Moving towards sustainability: insights from district heating, water systems and communal housing projects in local communities

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Abstract

Services such as energy supply, water supply and wastewater management or housing are part of daily life and are usually provided at the municipal level. They all play an important role in a transition towards sustainability. In this contribution, we report on findings from a project where sustainability innovations from three different domains were analysed. Cases included (1) innovative low-carbon heat grids using renewable sources or waste heat, (2) sustainable water management, and (3) community housing addressing people of different ages. The case studies are based on a series of semi-structured interviews (n=69 from 16 cases), document analysis and expert workshops. The paper addresses the following topics:

- Q1. What characterizes the innovation under study and how far is it developed?
- Q2. What are the influencing factors that are relevant in supporting the implementation of the innovation or act as a barrier?
- Q3. What are potential synergies between the three fields of action?

Overall the housing niche seems to be the one that is most established while the level of diffusion is lowest for water projects (Q1). Furthermore, we find that all niche projects rely on municipal support, that strong networks are important to accelerate learning curves and windows of opportunities are a precondition for success (Q2). However, while some of the relevant factors are similar across the cases it is very difficult to create synergies in real life and is hardly ever achieved although such opportunities are conceivable (Q3).

Introduction

To achieve climate goals and to foster the energy transition is part of a broader movement that acknowledges that the lifestyle of today's society is beyond the world's capability. Therefore, increasing sustainability is today's most crucial challenge. However, if this process is to be successful, multiple parties and societal actors need to act in concert. This includes moving the focus to the local, the city and municipal level, as well (United Nations 2015; Kemmerzell et al. 2016). In the literature on the transition of the energy system and climate change several societal groups are analysed, and policy makers are among the more frequently mentioned ones (e.g. Special Issue by Farla et al. 2012). Much of the literature refers either to the overarching levels of governance, i.e. the supranational, transnational or national level, or to the levels of individuals, i.e. households and citizens. However, the levels in between have been less regularly analysed. On the one hand, higher level policy makers on national and supranational levels set framework conditions by agreeing on goals and entering into transnational contracts like the Paris agreement and by translating these goals into legislation. On the other hand, a major part of the actual implementation of these decisions as well as managing compliance is realised at lower levels as the municipal level (Kemmerzell et al. 2016): This is where houses are built, companies founded, energy and water are consumed, heat and electricity generated etc. Setting up the relevant infrastructures require communal planning, administrative processes and local action. Thus, municipalities act as hinges between higher level policies and individual actions (Dütschke und Wesche 2018).

Services such as energy supply, water supply and wastewater management or housing are part of daily life. In spite of constituting important sectors in the overall supply system of a society that are therefore subject to national and international regulation, important parts of these services and systems are also governed at the municipal level. This governance level is at the core of this paper, which looks into innovations in three domains, energy, housing and water. The goal is to identify influencing factors across domains that are relevant in the realisation of sustainable developments. The three domains under study were chosen to cover systems that are crucial in the transition towards sustainability. In each domain, sustainability innovations were chosen and analysed based on 16 case studies of successful projects. For the energy domain, we focus on innovative district heat networks as a system that has the potential for low carbon energy provision for local communities and depends on setting up a cooperative system. In the water domain, we look into different approaches for local water and wastewater management including decentralised and self-contained systems. Communal housing projects focus on the analysis of innovation projects where people of different age who are not from the same family live together and share part of the facilities.

Both the domains under study as well as the selection of case studies are based on the assumption that a transition towards sustainability requires changes in institutions and practices at different levels of actors and on all three dimensions of sustainability – economic, social, and environmental. The chosen innovations were selected according to the following to criteria: They were supposed to have a particular impact on the everyday lives of citizens and they have a major impact on the sustainability of society. Conversely, they themselves are closely involved in overarching social and economic developments, with important governance elements of governance and design at the local level. However, analyzing the level of sustainability actually achieved by the innovations and the specific projects is not at the core of this paper. This also implies that it is possible that some of the projects did not use the full sustainability potential. We are, however, more interested in identifying the influencing factors that enable the implementation of such projects.

