

A retrospective on the first Real-world Lab for the energy transition.

Lessons learned on the transdisciplinary approach from *SmartQuart*

How can research on the energy transition be successfully organized in a transdisciplinary way? This design report analyzes the research and communication strategies of the first Real-world Lab for the energy transition, SmartQuart, and derives lessons learned based on the experience gained.

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Abstract

Societal transformation processes, such as the energy transition, accompanied by fundamental social, economic, and political changes require research approaches capable of capturing complex socio-technical interactions. Integrating regulatory sandboxes and Real-world Laboratories provides a methodological foundation for such interactions by incorporating scientific and nonscientific perspectives through transdisciplinary cooperation. This design report reflects the first Real-world Lab for the energy transition, *SmartQuart*, which was funded by the Bundesministerium für Wirtschaft und Energie. It focuses on evaluating research and communication strategies in a consortium of science, industry, and municipalities, with a qualitative online survey of the project participants forming the empirical basis. The results show that an open communication culture, personal encounters, and flexible exchange formats contributed to successful cooperation. However, staff turnover, unclear definitions of objectives, and the lack of independent project management posed challenges. Based on the analyzed experiences, the report derives design-relevant lessons for future real-world labs for the energy transition.

Keywords

energy transition, lessons learned, qualitative evaluation, Real-world Laboratories, regulatory sandboxes, transdisciplinary research

Design Reports are a GAIA-specific format analyzing research and communication design in inter- and transdisciplinary research. They examine design choices and offer insights into project configuration.

The energy transition represents not only a technological shift but—above all—a societal transformation (BMUB 2016). Innovative research approaches that integrate technological, social, economic, and regulatory dimensions are necessary to capture the complex, interactive, and social characteristics of the transformation. Real-world Labs (RwLs) offer a suitable framework for this purpose, as they transfer the principle of the laboratory to real contexts to develop, test, and analyze social innovations under real conditions (Schneidewind 2014).

Although the term “real-world lab” varies in definition across research-specific contexts, its transdisciplinary orientation is a widely recognized characteristic (e.g., Rose et al. 2019, Wanner and Stelzer 2019). The integration of disciplinary knowledge with scientific and practical insights within RwLs makes them not only analytical instruments, but also transformative design spaces (Wagner and Grunwald 2015, Wanner et al. 2018). The potential of RwLs has also been recognized and adapted in funding policy. As part of the 7th *Energy Research Programme*, the Bundesministerium für Wirtschaft und Energie (BMWE) initiated the *Regulatory Sandboxes for the Energy Transition* (box 1) funding line, which supports transdisciplinary research under real conditions with the participation of municipalities, businesses, and society. This format will continue in the 8th *Energy Research Programme* (BMWE 2023 b, n. d.).

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However, the simultaneous orientation toward practical relevance and scientific quality places high demands on processes and actors of these real-world research projects, especially for knowledge integration and collaborative design (Defila and Di Giulio 2018, Seebacher et al. 2018, Defila and Di Giulio 2019). This report therefore focuses on the design of transdisciplinary research in a real-world context, as well as the associated challenges. It is based on a systematic analysis and evaluation as part of the scientific work carried out within the *SmartQuart* project. The theoretical framework used to classify the results is described below.

Dimensions of transdisciplinary research: Theory and conceptual framework

Transdisciplinary research is distinguished by the integration of various knowledge domains, transcending the conventional additive understanding of multidisciplinary research. At the core of this approach lies the collaborative production of knowledge, objectives, and practical strategies (Thompson Klein 2008, Beecroft et al. 2018). Bergmann et al. (2010) proposed identifying three central dimensions for systematizing transdisciplinary processes.

1. **Cognitive-epistemic dimension:** This pertains to the effective integration of disciplinary, institutional, and experiential knowledge. The objective is to formulate context-related problem resolutions, that align with scientific and practice-oriented criteria.
2. **Communicative dimension:** This deals with understanding, trust, and social dynamics among the participants and forms the basis for mutual understanding and integrating different perspectives.
3. **Social-organizational dimension:** This refers to the structuring, coordination, and management of the research process. It encompasses the design of interfaces and the moderation of divergent interests.

