds. In the lower part, a list of projects with sample scores is given. To facilitate understanding, the tool offers different options. For example, a set of draft weights has been determined during the workshops using a simple criteria ranking approach. The tool allows to flexibly select different sets of weights and it also allows selecting default threshold values on the level of the main areas or the sub-criteria for testing purposes.

REVIEW STAGE

If a proposal has successfully passed the previous stages, it is subject to the review stage with a final assessment of the need for public engagement. Here potential deadweight effects (i.e. beneficiaries who would also implement the project without funding) as well as the level and extent of funding are considered. While complying with the general rule of equal treatment, it is necessary to think about minimum funding on the one hand. On the other hand, the maximum admissible aid intensity has to be determined. Compared to the previous stages, this stage is less formalised as a multitude of aspects and individual regulations apply.

Considerations for minimising deadweight effects

With regard to deadweight effects, it is necessary to check whether public engagement is really required or whether potential beneficiaries are willing to also carry out the implementation on their own. Current market trends can be an indication here, but other (forthcoming) national or international policies providing subsidies or regulation should also be considered.

Considerations on level and extent of funding

With regard to the level and extend of funding, national legislation requires the effective use of public funds. As a basic rule for research projects, the aid intensity for a beneficiary according to EU regulations has a ceiling of 100 % of the eligible costs for fundamental research, of 50 % for industrial research and of 25 % for experimental research. Depending on the specific situation, other ceilings and additional absolute thresholds apply. Additional national provisions for public funding may apply as well as and specific regulations for individual funding schemes. Thus, it is difficult to make generic provisions for the amount of funding. Accordingly, the appropriate funding finally has to be determined on a proposal-specific basis, taking into account the respective context.

Discussion

DISCUSSION OF THE APPROACH

If large-scale energy demonstration projects gain in importance, there is an increasing need to focus limited public budgets on the most promising funding opportunities and to respond to stricter requirements for transparency and documentation for public funding decisions. The DDS is a mean to help facilitate the evaluation process a) by providing a structured approach which bundles important evaluation aspects for demonstration proposal in one process, b) by helping to conduct a uniform evaluation of proposals largely independent of the individual evaluator, c) by enabling also less experienced evaluators to assist and become familiar with the process and d) by allowing a documented and transparent process.

Though parts are adapted to the German situation, the general approach could be also relevant for similar evaluation procedures in other countries. For this purpose, especially the first three main areas covering the specific situation in Germany might be modified. At the time of writing this paper, there is no funding programme yet that allows to thoroughly put the process into practice. However, the results from the workshops with representatives from German funding bodies as well as the system review with sample applications using two modified real-world projects seem promising. Yet, it is likely that adaptations will be required to meet the needs of specific funding programmes in the future. This is also linked to the question to what extent evaluation schemes should be communicated to applicants. On the one hand, providing this type of information will enable those submitting proposals to better understand what is expected from a successful proposal. This will also make it easier for evaluators to obtain the information they require. On the other hand, it might lead to an apparent need to excel in all aspects while an insufficient focus might be given to the core idea of a proposal.

In terms of lessons learned on the implementation process, we are grateful that the Ministry actively supported the project and that members from different areas of the funding bodies were engaged in the process. This considerably facilitated the development process and allowed to discuss the DSS from different perspectives. Furthermore, the additional system review (last phase as shown in Figure 2) starting after the first two workshops was quite helpful. It challenged draft assumptions, pinpointed potential challenges, but also allowed to review them during the third workshop. For instance, breaking down the general evaluation items also with sub-questions was considered as very helpful. Yet it was pointed out that some questions still leave room for interpretation. The discussion in the third workshop underlined that the evaluation practitioners appreciate some liberty of interpretation. This liberty is needed to avoid running the risk of having a DSS that is too rigid to adequately consider context-specific information. In addition, having some liberty in the scheme also allows adapting the depth of analysis, e.g. whether the scheme is applied to shorter project outlines or longer full-scale proposals.

From a methodological perspective, many different multi-criteria methods have been suggested. Using the relatively simple additive weighting method in combination with minimum thresholds can also be found in various other approaches for proposal evaluation in energy research. The simplicity of the method seems to make it very well suited to this type of problem, though there are more sophisticated MCDA methods.

IMPLICATIONS FOR FUNDING WHEN REVIEWING DEMONSTRATION PROPOSAL USING THE DSS

Using the DSS for proposal evaluation will have several implications for funding large-scale energy demonstration projects. First, focusing on a few large demonstration projects with a relatively high volume will lead to a more rigorous selection process than in traditional research funding. Thus, the value addition of the projects will have to be made very clear. Sec-

Settings

Selection of weights and thresholds

Weights	Equal weights: Main criteria
Threshold: Main criteria	At least 80% of the maximum scores
Threshold: Sub criteria	Minimum of 3 points

Overall evaluation	Performance																		
Weight	100,0																		
Area	Contribution to energy research program						Characteristics of the proposal implementation												
Weight	50,0						50,0												
Main criteria	Energy and climate policy		Competitivenes s		Technology development		Risk		Quality							Suitability			
Weight	16,7		16,7		16,7		16,7		16,7							16,7			
Threshold	8		8		8		8		28							16			
Sub criteria	Contribution renewables/ energy efficiency	Contribution to related targets	Improvment of domestic value added	Reinforcement of international competitiveness	Contribution to improved flexibility	Contribution to preparing pioneering solutions	Technological risk	Economic risk	Relevance for the funding priority	Quality of the preparatory work	Clarity of aims and targets	Quality of the working plan	Appropriateness of resouce usage	Appropriateness of management structures	Intensity of the demonstration/model character	Competences	Complementarity	Carrying capacity	Transfer experience
Weight	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	2,4	2,4	2,4	2,4	2,4	2,4	2,4	4,2	4,2	4,2	4,2
Threshold	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0

