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Multilevel knowledge management for municipal climate action: Lessons from evaluating the operational situation of climate action managers in the German Federal State of Lower Saxony

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A B S T R A C T

Effective actions to mitigate climate change are urgently needed, especially in the context of cities, which are major sources of global CO2 emissions. Establishing and managing knowledge systems that integrate local knowledge can contribute to establishing more effective responses to climate change as well as transformative change towards sustainability. However, it is still unclear how new forms of urban governance should acquire, store, create, or disseminate knowledge for fostering sustainability transitions effectively. In this study, we present a multilevel knowledge system approach based on design principles informed especially by the knowledge management literature. These address (i) working environments across multiple levels, (ii) knowledge forms and types, and (iii) knowledge processes. We apply this approach to municipal climate action in the German energy transition. In particular, we focus on the operational work of municipal climate action managers of regional centers of Lower Saxony, one of the largest of the 16 federal states, and investigate their involvement in knowledge processes. Based on semi-structured interviews in 14 of the 17 regional centers, we show that structural pre-conditions for successful knowledge management and organizational learning are present. However, we also show that there is a need for improvement regarding (i) the multilevel coordination for accelerating routine operation, (ii) the persistence of local operational knowledge, and (iii) the exploitation of local innovations. Relying on these results, we offer general recommendations for municipal climate action and suggest that policies should (i) rely on local knowledge for effective decision-making, (ii) foster multilevel exchanges of explicit and tacit knowledge for implementation, and (iii) enable open-ended learning processes that leverage local innovations for creating usable transformational knowledge.

1. Introduction

A broad spectrum of societal responses has emerged for addressing the harmful effects of climate change (IPCC, 2015; Steffen et al., 2011). Knowledge systems, which involve dynamic processes such as acquiring, storing, creating, or disseminating knowledge, are the basis for many of such responses. Therefore, rethinking, designing, and managing knowledge systems can support climate action (Alves et al., 2020; Cash et al., 2003; Jasanoff, 2010; Martins et al., 2019; Muñoz-Erickson et al., 2017). This is particularly true regarding the governance of cities because of their significant contributions to global CO_2 emissions (Edenhofer, 2014, p. 935; Grubler et al., 2012, pp. 1332–1335; IEA, 2008, p. 390; Wang et al., 2019). Over the past decades, cities have been dealing with this challenge proactively and have turned into vibrant fields of

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Abbreviations

CAM	climate action manager
MCAP	municipal climate action plan
MUCA	municipal climate action

action, interventions, experimentation, and knowledge creation (Caniglia et al., 2017; Castán Broto and Bulkeley, 2013; Dignum et al., 2020). However, it is still unclear how the related contents, processes, or organizational structures as part of the knowledge system can best be managed for governing cities and for leveraging their full transformational potential. Indeed, such processes are often dispersed and fragmented, and it is increasingly difficult to link the work of city administration, societal and academic stakeholders, and decision-makers in ways that can foster mutual learning for sustainability transformations (Grubler et al., 2012, p. 1391; Muñoz-Erickson et al., 2017).

A key strategy of cities is Municipal Climate Action (MUCA) (Bulkeley, 2010; Castán Broto and Bulkeley, 2013). MUCA comprises analyzing the status quo, setting targets, preparing an action plan, and implementing individual measures. Various cities have carried out MUCA successfully. The Global Covenant of Mayors for Climate & Energy documents gives examples of over 9000 municipalities in 127 countries (GCoM, 2018). MUCA merges the work of informal and flexible local experimentation with the work of formal and stable public administrative structures. This convergence has the potential to foster generating, sharing, and using the knowledge that supports effective actions across different actors and scales (Betsill and Bulkeley, 2006; Bulkeley and Betsill, 2005; Lenhart et al., 2014).

This study examines the knowledge processes of MUCA in the German energy transition from the perspective of municipal climate action managers (CAMs). As an essential instrument in the German energy transition, MUCA is financed out of the national energy and climate fund as part of the National Climate Protection Initiative (Bickel, 2017; BMUB, 2015; German Federal German Federal Government, 2011). Through this initiative, 2180 municipalities have developed municipal climate action plans (MCAPs) and employed 650 CAMs since 2008 (BMU, 2019; BMUB, 2015). CAMs represent the lower end of public administration for operationalizing MUCA, e.g., by advancing the implementation of action plans. They carry crucial operational knowledge and work at the interface of strategic planning and implementation. Their tasks include, for instance, internal and external communication and networking, the coordination of integrated collaboration, or the initiation of individual processes and comprehensive technical or non-technical projects (BMUB, 2016). Their cross-cutting agenda as "change agents" (Battilana et al., 2009) is atypical for traditional structures in public administrations and makes CAMs an interesting study example regarding institutional change towards effective climate action.