These dimensions are closely interwoven and markedly influence the quality and effectiveness of transdisciplinary research. Furthermore, their integration is invariably context-bound and profoundly contingent on the respective actors, issues, and institutional framework conditions (Thompson Klein 2008).

The *SmartQuart* project: Context and evaluation method

Utilizing the theoretical framework of the transdisciplinary research dimensions by Bergmann et al. (2010) as a foundation, this design report examines the research and communication design of the *SmartQuart* project (box 2, p. 48). The project aimed to gain practical insights into existing regulatory constraints (i. e., regulatory learning) through implementing innovative energy

BOX 1: Real-world Labs and regulatory sandboxes in energy transition research

RwLs for the energy transition provide an opportunity to test innovative technologies on a large, real-world scale, under authentic conditions, in compliance with current legislation, with scientific support. They aim to promote learnings on existing regulatory frameworks (regulatory learning) and accelerate the transfer of knowledge, but they do not require regulatory exemptions (BMW 2023 a).

In contrast, regulatory sandboxes are regulatory experiments where existing regulatory requirements are temporarily relaxed or suspended to allow testing of innovative solutions under real-world conditions. The focus is less on systematic regulatory learning and more on enabling and promoting new products, services, or business models that would not (yet) be allowed under the regular regulatory framework. RwLs can be embedded in regulatory sandboxes as real-world testing grounds for implementation and experimentation, thus combining both formats (Bauknecht and Kubezko 2024).

The *Real-world Labs for the Energy Transition* (in German: *Reallabore der Energiewende*) funding initiative is officially translated as *Regulatory Sandboxes for the Energy Transition*. Although this program does not aim for legal exemptions, but rather to create large-scale innovation spaces in real operation. Therefore, the term RwL is used for the *SmartQuart* project, which does not require regulatory exemptions.

concepts in three German districts, which formed the RwL. The implementation concepts were developed jointly with scientists, practitioners, and municipalities (co-design). Industry and practice partners carried out the technical implementation, and scientists continuously monitored the process, to integrate existing knowledge and utilize empirical insight from the application into the project's research. This iterative exchange exemplifies the principle of co-production. The outcomes were evaluated and further developed from the perspectives of the various partners involved in the project (co-evaluation). This evaluation considered technical, economic, and social dimensions, as well as the acceptance among local citizens. Regular exchange formats, structured workshops, and participatory formats in the districts facilitated the integration of different forms of knowledge. The purpose was to combine insights from practical implementation and scientific analysis to generate practical and scientific knowledge.

The consortium implementing this transdisciplinary approach comprised eleven partner institutions, with around 60 participants from industry, municipalities, and academia. Industry partners ranged from established energy companies to innovative start-ups, providing technical expertise, business models, and implementation experience. Municipal representatives contributed local connectivity, access to the districts, and social perspective inclusion, while scientific partners from academia ensured methodological support and systematic evaluation.

A central component of the scientific work was the structured preparation of best practices and reflection on lessons learned. A particular thematic focus of this work was placed on transdisciplinary research designs as a key characteristic of the RwL. Evaluating strategies for integrating this research approach

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BOX 2: SmartQuart – smart energy districts

The *SmartQuart* project was funded by the BMW (from 2020 to 2025) as part of the *Regulatory Sandboxes for the Energy Transition* funding initiative. The project aimed to demonstrate that a climate-neutral energy supply at the district level is already technically feasible and economically viable.

For this purpose, so-called “smart districts” were planned, implemented, and tested at three locations in Germany: a new residential area in the municipality of Bedburg (North Rhine-Westphalia), an urban digital quarter with residential and commercial use in Essen (North Rhine-Westphalia), and an industrial area with hydrogen infrastructure in Kaisersesch (Rhineland-Palatinate). The variety of the chosen locations represented typical settlement structures, thus ensuring the transferability of the results to other regions.