RESEARCH QUESTIONS

The first step of the analysis is to describe the innovations in each domain separately and to identify the respective stage of development of the innovations (Q1). The findings on this first research question are summarised in the next section of this paper together with some background information on the cases analysed and the empirical data base of this paper. Secondly, in the next section, we will expand on the influencing factors that contributed to the success of projects or constituted challenges (Q2). Finally, we examine potential synergies and discuss in how far these different types of innovations could learn from each other or support each other (Q3). To sum up, we discuss our findings and draw final conclusions.

RESEARCH APPROACH

As an empirical basis, this paper draws on a series of case studies. The kind of innovation under study within each domain (district heat networks, communal housing projects, local sustainable water management) were chosen based on a literature review on the respective domain (heat in the energy sector, water, housing) (Köhler et al. 2017). Part of this analysis was also to identify criteria to select specific initiatives or projects which are then included into the case studies. This will be outlined in more detail below and is more extensively documented in the project reports (Hacke et al. 2018; Wesche et al. 2017; Peters et al. 2017). The empirical data for the case studies was collected in 2016–2017 and the core of this data are an interview series (67 interviews overall) mainly with key actors from the chosen cases and complemented by a smaller number of interviews with experts on a higher, usually national level. Interviews were usually audio-recorded, fully transcribed and coded drawing on coding schemes that were partly informed by earlier literature analyses and then refined according to the actual content of the interviews. The interview material is complemented by document analyses and in the case of housing a survey of occupants. Domain-specific findings were discussed in dedicated workshops with experts from the respective field, a symposium was held to validate overall conclusions.

Domain-specific analysis

DISTRICT HEAT NETWORKS

Space heating is a major part of energy consumption, being 27 % of the total in Germany in 2017. The proportion of heat supplied by renewable energy grew by from 10.3 % in 2009 to 13.2 % in 2016 (2.9 percentage points in 7 years) (BMWi 2018). In contrast, over the same period of time the proportion of electricity supplied by renewable energy grew from 15.1 % to 31.6 % (about five times faster in absolute terms). Thus, the German "Energiewende"[1] can so far be described as mainly an electricity transition. However, to reach climate goals, the heat sector also needs to receive further attention. Within the heat transition district heat networks are considered to be a promising option to achieve sustainability. Currently, in Germany just above 13 % of the heat supply comes from heating grids (AGEB-Stat 2019, p. 1.10). Hence, renewably supplied and well operated heat grids can support to curb CO_2 emissions in the German heating sector. For these reasons, we chose heating grids as the subject for our case studies – with a special focus on newly installed small community operated heat grids. Local heat networks are understood as small grid-connected heat supply systems that use innovative means to provide heat e.g. renewable source or waste heat. They are characterised by lower carbon dioxide emissions than conventional systems that run on natural gas or heating oil and can therefore contribute to a more sustainable heat supply. In our understanding, a heat network comprises heat source(s), transportation tubes and

1. The term 'Energiewende' refers to the political decision in Germany to phase out nuclear energy by 2022 Hermwille 2016 and to aim for ambitious goals regarding renewable energies. A comprehensive policy mix has been implemented to achieve the target of 80 % of electricity generated from renewable energies by 2050 BMWi und BMU. 2010.

Table 1. Overview district heat networks.

Case	Operational	Type of district heating system	Organisation	Type of housing	Support scheme
Case M	2007	Solar thermal, Gas, large heat storage unit	Community energy provider	Urban/New build	Yes
Case S	2011	Biogas	Cooperative	Rural/existing housing stock	Yes
Case B	2014	Industrial waste heat, wood pellets	Run by the manufacturer	Rural/existing housing stock	No
Case D	2014	Solar thermal, Heat pumps, district heating, network with variable temperatures	District council (Kommune)	Rural/existing housing stock	No
Case P	2014	Virtual power station, district heating, heat pump, storage unit	Land BaWü, Generation company	Rural/existing housing stock	No
Case W	2016	Heat collector in agricultural land with heat pump and low temperature network	N/A	Rural/New build	Yes

transfer stations. District energy systems are relevant for the overall energy system and energy transition e.g. by providing thermal storage (Verda & Colella 2011; Nuyetten et al. 2013).