In this context, this study asks: How can we systematically understand and evaluate the way how knowledge is managed in MUCA in the public sector? What can we learn from current practices and experiences of CAMs about effective ways to manage knowledge in MUCA? Which challenges and opportunities can we identify in MUCA from a knowledge system perspective for designing or supporting societal responses to climate change? For addressing these questions, we compiled design principles for multilevel knowledge systems from the literature and interviewed 14 CAMs in the German Federal State of Lower Saxony (Lower Saxony).

This study leverages the potential of knowledge management for sustainability transitions to contribute to the multilevel analysis of MUCA. Recent research on MUCA calls for more integrated multilevel analyses that can help to exploit the innovation potential of experimental approaches (Bickel, 2017; Bulkeley, 2010; Hildén et al., 2017). Further, research is needed regarding the challenges and opportunities that professionals face in municipal transition activities (Feagan et al., 2019). This study contributes to closing this gap with empirical insights into the operational work of CAMs using a knowledge management approach that identifies critical spots in the knowledge system. Knowledge management approaches for climate action are sparse, especially regarding the municipal context (Massaro et al., 2015). In Germany, there is hardly any research focusing on knowledge in a climate action context.[1] The empirical study most related to the present one investigates how "knowledge orders" influence the preparation of municipal climate policies (Zimmermann, 2018). The present study puts a stronger focus on multilevel and operational aspects and, thus, provides new insights and recommendations that might be relevant for other transition contexts.

The rest of this study is organized as follows. Section 2 first introduces the methodological approach for conducting the empirical work in Lower Saxony. It then summarizes various features for systematically analyzing multilevel knowledge systems. Section 3 present the interview results. Section 4 discusses the results and highlights general challenges and opportunities for CAMs in Germany and MUCA more generally. Section 5 concludes with a summary of the main findings and recommendations. It also discusses limitations of this study and points out research needs.

2. Materials and methods

2.1. Study cases and general methodological approach

2.1.1. Cases in Lower Saxony

The theory of central places (Christaller, 1966; Getis and Getis, 1966) defines municipalities that fulfill vital functions for their regions as regional centers. Their situation affects their entire regions and is an indicator of the average regional municipal situation. Due to the number of over 150 regional centers in Germany (BBSR, 2018), this study focuses on a single federal state. There are 16 federal states in Germany, which are key administrative and political units. This study concentrates on Lower Saxony, which belongs to the largest states. German municipalities share many commonalities regarding the conditions for MUCA (Kern et al., 2005). Thus, despite the geographical limitations, the present study still reflects patterns that might be encountered in the whole of Germany.

In Lower Saxony, the regional development plan (Lower Saxony Ministry of Food, Agriculture, 2017) defines 17 regional centers. These include Hanover, the state capital, which was excluded from the analysis. As the capital, it benefits from more advantageous conditions than other municipalities. Another exclusion criterion was its size. This study focuses on cities with fewer than 300,000 inhabitants. This city class is currently dominating globally (UN DESA, 2019, pp. 55–58). Appendix A provides the detailed population statistics of the cities examined. Other researchers also recommend not focusing exclusively on forerunners or large cities

[1] This conclusion is based on a query in the Scopus database in January 2020. One of the search phrases we used to come to this conclusion is: TITLE-ABS ((knowledge AND climate W/5 mitigation) OR (knowledge AND ("energy transition" OR "climate action"))) AND TITLE (knowledge OR information OR learning OR "co-production") AND (LIMIT-TO (AFFILCOUNTRY, "Germany")) AND (LIMIT-TO (DOCTYPE, "ar")).