The intelligent networking of energy generation and consumption within and between districts was at the center of the technological approach. For this purpose, the so-called *SmartQuart Hub* was developed, as an overarching energy management system that links all producers and consumers and optimizes energy flow. This enabled efficient use, storage, and exchange of energy between districts.

The project aimed to combine the practical implementation with the systematic investigation of encountered obstacles, and at deriving technical, economic, and regulatory recommendations for implementing energy-efficient district concepts. The project results are crucial for scaling up cross-sector energy solutions and indicate important governance and transformation requirements for the energy transition in Germany. A schematic overview of the project’s scope is depicted in figure 2 (p. 53) (BMW 2025).

forms the empirical and conceptual basis of this design report, enabling *SmartQuart* to contribute not only to the technical and social testing of innovative energy concepts, but also to the development of the *Real-world Laboratory for the energy transition* research format.

An internal qualitative survey was conducted midway through the project to facilitate a systematic analysis and evaluation of the transdisciplinary research design. The survey comprised an online questionnaire sent via email to around 70 current and former members of the project team. The survey was open for three weeks, and participation was anonymous and voluntary. Potential participants were informed in advance about the survey’s objectives and scope. The survey aimed to ascertain measures, based on the project participants’ experiences, that have proven beneficial for collaboration and to highlight challenges to identify the potential for optimizing the research and communication design. The survey incorporated open-ended inquiries, allowing respondents the option to provide multiple responses, intending to encompass both positive and challenging experiences. Data was collected from a total of 27 people. Since no sensitive data was collected and the survey was complied with institutional guidelines, formal ethical approval was not required. The survey was originally conducted in German. For transparency, box 3 contains an English translation of the complete survey structure.

The methodological approach of qualitative content analysis—as developed by Mayring (2015)—was selected for the systematic evaluation of the open answers. The categories were derived inductively from the text passages of the experiences, whereby the answers were assigned to the respective categories through paraphrasing and generalization. A detailed description of the categories analyzed and their classification according to the dimensions of transdisciplinary research as outlined by Bergmann et al. (2010) can be found in table 1 (pp. 50 ff.).

Experiences with the research design and communication strategies

This section discusses the key research and communication design strategies that contributed to positive and challenging experiences throughout the project, influencing its progress. After accompanying the transdisciplinary collaboration and conducting the survey, the scientific partners from academia critically reflected on these strategies. From a scientific perspective, the identified challenges hold particular interest because they reveal considerable optimization potential. Accordingly, this report places a strong emphasis on analyzing these challenges. However, it is important to note that the transdisciplinary collaboration should not be viewed as problematic overall. The project also generated many positive experiences, especially regarding cognitive-epistemic dimensions (figure 1, p. 52).

Formal and informal exchange formats

The project strengthened the cognitive-epistemic and communicative dimensions through a variety of formal and informal exchange formats.

Formal exchange formats were primarily used for regular coordination and consultation within the project team. However, when the project started in spring 2020, the consortium was immediately confronted with restrictions imposed by the COVID-19 pandemic. As a result, the exchanges took place almost entirely digitally for the first year and a half. Although these digital structures were functional, efficient, and remained in place for regular communication as the project progressed, a noticeable qualitative change in communication was observed upon returning to face-to-face meetings. The biannual consortium meetings were a particularly impactful format, in which all project partners came together in person. These meetings not only facilitated structured exchanges and discussions on content, but also enabled informal knowledge sharing in between the formal program, particularly during coffee breaks, joint lunches, and dinners. Direct face-to-face contact—beyond digital routines—proved central to building mutual trust, consolidating an open communication culture, and establishing an appreciative feedback practice. This concerned internal collaboration within the consortium and communication with the funding body. In addition, holding these meetings at different locations provided insights into the working contexts of the partners, which included companies,

scientific institutions, or municipal administrations. These experiential spaces enabled a deeper understanding of different working realities, process challenges, mindsets, and transdisciplinary knowledge.