In our selection of cases, we tried to include networks of different age. This allows for a variety of technological approaches selection, different initiators and operators, within new or existing housing stock and with and without support schemes (see Table 1). We explicitly analysed only recently built grids that supply local communities or in the case of case M a single neighbourhood in a larger city. Third party access to these newly built grids was not part of the discourse back then, since the data collection was conducted before the EU directive "on the promotion of the use of energy from renewable sources" was implemented in 2018[2]. Furthermore, we only looked at energy carrier related sustainability gains and did not focus on fuel switch of existing heat grids or optimizing the operation of a heat grid that can also lead to sustainability gains.

Level of Diffusion

The focus on small heat supply systems means that a minimum amount of 15 buildings is connected to the grid. In Germany, heat networks are traditionally restricted to larger systems in cities and have only a minor share in heat production. Naturally, only some of them fall into the category of sustainable district heat networks as understood here. The precise number cannot be retrieved from official statistics, but drawing on figures assembled on community energy project in Germany (Kahla et al. 2017) allow for the preliminary estimation that the number of heat grids might be around 130 plus grids that are operated by the municipalities themselves.

2. The EU directive "on the promotion of the use of energy from renewable sources" obliges the member states to ensure that "operators of district heating or cooling systems are obliged to connect suppliers of energy from renewable sources and from waste heat" and it also provides enhanced transparency rights for consumers as well as the right to terminate the contract with an operator in case of unsustainable energy production in its article nr. 24 (https://eur-lex.europa.eu/legal-content/DE/TXT/HTML/?uri=CELEX:32018L2001&from=EN).

Main factors influencing the development

There are a series of barriers to the wider deployment of district heat systems. These systems often have a low priority in local or district development plans and budgets. The reasons for this are the lack of pressure from national or regional policy, lack of financial resources at the district level, and an inconsistent structure of economic incentives, which partly support fossil fuels. The current (2016–2018) historically low energy prices for heating oil for households also means that there is little financial incentive for households to look for alternatives to their conventional (fossil) energy and heating system. Furthermore, as Wesche et al. (2019) argue, the heat system is systematically different from the electricity by its more configurational innovation system which leads to a higher context dependency and makes a transition more challenging.

Additionally, findings from the cases point out that the development of a district heat network requires an enthusiastic team to start the project that is trusted by the local community and has the support of the district council. It further requires the availability of a heat source and a suitable site for the heat source and other installations. Problems with the local conventional energy system (e.g. a need to replace ageing conventional systems) and a high level of awareness of renewable energy systems and the climate change issue in the community are likely to provide a supportive environment leading to actual successful implementation.

COMMUNAL HOUSING PROJECTS FOR THE ELDERLY

Communal housing projects are organised by alternative forms of community, which include features of communal living that is self-organised and organised for mutual support. They involve participation of the households in decision making and usually set the objective of environmental standards above the market average (Tornow und Dau-Schmidt 2012). They have had to develop new ways of organising, financing, building, and use of the housing. Communal housing projects are a reaction to limitations of local social networks due to long term trends to individualisation, demographic change and difficulties in finding affordable housing.

All of the chosen cases have the following features:

- the households are not related to each other
- households live together in a single location with their own living space and communal facilities
- there is an expectation that all households are active and mutually supporting in everyday living
- communal life and at least a part of the property management is self-organised in a democratic way within the project

The projects were chosen according to the criteria displayed in Table 2 with the aim of heterogeneity.