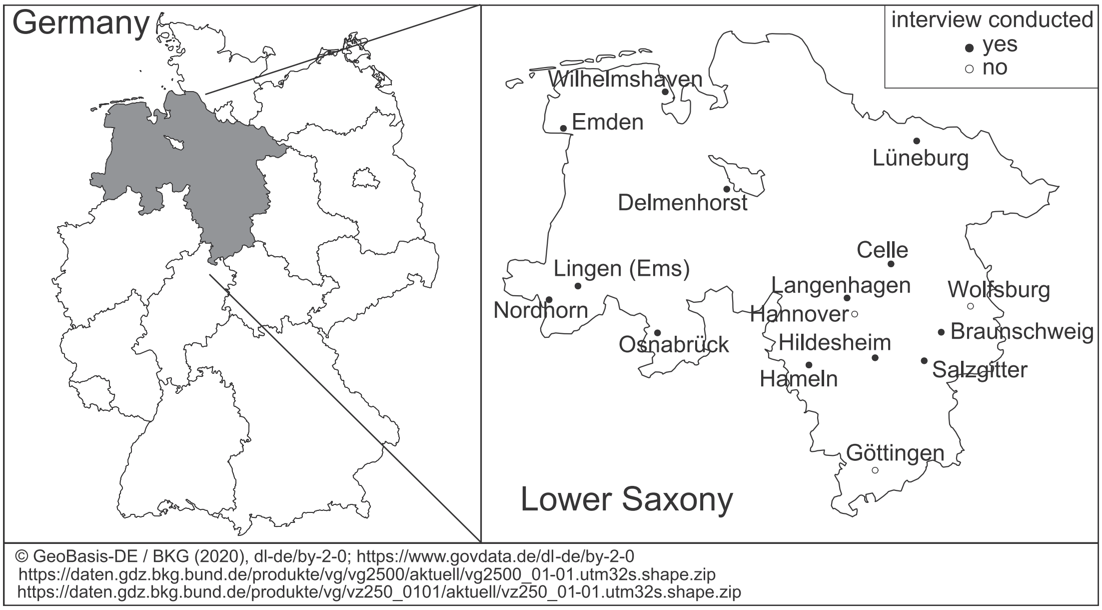

Fig. 1. Map of Lower Saxonian regional centers created using the R (R Core Team, 2019) package rgdal (Bivand et al., 2020) and public geospatial data.

(Hoppe et al., 2016; Kern et al., 2005).

For this study, interviews with CAMs in 14 cities were conducted. On a map, Fig. 1 provides an overview of Lower Saxonian regional centers where interviews were conducted. At the time of conducting the interviews, Göttingen had no CAM, and the one in Wolfsburg was not available. In 2016, there were around 60 CAMs in Lower Saxony financed by the national funding scheme (KEAN, 2016). In several German municipalities and some of the ones examined here, environmental officers or energy managers fulfill comparable functions as CAMs, although they are not CAMs in the strict sense of the funding scheme. This study refers to all of them as CAMs.

This study considers three of the selected municipalities as advanced in terms of MUCA. They base their activities on comparably detailed MCAPs and targets with political backing. On this basis, they have achieved an active involvement of various sectors and local stakeholders. Moreover, they have received awards from external bodies for their success. This study refers to selected developments in these municipalities as distinguishing examples in the results and discussion sections.

2.1.2. Semi-structured interviews

For this study, semi-structured interviews were used as a flexible and effective method of investigation (Steinar and Brinkmann, 2009). For improving the preliminary understanding of the regional situation, the authors of this study personally visited the regional energy agency of Lower Saxony (KEAN). This agency is a regional facilitator of MUCA (KEAN, 2016). Making this contact should contribute to being perceived, to a certain extent, as an insider during the interviews. This precondition should further increase the quality of the knowledge shared by CAMs.

The 90–120 min interviews took place in the CAMs' offices in 2016. Through this face-to-face exchange, a vital factor for knowledge sharing (Krogh et al., 2000, pp. 82–92; Nonaka and Krogh, 2009), the authors sought to increase the quality of the interview results. Phone interviews, for instance, might not have produced the same high quality. To ensure privacy and comply with good research practice, a non-disclosure agreement was signed. The interviews consisted of open-ended questions about organizational structures, available knowledge types, and the involvement in knowledge processes. They were based on a set of standard questions on knowledge management (Probst et al., 2012) and that was extended to cover context-specific aspects. After a pre-check with one of the municipalities, the final interview guideline was prepared. Appendix B contains the final version. As a good precondition for this study, the education and professional backgrounds of all interviewees, which are summarized in Appendix C, enable them to engage in advanced knowledge processing potentially.