Additional participatory formats took place in informal settings, such as street festivals, information evenings, and trade fair attendances in the project districts. These formats provided an opportunity for casual exchanges with local citizens and project members. These events were used to gather the local population's experiences of implementing the developed approaches, and to include them in data collection through surveys and interviews. This approach enabled the integration of local and social perspectives into the results, broadening the scope of transdisciplinary knowledge.

Transparent communication of work steps and sub-project objectives

A central challenge of the project was to coordinate the diverging sub-project objectives, which affected the social-organizational and communicative dimensions. In transdisciplinary research contexts, groups of actors—despite sharing an overarching project goal—pursue distinct sub-goals due to differing institutional logics, action rationalities, and disciplinary perspectives. For example, commercial enterprises generally prioritize the economic feasibility and marketability of the solutions developed, while scientific institutions focus on research criteria, such as knowledge generation, methodology, and publishability. Municipal partners focus on the long-term feasibility and institutional practicability of the measures developed (Scholz and Steiner 2015). These differences are not only unavoidable but can also be complementary. Addressing them early and ensuring ongoing communication and reflection throughout the project are crucial. However, this was implemented with varying degrees of consistency across the project's work packages. Where regular coordination took place, sub-project objectives were discussed jointly in workshops—for example—and related to the overall project, which led to a mutual understanding and greater acceptance of the ongoing work. This continuous reflection ensured that tasks were developed in line with the overarching project objective and that individual interests were identified and balanced early on. The ongoing exchange also promoted the integration of different perspectives, thus strengthening the transdisciplinary approach of the collaboration.

However, other work packages featured inconsistent communication of work steps and sub-objectives. Tasks were carried out independently and without coordination with project partners, leading to content-related misunderstandings due to, for example, a lack of shared knowledge or different technical terminologies. Similarly, the connection between individual work and the overall project became unclear in some cases, contradicting the transdisciplinary approach. This created tension and discontent within the consortium, giving the impression that partners were primarily pursuing their own interests and leading to critical assessment of other project partners' objectives, as the evaluation

BOX 3: *SmartQuart* questionnaire

English translation of the internal, qualitative survey sent to active and past partners in the *SmartQuart* Real-world Lab project, aiming to capture insights regarding their positive and challenging experiences within the project.

Questionnaire:

1. Which area of the *SmartQuart* project team do you belong to? (single choice)
 - ☐ industry
 - ☐ municipality
 - ☐ science
2. How long have you been part of the *SmartQuart* project team? (single choice)
 - ☐ < 1 year
 - ☐ 1–2 years
 - ☐ 2–3 years
 - ☐ 3–4 years
 - ☐ 4 years
3. What advantages have interdisciplinary and transdisciplinary collaboration brought to *SmartQuart*?
 - Planning phase: (text box)
 - Realization phase: (text box)
 - Operational phase: (text box)
4. What challenges have arisen in interdisciplinary and transdisciplinary collaboration at *SmartQuart*?
 - Planning phase: (text box)
 - Realization phase: (text box)
 - Operational phase: (text box)
5. What recommendations would you give to other Real-world Laboratories? (text box)
6. Do you have any further comments? (text box)

showed. In retrospect, the project lacked an overarching, independent authority to intervene as a moderator in such situations, to work toward coherence of the project objectives, and to actively demand transdisciplinary cooperation.

Staff turnover

A key challenge that affected the social-organizational and cognitive-epistemic dimensions of the project was the high level of staff turnover within the consortium. The long project duration (more than five years) and the structural differences in partner organizations' internal setups directly affected staff continuity.

For the partners from commercial enterprises, project-related activities were designed as temporary from the outset. In some companies, staff planning follows a phase-specific model or relies on rotational staffing for defined periods. In addition, project-related staff members were brought in for specific tasks for a limited period, which prevented long-term continuity. Staffing continuity was not always guaranteed in scientific institutions either, due to temporary employment in the university and research sector regulated by the German *Law on Fixed-Term Contracts for Academic Staff* (in German: *Wissenschaftszeitvertrags-gesetz*).