Level of Diffusion

There are an estimated 2,000–3,000 (in 2016) communal housing projects in Germany (Fedrowitz) and although the number is increasing it remains a very small part of housing projects in Germany. Projects for the elderly have shown a particularly strong growth since the 1990s (Tornow und Dau-Schmidt 2012) and multiple-generation housing is also increasing.

Main factors influencing the development

Market prices in the larger urban regions are increasing (Statistisches Bundesamt 2015) and for lower income groups it is getting more difficult to find affordable residential spaces (BBSR 2015). Therefore, communal housing projects on the one hand meet societal needs, on the other hand often require the support of local government combined with community engagement. They are often initiated by local actors, who then have to develop or find the expertise to carry out a housing project. A further challenge is to develop the necessary legal and project management skills to set up an organisation and collect and manage the capital. The cultural distance between the established housing developers and markets and community housing is large. Few suitable sources of advice or consultants are competent in communal housing projects. So far, due to their low number and only local political support, the projects themselves do not exert pressure on the housing industry or on lobby networks, being self-run and often too busy managing their own project for the community members.

However, there is evidence in the cases studied of some opening up of the system. In some regions, professional advice and consultancy and some organisations specialising in community housing projects have developed. A few organisations specialising in community housing developments have been established. Financial support for the acquisition of land is limited to a few cities. Well-known examples are Hamburg and the city of Munich.

LOCAL SUSTAINABLE WATER MANAGEMENT

The context for water supply and wastewater treatment is changing in various ways. Impacts of climate change like extreme weather events, changes in rainfall quantity and distribution are affecting water systems in Germany. Various regions in Germany are experiencing a decline in population, with a reduction in the number of users of water systems, while the continuing increase in the area of built-up land and transport infrastructure is increasing the area requiring water supply and sanitation (Hiessl et al. 2012; Hillenbrand und Hiessl 2016). There are also new environmental standards, for example concerning energy efficiency of water management systems (biogas, heat recovery) or the control of micro-pollutants. There is a considerable requirement for the adaptation and renewal of water infrastructure, such that district authorities face the challenge of developing a strategy for modernising their water and sewage systems (Hiessl et al. 2012). There are various new system concepts for meeting these challenges. Three of the most important technologies, which form niches in the water and sewage systems are new sanitation systems, integrated rainwater management and centrally managed decentralised wastewater treatment.

New sanitation systems (DWA 2008) increase the separation of wastewater flows (e.g. into grey and black wastewater) to enable the recovery of energy, water and nutrients. These require major changes in the layout of piping and systems inside and outside buildings. The case chosen is one of the first applications of this kind and is the wastewater system in an ecological housing project, established in 2000. This project implemented a system for separation of rainwater, grey (bathroom, washing machine) and black wastewater (toilet, kitchen) and organic waste. This enabled differentiated treatment, recovery and utilisation of the nutrients of value in household wastewater including organic waste. The system included vacuum toilets.

Sustainable or integrated rainwater management has the objective of management systems that are compatible with

Table 2. Summary: Communal housing projects for the elderly.

Project	No. of flats	Structure of inhabitants	Age	Care provision	Project type	Growing/ Declining area	Location
GH	37	Renters	old and young	Yes	New	+	Mid-size city
TA	30	Owners, Renters, Supported Renters	old and young	–	New	-	Small city
HM	24	Owners, Supported Renters	old and young	–	New	+	Major city
WIV	28	Renters, Supported Renters	old and young	–	New	+	Major city
Gä	11	SR	60+	–	Refurbished	-	Mid-size city
G1	26	Owners, Renters,	50+	Yes	New	+	Mid-size city

Table 3. Summary: Innovative water management projects.