2.1.3. Content analysis

All interviews were transcribed, coded for content analysis, and analyzed following the principles summarized in Table 2 in Section 2.2.2. Using qualitative content analysis (Baxter and Jack, 2008; Mayring, 2014, pp. 10–15, p. 10–15), the interviews were coded in an iterative exploratory process for deriving findings at a higher order of abstraction. Where necessary, additional background information was considered, e.g., from websites of municipalities or institutions such as regional energy agencies,[2] the German Institute for Urban Affairs[3] (Difu), or the German National Climate Protection Initiative.[4] The software MAXQDA (VERBI, 2017) supported the coding process and the analysis of code frequencies.

2.2. Features of multilevel knowledge systems for systematic analyses

In the German energy transition, MUCA is embedded in the national administrative structure, an organization with a multilevel knowledge system. To systematically analyze the latter, this study mainly relies on the literature on organizational knowledge management. The following section first present a working definition of knowledge and, secondly, a multilevel knowledge system approach considering: (i) working environments across horizontal and

[2] Examples of regional energy agencies are the one of Lower Saxony (https://www.klimaschutz-niedersachsen.de/) or of Northrhine-Westphalia (https://www.energieagentur.nrw/).

[3] https://difu.de/.

[4] https://www.klimaschutz.de/.

vertical levels (ii) knowledge forms and types, (iii) knowledge processes, and (iv) design principles for evaluating knowledge systems.

2.2.1. Information and knowledge

Knowledge has a human character. It resides in individuals and their interactions. People create or utilize knowledge when they act, whether intentionally or not. (Nonaka, 1994; Probst et al., 2012, p. 23; Wiig, 1993, pp. 68–69). Individuals receive information flows, in other words, messages or signals, from external sources, e.g., by personal exchange, reading texts, or consuming media. Information flows may restructure existing knowledge and may serve to create new knowledge (Dretske, 1981, pp. 44, 82; Machlup, 1983; Nonaka, 1994). If and how information flows influence knowledge depends on experiences and beliefs, which act as a filter, as well as on the situational context in which information is received (Krogh et al., 2000; Nonaka, 1994; Venzin et al., 1998). Thus, knowledge carries a normative character (Nonaka, 1994). For evaluating the knowledge system of organizations, analyzing the "semantic aspects of information," i.e., the meaning conveyed in action-oriented contexts, can provide helpful indications as long as the human characteristics of information processing are recognized (Nonaka, 1994).

2.2.2. Working environments across horizontal and vertical levels

Organizations consist of groups or teams of individuals that are usually formally structured and that dynamically interact in networks (Hannah and Lester, 2009; Pentland, 1995; Yang and Maxwell, 2011). Regarding the multilevel structure of organizations, a distinction can be made between static structural units defined by the prescribed horizontal and vertical structure and dynamic functional units formed for addressing specific tasks or fields, often project-based (Nonaka, 1994). These units are the individual working environments shaped by the context-specific (administrative) rules, processes, or working culture. An organization may create and advance knowledge or, in other words, learn from exchange processes across both, horizontal levels, e.g., across departments, and vertical levels, e.g., from local to national, (Probst, 1998; Senge, 2006; Yeo, 2005).

2.2.3. Knowledge forms and types

Knowledge forms and types are features of the static structure of knowledge. Table 1 provides a summary of these features, including references and practical examples. The table categorizes knowledge regarding (i) the continuum between explicit and tacit forms of knowledge, (ii) the content types of knowledge with a focus on aggregated types that are particularly relevant in sustainability science, i.e., system, target and transformational knowledge, and (iii) the generalizability of knowledge.

2.2.4. Input-output model for knowledge processes

Individuals and organizations process and create knowledge through different interlinked steps (Fazey et al., 2013; Pentland, 1995; Probst, 1998). The literature conceptualizes knowledge processes in a multiplicity of ways (Fazey et al., 2013; Holzner and Marx, 1979; Nonaka and Toyama, 2003; Probst, 1998; Wiig, 1993, p. 53; Yang and Maxwell, 2011). This study uses of a simple input-output model to analyze knowledge processes of organizational units comprising the steps: input, conversion and creation, storage, and output (Fig. 2). Strictly speaking, with reference to Section 2.2.1, the input and output are information flows, not knowledge flows. Mechanistically applying input-output models is not reasonable for analyzing knowledge systems (Nonaka, 1994). This study uses an input-output model as this model can be easily linked to the practical context of MUCA, which strongly relies on the structure of public administration that explicitly defines various organizational units, e.g., for receiving or disseminating information. This study avoids a mechanistic perspective by acknowledging the meaning and purpose of information flows and the relevance of different forms and types of knowledge.