TABLE 1: The results of the qualitative content analysis, according to Mayring (2015), performed on the qualitative survey responses from participants of the *SmartQuart* project (N=27). It contains the identified categories, together with a description of the content-related aspects that contributed to the formation of these categories based on the respondents' statements. The categories are listed separately according to positive and challenging experiences, and sorted within these groups in descending order according to the frequency with which they were mentioned (for a visual representation of the frequency of mentions, see figure 1, p. 52). Each category is also assigned the corresponding dimension of transdisciplinary research according to Bergmann et al. (2010) to classify the thematic relevance of the experiences. RwL = Real-world lab.

CATEGORY	DESCRIPTION	FREQUENCY OF MENTION	DIMENSION OF TRANSDISCIPLINARY RESEARCH			
			COGNITIVE-EPISTEMIC	COMMUNICATIVE	SOCIAL-ORGANIZATIONAL	
exchange of knowledge and experience	Respondents emphasized the intensive exchange of knowledge and practical experience as a central positive experience of inter- and transdisciplinary cooperation. The transfer of knowledge across institutional and professional boundaries was perceived as enriching through the opportunity to gain insights into the working methods and expertise of other disciplines.	12	x			
open culture of feedback and communication	The establishment of an open communication structure was positively highlighted by the respondents. Regular exchange and a strong feedback culture fostered trusting cooperation and facilitated collaboration in a complex project context.	11	x	x		
diverse perspectives	Respondents highlighted the diversity of perspectives and professional backgrounds in the consortium as a particularly valuable and positive experience. This diversity contributed to more comprehensive problem analyses and differentiated approaches to solutions, which was perceived as a strength of the inter- and transdisciplinary setting.	6	x			
shared motivation and cohesion	Respondents described a strong common motivation and a noticeable cohesion within the project team. The common goal and the actual implementation of the RwL led to a high level of commitment and mutual support.	6			x	
shared anticipation	Especially in the application and early project phase, the shared anticipation of the project was experienced as positive. This emotional atmosphere strengthened the willingness to cooperate and the trust between the partners from the very beginning.	5		x		
practical implementation of concepts and tools	Interviewees appreciated the opportunity to apply the developed concepts and digital tools in a real district context. Practical testing was described as motivating and as an opportunity for direct feedback on development.	3	x	x		
data sharing and provision	It was occasionally emphasized that the sharing and provision of data was enriched by the diverse composition of the consortium. Access to different data sources was seen as supporting the project work.	2	x			x

POSITIVE EXPERIENCES

TABLE 1 (CONTINUED)

CATEGORY	DESCRIPTION	FREQUENCY OF MENTION	DIMENSION OF TRANSDISCIPLINARY RESEARCH			
			COGNITIVE-EPISTEMIC	COMMUNICATIVE	SOCIAL-ORGANIZATIONAL	
CHALLENGING EXPERIENCES	different sub-objectives and interests	Respondents mentioned the diverging objectives and interests of the project partners as a key challenge. The inter- and transdisciplinary orientation led to different interpretations of tasks and objectives, which often resulted in a high need for coordination and delays in decision-making processes. This was particularly the case when the work steps and procedures were insufficiently communicated from the outset.	11		x	x
	high staff turnover	The repeated changes of staff during the project were perceived as stressful by many participants. In particular, the loss of knowledge, the need to train new staff, and repeated coordination processes were described as time-consuming and resource-intensive.	9	x		x
	unclear competencies, responsibilities, and interfaces	Respondents reported difficulties in defining clear responsibilities and task-related interfaces between stakeholders, meaning that cooperations and dependencies between work packages were insufficiently defined. These uncertainties were partly attributed to a lack of communication by the project management team and high staff turnover, which made it difficult to run the project efficiently.	6	x		x
	problems with data transfer	The exchange and sharing of data was a recurring challenge for participants. In particular, problems arose due to a lack of data sharing, inadequate technical infrastructure, and additional work resulting from repeated requests. This was seen as a barrier to project progress, particularly from a scientific perspective.	5	x		x
	misunderstandings with the terminology	According to respondents, different discipline-specific terms and jargon led to misunderstandings in communication. This affected both the exchange of content and coordination at the conceptual level, and was perceived as an obstacle to smooth cooperation if the technical vocabulary was not sufficiently defined and task-specific.	4		x	
	time delays in the project process	Participants referred to delays in the course of the project caused by various factors, including staff changes, coordination problems, and external dependencies (e.g., in the provision of data). These led to an increased need for coordination and made it difficult to implement planned activities on time.	4			x
	lack of participation	Respondents considered the participation and publicity work to be inadequate. In particular, the involvement and information of the local population in the districts was perceived as insufficient, which contradicted the transdisciplinary objective.	3	x		x
	lack of overarching project management	Respondents criticized the lack of an independent, overarching project management as a structural deficit. The close involvement of those responsible for management in the operational tasks and their proximity to individual project partners made it difficult to achieve overarching coordination, clear lines of responsibility, and transparent project management.	3			x