	Status	Status of Stakeholders	Main Goals/ Motivation	Comments
New Sanitation Systems	Pilot	new	Energy efficiency, Resource efficiency	Delay due to change of project management
Sustainable Rainwater Management	Pilot/ Market Entry	partly new	Legal requirements, Water management, Climate Adaptation	
Centrally operated decentralised wastewater systems P1	Pilot	association	Legal requirements, Water management, Cost reduction	In 2nd decade of operation
Centrally operated decentralised wastewater systems P2	Pilot/ Market Entry	new	Legal requirements, Water management, Cost reduction	

the local environment and ecosystems in urban settings. Local natural water circulation processes and resources should be retained. Rainwater runoff should be reduced or delayed through storage or sinks, to reduce the flow through drains and hence reduce flooding. Rainwater should also be made available for use in households. While rainwater systems also have impacts on the planning of roads and the built environment. As a case to study this approach a project by a cooperative was chosen.

Centrally managed decentralised waste water treatment systems are intended to counter the criticism that decentralised waste water systems are not operated and maintained to the necessary standards for safe and reliable services. This enables areas with low densities of occupation or decreasing population to develop a sustainable, cost-efficient and flexible wastewater management system. Two projects were studied in this field. Table 3 summarises the case studies in sustainable water management all of which receive additional funds by support schemes to be realised.

Level of Diffusion

In contrast to the other two areas, the water cases cover a range of fields of application. All three types of systems have been successfully demonstrated, but the further application of these concepts is still limited.

The new sanitation system project was a successful demonstration that has led to a few further projects and also the development of new regulatory standards, e.g. DWA A 272 (DWA 2014). With many contacts to other regions in Germany, the rainwater management project has received attention that is more widespread. The concept of reducing sealed urban areas that generate rainwater runoff has been taken up in other municipalities. The centralised management of decentralised water treatment systems has not been widely adopted so far. The interviews indicated that users who are prepared to adopt such a system also prefer to manage it themselves, while there is little political will at the district council level to encourage this type of solution.

Main factors influencing the development

The new water treatment systems described above face considerable barriers to their diffusion. For instance, they require support at the district governance level, but these ideas are not yet widely accepted as suitable solutions for upcoming challenges (demographic change, climate change etc.). The legal structure of water treatment requires modification to support these alternatives. Because water treatment is a basic service (like energy provision) which must be provided with very high reliability, it is highly regulated which reduces room for the implementation of innovative approaches. There is also a lack of coordination at the district level between the complex array of stakeholders: town planning, local agriculture, housing, households, insurance, emergency services etc.

The economic viability of alternative systems must also be demonstrated for further projects to be undertaken. The new projects are very different to the old systems, which makes the financial assessment complex and therefore uncertain, which is also a barrier. Another hindrance for diffusion is that alternative systems often require the adaptation of the conventional or the development of new business models.

The relative success of the new rainwater management schemes does not face all these barriers. They are primarily enacted by local government officials and planners over a long timescale and are part of public infrastructure provision. They can be incorporated into town development plans, which then form part of the context for housing, rather than having to be adopted as part of each individual housing project. The limitation is that town planning is a long-term task, partly because the built infrastructure is long lived, such that changes are slow. The adoption of new schemes is also heavily dependent on the enthusiasm and resources of local councils, both in terms of developing expertise in the alternative systems and in budget allocations.

Review of influencing factors for local innovation implementation

To cluster the factors identified in the case studies that are reported by interviewees as influencing the implementation process of the sustainability innovations under study we drew on the existing literature: We apply the typology of systemic failures influencing the adoption of sustainable technologies developed by Woolthuis (2005) and adapted by Negro et al. (2012). Negro et al. (2012) built their adaptation on a review of the literature on systemic innovation failures in renewable energy from a Technological Innovation System (TIS) perspective, which identifies barriers to the uptake of alternative, sustainable technologies in innovation systems. In the synthesis of the district heating, communal housing, and sustainable water systems discussed in this paper, the systemic challenges are interpreted as influencing factors that impede or foster the development and diffusion of these niches, i.e. may act as barriers or drivers (cp. Table 4 for full list and short definitions).