2.2.5. Design principles for multilevel knowledge systems

High interconnectedness is an essential feature of a multilevel knowledge system that effectively makes use of the innovations created in diverse teams (Dyer and Nobeoka, 2000; Hannah and Lester, 2009; Nonaka, 1994; Phelps et al., 2012). Fig. 3 provides a scheme of such a knowledge system. Ideally, knowledge processes at different levels are designed and interconnected in a way that the knowledge required for finding solutions to complex problems is exchanged and available across all vertical and horizontal levels in suitable forms and types. Table 3 summarizes design principles for highly interconnected multilevel knowledge systems. The principles in the table do not represent an exhaustive list. They were tailored to the evaluation of the MUCA knowledge system in Germany.

3. Results

The following Section 3.1 provides a general overview of the multilevel knowledge system of MUCA in Germany with reference to Fig. 2. This overview is independent of the interviews. Subsequently, Sections 3.2 to 3.5 present the findings from the interviews.

3.1. Multilevel knowledge system of MUCA in Germany

Regarding the local level of MUCA, CAMs use the information output from higher levels or other municipalities as input for their operational work. They further absorb input from various non-state sources, e.g., companies, civic organizations, press, or research institutes. Regarding knowledge conversion and creation, e.g., during project development with stakeholders, innovations may emerge by combining knowledge from different domains and groups (Fazey et al., 2013). Storing their knowledge can be a critical issue since the national scheme usually grants funding for the positions of CAMs for three years only. Afterward, not all municipalities can prolong their positions without funding. Considering knowledge dissemination, the multi-faceted knowledge of CAMs can be a valuable information output to higher levels concerning local innovations but also prevailing local conditions.

At the federal state level, information inputs include outputs from the national level, e.g., laws, policies, or guidelines, and outputs from the local level, e.g., concerning needs of municipalities or local innovations. At the federal level, organizational units such as the regional energy agencies (eaD, 2017) may serve as "intermediaries" (Matschoss and Heiskanen, 2017) between these two levels. Federal agencies collect information, store it, and translate the inputs from one level into outputs that the other level can better incorporate. For example, they may initiate networking events that support exchange between CAMs and, also, support the dissemination of information from the national to the local level.

At national level, the input covers all kinds of information from various levels and sources, e.g., reports from selected municipalities or regional energy agencies, position papers or reports from trade associations, or various research outputs. In a conversion step this input is turned into more aggregated, abstract forms. Typically, the aggregated parts serve for building general databases, i.e., storages, that lead to information outputs such as the database on funded projects for MUCA (BMU, 2018a). The abstract parts such as strategy papers lead to, e.g., laws and policies connected to climate action.

Table 1
Forms of knowledge and aggregated types of knowledge.

	Short explanation	Exemplary references	Practical examples
Knowledge forms			
Explicit	- Codified knowledge that is formally transmittable, e.g., via numbers or words - Conscious embrained knowledge of individuals	(Ambrosini and Bowman, 2001; Anderson, 1983; Krogh et al., 2000, pp. 82–84; Lam, 2000; Nonaka and Krogh, 2009; Polanyi, 1966, 4–6, 14–16; Spender, 1996)	Text in MCAPs, disciplinary facts or calculation formulas
Along the continuum between explicit and tacit knowledge, there is a point where both forms converge, and tacit knowledge can be shared through interaction.			
Tacit	- Unconscious, embodied, action-orientated know-how or routines learned from practical activity or bodily experience - Personally bound to the human body and mind - Cannot be shared directly - May manifest in shared norms within organizations		Practical skills or experience of individual CAMs
Aggregated knowledge types composed of basic types			
System	- Detailed understanding of the initial system state or status quo - In the optimum case, comprehensively considering the more basic knowledge types such as descriptive, relational, temporal, or causal knowledge.	(Alavi and Leidner, 2001; Chandrasekaran et al., 1999; Preisinger-Kleine, 2013; ProClim, 1997; Venzin et al., 1998; Wiek et al., 2006; Wiig, 1993, 119, 137–139).	Local infrastructure statistics; estimated municipal greenhouse gas emissions
Target	- Definition of a desirable future system state - Basis for envisioning the future or setting goals		Municipal emission targets
Transformational	- Comprehensive sets of processes, actions, or pathways for reaching a desired future system state from the initial state		Project ideas or methodological pathways for realizing projects
Generalized	- Knowledge with more general applicability, usually condensed from multiple cases - Condensed to the point but may lack specificity	Raymond et al. (2010)	Guidelines for municipal climate action issued at national level
Contextual	- Case-specific knowledge emerging from a specific context of a multilevel organization, e.g., local knowledge - Detailed but may lack general validity		MCAPs that translate national guidelines to the local level for reflecting the local characteristics