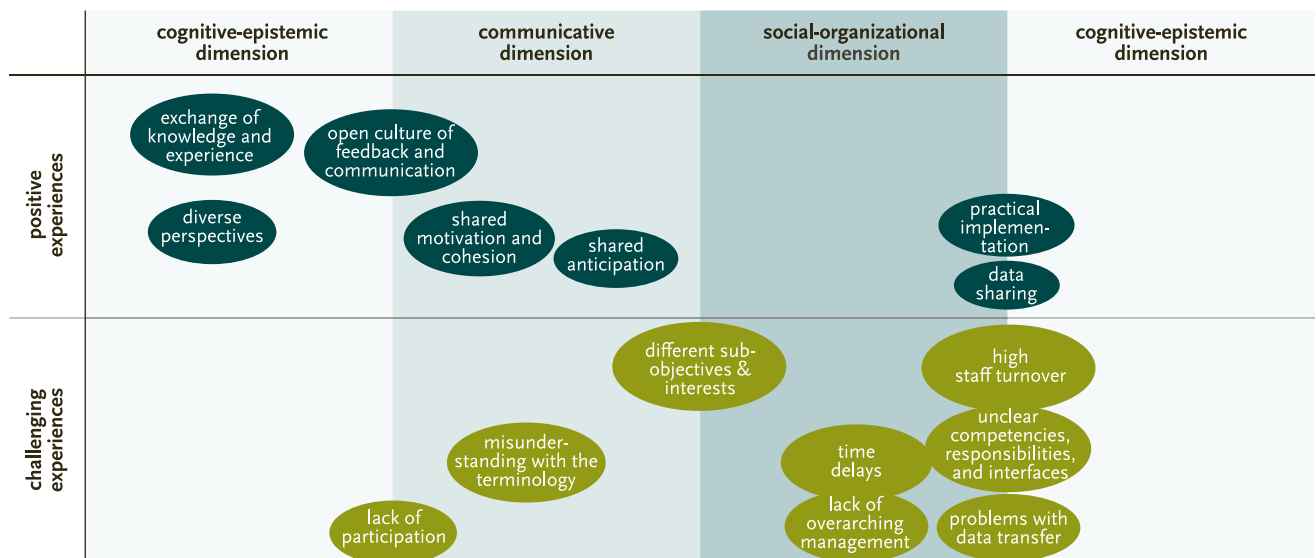


FIGURE 1: An overview of the categories of positive and challenging experiences identified in the qualitative survey responses of participants of the *SmartQuart* project and evaluated using the qualitative content analysis, according to Mayring (2015). The categories are assigned in relation to the dimensions of transdisciplinary research according to Bergmann et al. (2010). The size of the individual display elements reflects the frequency of mentions (table 1) in the surveys, illustrating the relative importance of the respective categories within the data collected.