With regard to *hard institutions***,** it can be shown that niches across domains investigated are struggling with limited conformity of current regulations and institutions, which are in line with the current system. Thereby, the specific challenges for niches differ for the different domains. While in heat networks the number of different rules and requirements of incentives hinder a cost-effective implementation, profitability in the water domain is hardly possible due to an insufficient compatibility with current fees and charges. In the housing domain, the high number of differing regulations and missing standard solutions present an obstacle to actors in practice with a lack of expert knowhow.

Concerning *soft institutions,* there are often tensions between project teams and other stakeholders, e.g. users and residents or other institutions such as banks. Consultants or other intermediaries are particularly important here if they are present. They are required to support the development of professional expertise in project teams to ease communication with other actors and represent the interests of the project. These services and sources of advice are even less present in the water domain than in heat networks and housing cooperatives.

Market structures are a challenge in all three areas, but with differing severity. Path dependencies including established/regime institutions that support current systems often make the implementation of new systems difficult. The market structures in all cases investigated are not aligned with the needs of the niches. There is a lack of incentives or in the case of heating, an inconsistent policy and incentive structure.

Project groups have a lack of *competencies and expertise* in all areas. Projects are often initiated by potential users who have a vision of the new system or local members of the public or particular individuals in local government (e.g. local mayor or district council members), rather than specialist development organisations. The innovative systems are by nature less familiar to all actors, so that there is a lack of detailed knowledge, which has to be overcome during the project. Solutions are often project specific and not generalizable. Local government often lacks the expertise and specialist capacity, as well as the interest in developing the necessary knowledge, to support innovative niches.

There is a connection to *interactions* as an influencing factor. If the necessary networks have already been established through contacts to similar projects, consultants or intermediaries of the current regime, e.g. the housing market, they can enable synergies to be realised and increase efficiency in the project.

Infrastructural factors have an influence similar to market structures: control over the current infrastructure or the ability to change are essential for successful niche projects. This raises the question of whether there are windows of opportunity that enable path dependencies to be overcome. The realisation of innovative concepts is easier in new building projects than in renovation. Most importantly, the selection of a site for development or redevelopment in the German context, where land is scarce and often expensive, presents an important opportunity. They can arise through the redevelopment of brownfield sites and when infrastructure or buildings need to be renewed.

Synergies between the case studies and implications for change

The analysis of influencing factors leads to a long list of factors that turned out to be a challenge for the projects under study. In our cases, these challenges were finally overcome as the study only included successful cases. Thus, in this section we take this a step further by looking again into the categories of influencing factors but now through a lens of potential mutual learning. At this point, it is also important to note that the topics analysed here are not only linked by the municipal dimension, but that they are even more closely linked as housing projects are connected to the energy-water-nexus. An important aspect of this connectedness is also the possibility that windows of opportunity could arise, i.e. during designing/planning a new house or a refurbishment that enable innovations from all three domains to be implemented jointly. From a technical point of view, one possibility is the use of advanced decentralised wastewater separation systems to recover heat in a building. However, as the earlier analysis showed the implementation in a single domain already leads to major challenges, a combined realisation would need to draw on synergies. Otherwise, the resulting complexities could become too high and ultimately could stop the overall project. The standards and legal frameworks as *hard institutions* set by the national government are an important contextual factor in innovation processes. Inappropriate standards and regulations constitute significant barriers for the alternative niche systems investigated in the case studies. The highly regulated nature of housing and infrastructure means that the authorisation of local government is required for a change to open up new perspectives for innovative solutions. In all three areas, there are technical, service-oriented and/or organisational solutions that, given effective management and operation, can meet the changing conditions while improving sustainability. The cases studied provide examples of demonstration projects that function effectively. They can serve as a starting point for the development of supporting regulations and technical standards.