Project scoring	E1	E2	W1	W2	T1	T2	R1	R2	Q1	Q2	Q3	Q4	Q5	Q6	Q7	A1	A2	A3	A4	Score	Status
Dummy proposal 22	4	4	5	5	5	4	5	5	5	5	3	5	4	3	3	4	5	5	5	88%	Adequate performance
Dummy proposal 27	4	5	5	5	5	4	4	4	5	4	3	5	4	3	4	5	5	5	4	87%	Adequate performance
Dummy proposal 6	5	5	5	4	5	5	5	5	5	5	4	4	**2**	**1**	5	5	5	5	**1**	85%	Insufficient performance
Dummy proposal 15	3	5	5	4	4	5	3	5	3	5	5	5	5	3	3	5	5	4	4	85%	Adequate performance
Dummy proposal 17	4	**2**	5	5	5	5	5	4	4	4	3	5	5	4	3	3	5	5	4	84%	Insufficient performance
Dummy proposal 27	4	3	3	5	4	5	4	5	5	4	5	4	5	3	4	4	5	5	3	84%	Insufficient performance
Dummy proposal 4	5	3	**2**	3	5	3	5	4	4	5	4	4	3	4	5	5	5	3	5	81%	Insufficient performance
Dummy proposal 15	5	4	5	4	5	3	3	5	5	5	**0**	5	5	5	3	5	**2**	5	3	81%	Insufficient performance
Dummy proposal 25	5	4	3	3	5	3	5	4	**2**	5	4	4	3	4	5	5	5	3	5	81%	Insufficient performance
Dummy proposal 8	4	5	3	4	4	4	5	4	3	5	5	3	4	5	3	5	4	3	4	81%	Insufficient performance
Dummy proposal 7	4	5	5	3	4	4	5	4	3	5	5	3	4	5	3	3	4	3	4	80%	Insufficient performance
Dummy proposal 6	4	5	**2**	**2**	4	4	5	4	3	5	5	3	4	5	3	5	4	3	4	78%	Insufficient performance
Dummy proposal 5	3	5	**2**	3	5	5	5	3	5	4	3	**2**	5	**1**	5	3	3	5	5	76%	Insufficient performance
Dummy proposal 27	**0**	5	5	4	5	5	**1**	**1**	5	5	5	5	5	5	5	4	**1**	**2**	4	76%	Insufficient performance
Dummy proposal 4	**2**	3	**2**	**2**	**0**	3	5	5	3	4	5	5	4	3	4	5	**1**	5	5	69%	Insufficient performance

Figure 9. Tool for illustrating the scoring stage including (sample) weights for the main and sub-criteria as well as (sample) threshold values with dummy proposals for illustration of knock-outs due to insufficient performances (bold red numbers: sub criterion below threshold; colored backfill: sum of sub-criteria in main criterion below threshold).

ond, there must be very high chances that the results of the project will later be successful on the market. Third, there must be a clear need for funding. That means that there has to be a technical and economic risk that prevents investors from setting up a demonstrator on their own. Yet there must also be a realistic chance that these risks are manageable. Fourth, a central purpose of demonstration projects is to show the practical applicability of a new technology. The project should therefore be broadly visible and the project consortium should have the ability to ensure this visibility. Fifth, the proposal should clearly describe its substantial contribution to the main targets of the energy research programme.

Conclusions and outlook

If energy policy is to increasingly support large-scale energy demonstration projects, DSS could be helpful to support funding bodies in selecting promising proposals. The aim of this contribution was to develop a prototype DSS for evaluating proposals for large-scale energy demonstration projects as public funding opportunities. The DSS presented in this paper is a multi-staged system spanning the entire evaluation process. It allows to concurrently consider various evaluation criteria using a multi-criteria approach.

The DSS suggested here can be characterised as a validated prototype system in the sense that it has been discussed during the workshops with practitioners and that it has been subject to a prototype application in the system review. The discussions during the workshops and the findings from the system review suggest that it is helpful to deal with the complexity of the evaluation process. However, the DSS remains yet to be reviewed in daily operation when a corresponding funding programme is established. There is also a need to analyse where adaptations to a specific programme are required and to what extent it can help those submitting proposals to facilitate the processes.

Further research activities could address other types of projects. While demonstration proposals can be considered as experimental research, 'model projects' might require specific adaptations and 'living labs' as a forthcoming project type in Germany's energy research activities might need adaptations, as well. Moreover, future research could focus on weights and knock-out criteria for which various default sets were defined during the workshop. But these were not investigated in further detail. And finally, when it comes to choosing large energy projects for funding, it might be worth to consider also involving new groups of stakeholders in funding decisions. Their active inclusion might require the consideration of new requirements for future DSS.

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Acknowledgements

The authors gratefully acknowledge the support of the German Federal Ministry for Economic Affairs and Energy BMWi, grant agreement numbers 03ET4036A-C (August 2016 to April 2018). The responsibility of this publication lies with the authors. They would like to express their gratitude to all participants involved in the workshops.