These personnel dynamics were noticeable at the work package management level, even though most positions were filled twice to prevent loss of time and knowledge. Changes in leadership positions triggered delays in work processes due to the need for onboarding periods and required repeated coordination processes to clarify roles, responsibilities, and objectives. In addition, the lack of continuity in staffing had a negative impact on transdisciplinary collaboration within the project, particularly regarding building personal relationships, trust, and continuous communication.

Organization of the research process and project management tasks

Project management was a key structural issue at the project's social-organizational level. It was handled by one of the consortium partners, as is common in research alliances. The project proposal included a work package for project management, which is useful for the overarching coordination. In practice, this structure proved insufficient to meet the requirements of a transdisciplinary project. Traditional management tasks were effectively carried out, such as organizing project meetings, preparing reports, and communicating with the funding agency. Nevertheless, these activities should only be seen as basic functions of a management system (Bergmann and Schramm 2008). Transdisciplinary projects also require specific management approaches that consider the structural and cultural differences between scientific and nonscientific stakeholders (Lang et al. 2012). For example, this includes establishing shared communication structures, common terminologies, and reflexive coordination formats to facilitate knowledge integration and dialogue across disciplinary boundaries.

This was particularly evident in interface and competence management and the communication of heterogeneous disciplinary knowledge between the partners. These tasks—which are central to the integration of disciplinary and practical perspectives—were given very little attention by project management. A further complicating factor was that project management was not staffed independently but was directly involved in the content of the project work. This compromised the necessary neutrality and moderation skills, as well as led to the evaluation's assessment of the lack of overarching project management. Project management appeared to lack the necessary visibility due to its deep involvement in content-related work and its limited moderation of transdisciplinary tasks.

Lessons learned

Communication as a key resource

The project experience has shown that successful transdisciplinary research is largely based on continuous communication. Beyond formal formats such as meetings and workshops, informal exchanges in a casual setting, particularly in the real-world context played an important role. Personal encounters and insights into the working contexts of the partners fostered mutual trust and productive cooperation. Future projects should establish similar formal and informal communication structures from the outset and implement them consistently, while also providing sufficient space for personal encounters and low-threshold knowledge exchange to support long-term knowledge transfer, mutual understanding, and trust-based collaboration.