The case studies obtained different results concerning *soft institutions***.** One common feature can be identified in tensions between project teams and other stakeholders e.g. users and residents or other institutions such as banks. Acceptance in the local community (e.g. users) can influence the outcome of project proposals. The advantages and requirements of the niche alternatives in all three areas need to be discussed and agreed with the local communities if they are to be accepted and hence supported. However, good networks and high level of acceptance could also support in triggering spill overs at low levels of resistance – for example using a window of opportunity to transform a district on different sustainability dimensions and across domains instead of fighting for all of them separately.

The support of the district authority is decisive in the provision of sites or buildings. This has to be complemented by financial support where market prices for land and buildings can often not be met from the capital resources of the community niche. The costs of rebuilding and restructuring the heat energy

Table 4. Overview of factors influencing the success of niche development in three domains: district heating, water infrastructure and housing.

	Definition	Energy: District heating	Water infrastructure	Housing
Hard Institutions	Formal, legal requirements, regulations, standards etc.	Numerous legal instruments and support mechanisms – difficult for local actors to apply because of the complexity; Some conflicting incentives e.g. support for fossil fuels and continuing support for fossil heating systems; Lack of direct Statutory requirements (e.g. in heat systems planning, heat maps)	Innovative systems cannot be fully financed from current charges. Technical standards are still focussed on conventional systems. Increased complexity due to e.g. the increased number of relevant stakeholders	Requirements from Social, Communal, Property and tax law require creative solutions for specific projects. Housing requirements are not necessarily compatible with the project design. Support from the local administration often decisive. Some (financial) support at the federal state level. Pre-existing housing development as a challenge.
Soft Institutions	Informal rules and values, norms und culture	Differing responsivity from different social groups. Distributional justice in costs, possibilities/requirements for connection/compulsory connection depending on local (governance) culture and the assertiveness of decision makers.	Compliance with soft institutions is improved in some new systems (centrally managed decentralised systems), more difficult in other areas (restrictions on use of areas for water infiltration); Actors from the water domain tend to be resistant to change.	Strong motivation of project members. Successful process of team building is decisive. Experienced/established consultants can address limited trust of other actors (banks, local government).
Market structure	Market mechanisms, costs and value chains	Wide range of current and innovative technologies makes an overview of the market difficult. Split incentives in case of tenants as a challenge; Recently installed conventional systems lead to path dependency. Local government has limited control, decisions taken by individual households/ property owners.	Quasi monopoly market; no self-regulating market mechanisms. Structure of charges and fees as well as perhaps constitutions must be adapted.	Proof of members' own financial resources often difficult – leads to unfavourable conditions for finance; can be overcome by local authority support. Competition from development corporations. High land prices in cities. Households with capital tend to prefer to buy their own home.
Capabilities & Competences	Competences, skills, and resulting structures	Active local stakeholder groups as a precondition. Local expertise and consultants are often lacking. Very limited resources and expertise in local governments (councils).	Very limited resources and expertise of the relevant stakeholders – lack of specialist expertise in water management in general.	Lack of (legal) knowledge in project members is a challenge. Process of team building in the project needs to be managed – high social skills needed.
Interactions	Interactions between social actors, the public and other stakeholders	Established networks and lobby of the conventional suppliers (with local variation). Numerous individual decisions are required for project implementation. Weak networks in district heating (local government, suppliers, consultancy).	Establishment of networks and communications structures, including users and residents required.	Cooperation with conventional housing market needed, but is not established. Cooperation with social services still weak. Consultants or contact with other projects or cooperatives is useful. Limited availability of consultancy.
Infrastructure	Technical, infrastructure and environmental situation.	Windows of opportunity, e.g. cyclical replacement of systems, new developments. Availability of space for heat sources/systems and available heat sources	Many new concepts are especially favourable for operation without connection to local infrastructure. Long life of current infrastructure – windows of opportunity.	Purchase of affordable land that is consistent with project aims – windows of opportunity; Particular challenge to adapt existing buildings to project needs.

or water management system are not reflected in market prices for the heating and energy services to households, such that support programmes are required for these kinds of projects to be realised. These are sometimes made available from local authorities. Additionally, the *market structures* in the three domains investigated are different. Therefore, tailored solutions for each domain are necessary as synergies are difficult to find.