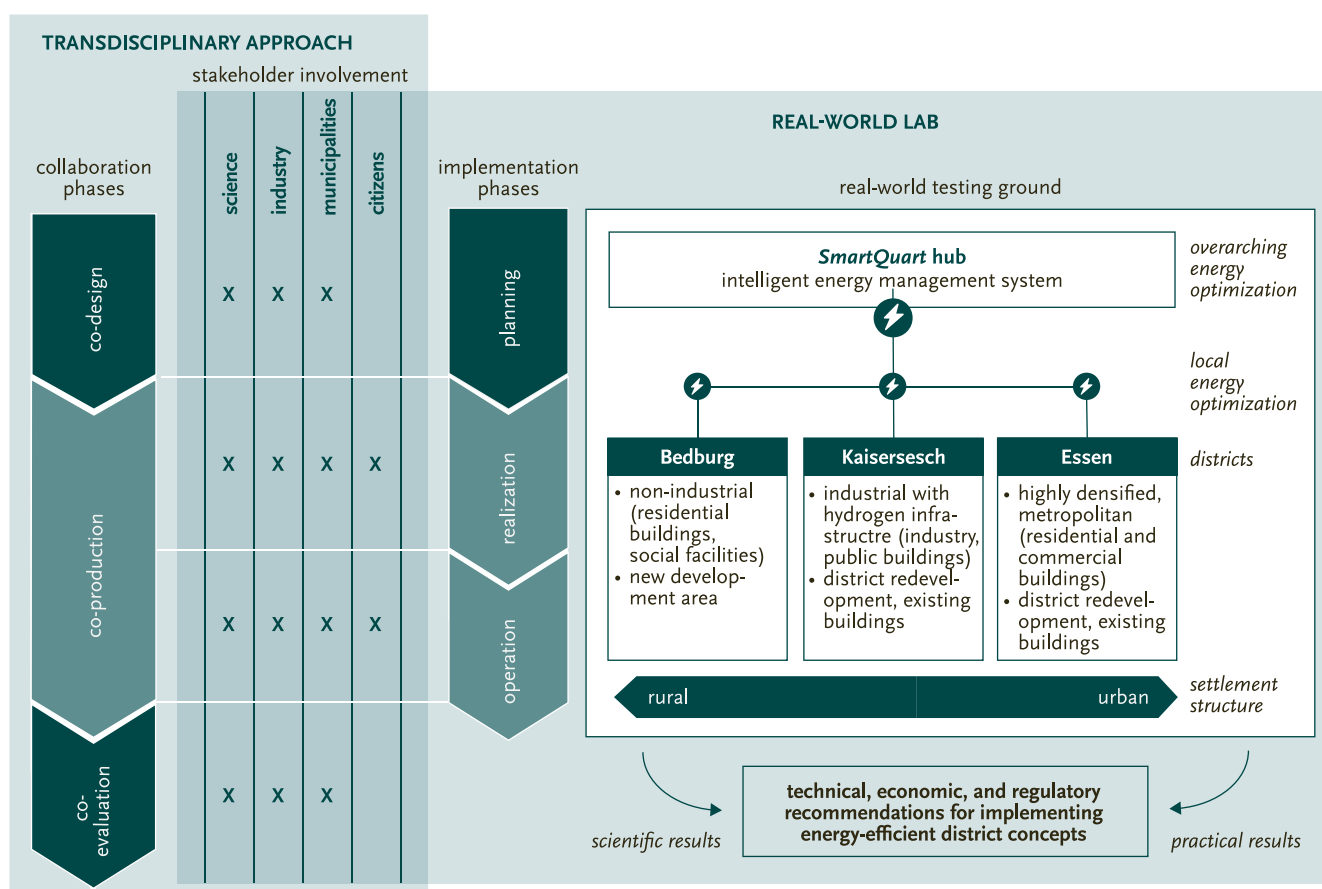


FIGURE 2: A schematic overview of the *SmartQuart* project and the Real-World Lab (RwL) funded by the Bundesministerium für Wirtschaft und Energie, which implemented innovative energy concepts in three German districts to gain insights into the regulatory constraints for the energy transition. The figure displays the three districts (i. e., Bedburg, Kaisersesch, and Essen) and their characteristics, as well as the energy optimization via the intelligent energy management system, called the *SmartQuart* Hub. Additionally, the figure illustrates the stakeholders' involvement in the various implementation phases and the parallel integration of the transdisciplinary approach into the project.

Staffing continuity

Long-term projects benefit from stable personnel structures, especially in management or coordination roles. As personnel changes are unavoidable, strategies for securing knowledge and organizing handovers must be developed at an early stage. Double staffing of key positions, transparent communication about upcoming changes, and structured onboarding processes have proven useful in this project. Personnel stability should be an integral part of the project designs and (as far as possible) should be taken into account in the personnel planning of all project partners from the outset.

Transdisciplinary project management

Traditional project management approaches reach their limits in transdisciplinary research, necessitating a broader understanding of project management. It must have the classic qualities of organization and coordination, but use them specifically for the necessary moderation between different disciplines, interface management, and integrating different knowledge perspectives to actively promote the transdisciplinary process.

This requires substantive and institutional independence to act as a mediator between the logics of science, industry, and society. This independence can be ensured structurally by designing it, for example, as an independent work package.

Reflection and willingness to adapt in research and communication design

Research and communication design in transdisciplinary projects should not be seen as static. Ongoing, structured reflection supports the early identification of dissatisfaction and undesirable developments, enabling timely countermeasures. Not only are its structural integration into the work plan and its regular implementation crucial to this process, but also a consortium-wide openness to modifications in familiar structures that are incompatible with the transdisciplinary context of a RwL—reflecting a lacking element in the project under review. Only through the willingness to reflect, develop, and adapt established project management and communication structures can findings not only be used for future projects, but also be made effective in the ongoing project process.



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