The need for coordination and expertise across a community of households is a common feature. The stakeholders need to be capable to develop *competencies* in technical and legal specialist areas and must at the same time form new organisations. The stakeholders are similar for the three areas: householders and local communities, district councils, technical/standards authorities covering the various aspects of design, installation, operation and maintenance, construction companies and service providers. Specialist consultancies have an important role to play in providing specialist knowledge to the projects. A network of advice centres and specialised consultants at the district or higher administrative level could help to pool relevant knowhow for a range of subjects. This is closely related to the question around *interactions*. Successful projects demonstrate the development of a community spirit where people mutually support each other. A promising pathway is engaging with major networks that trigger exchange of information, contacts and best practices.

Windows of opportunity are important for the implementation of sustainable *infrastructure* systems or services for communal housing. The realisation of innovative concepts is generally easier in new building projects than in renovation. Most importantly, the availability of a site for development or redevelopment in the German context, where land is scarce and often expensive, presents an important opportunity. This can arise through the redevelopment of brownfield sites, and also when infrastructure or buildings need to be renewed.

Discussion and conclusion

From the three types of innovations studied in this paper, the communal housing projects form a small but stable niche in the field of housing, which is growing steadily, albeit slowly. This growth is being driven by the increasing number of older people living in single-person households in Germany, some of whom are looking for alternative forms of housing. Heating networks, on the other hand, are not yet established. There is a number of projects, but a number of negative influencing factors currently hampers their realisation: little pressure, e.g. from the federal or state level, insufficient equipment/competence of the municipalities and a partly inconsistent incentive structure, which continues to promote fossil fuels. Possibly, the current EU directive on "on the promotion of the use of energy from renewable sources" as mentioned above will lead to significant changes in the future. The (currently) low prices for heating oil at individual household level however reduce the motivation of people to get involved in local heating networks or to be connected. In the cases from the water domain, the development of this niche is even more difficult: New technologies that can increase water and resource efficiency and increase flexibility in terms of adaptability of infrastructures are used in some projects, but are only spreading very slowly. The concept of centrally operated, decentralised wastewater disposal plants has not yet been adopted and only few of the demonstration projects remain. Rainwater management is now subject to great pressure to act in the face of increasing urbanisation and increasing heavy rainfall events in the wake of climate change. Here, innovative solutions might have a better chance in the future to diffuse. With regard to the present study, it should also be noted that the case studies only considered those initiatives that were successful in the end. Even if a number of challenging influencing factors are identified, other factors that do not emerge may be added in the case of failing initiatives. Furthermore, with regard to sustainability, we simply chose our cases such that they cover innovations that have the potential to increase sustainability and analysed the actual achievements only qualitatively (findings not reported in this paper). This means that our analyses do not allow to assess if sustainability potential were actually fully realised (e.g. if heat grids were operated efficiently).

Given the difficulties of diffusion that all three niches exhibit, it was also the question to what extent they could benefit from synergies among themselves in order to promote their diffusion. A starting point could be housing projects, which by their very nature are connected to energy/heat and water systems and therefore offer the possibility of combining the social objective of shared housing with the sustainability objectives for heat and water. In fact, the case studies showed that the projects here often have the ambition to realise ecological sustainability beyond the legal standards. However, the available capacities and resources set a limit here. This refers to the municipal level as a coordinator and mediator. Here, water supply, sewage supply and energy infrastructure could be jointly developed in the planning phase and corresponding statutes and award procedures implemented. In practice, however, this has so far only been done in individual cases - partly because there is a lack of capacity and resources or incentives. This would also provide an opportunity to strengthen local civil society and promote awareness and action for sustainability. Implementation is therefore also a question of political priorities and the attention of local actors. Advisory and other networks can be decisive for the establishment of projects in all areas of action in order to accelerate learning curves.

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