The latter are elements of the comprehensive "organizational vision" (Nonaka, 1994) that, as explicit target knowledge, is a crucial national output setting the ground for knowledge processes across horizontal and vertical levels. The general national project management agency (Projektträger Jülich, 2018) or the national service center for climate protection (Difu, 2015) apply an additional conversion step towards operationalization. They are major organizational units for distributing the national output, e.g., in the form of guidelines or funding advisory services.

3.2. Empirical insights from the interviews

Based on the interviews with the 14 Lower Saxonian CAMs, the following sections present empirical insights into the dynamics of the knowledge system of MUCA. The results are structured according to the main knowledge system elements: the working environment of CAMs, types and forms of knowledge they need for supporting MUCA, and key multilevel knowledge processes. Table 3 provides a summary of the results. Appendix D contains the raw codes, their frequencies, and exemplary statements from the interviews.

3.3. Working environment of CAMs at local level

The interviews show that CAMs often face uncertainty concerning their legitimization in their working environment due to their low positions in local administrations in specialist departments. The degree of their official involvement in local knowledge processes depends on their formal position. Therefore, CAMs highlighted that their success in internal exchange strongly depends on personal contacts and sympathy. In several cases, this results in delayed or blocked information flows from other (disciplinary) departments towards CAMs. Also, the bureaucratic nature of administration often negatively influences information acquisition or innovative approaches, especially when the latter involves open-ended experimentation. In this context, several CAMs strategically set up information channels, usually on a personal basis, that are not foreseen by the standard procedures of administration. An interesting observation is that in all of the few advanced municipalities that have established structured adaptation processes concerning targets and transition pathways, CAMs had a solid argumentative stance independent of their formal position.

3.4. Knowledge forms and types at local level

Vague target knowledge and limited usability of methods or limited focus on building sound system knowledge are constraints for creating transformational knowledge. The answers of CAMs indicate that, in most of the municipalities, only rough qualitative visions or highly aggregated descriptive numbers concerning emission targets prevail. CAMs stated that they mostly adopt a step-by-step workflow instead of following a comprehensive work plan due to missing guidance or the vague definition of the target state. Concerning building up system knowledge, CAMs considered carbon accounting, one of the primary methods commonly used for MUCA, controversial due to missing or impracticable standards, and missing data. The limited usability of this methodology sometimes brought CAMs and municipalities in difficulties explaining or justifying published municipal emission balances.

The interviews indicate that the incomplete target and system knowledge complicates the creation of transformational knowledge. Concerning building causal knowledge, CAMs confirmed that unstructured approaches or ad-hoc information exchange prevail. This hampers, e.g., setting up procedures and initiating campaigns effectively since influencing factors concerning potential target groups are rarely clear. In the advanced municipalities, there was a

Table 2
Aggregated design principles for a highly interconnected multilevel knowledge system grouped by the main knowledge system elements.

Element	Principle	Exemplary references
Working environments across horizontal and vertical levels		
Structural	STRUCTURAL OPENNESS: Overcome structural knowledge barriers across horizontal and vertical organizational units by close connections.	(Hansen, 1999; Probst et al., 2012, p. 168; Tortoriello et al., 2012; Yang and Maxwell, 2011)
Functional	FUNCTIONAL OPENNESS: Overcome functional knowledge barriers by close connections between disciplines or professions, e.g., by supporting a culture of interdisciplinary exchange.	(Hansen, 1999; Probst et al., 2012, p. 168; Tortoriello et al., 2012; Yang and Maxwell, 2011)
Individual	RULES: Create open communication channels by communication rules that secure a minimum level of connectedness of individuals working on related content.	(Dyer and Nobeoka, 2000; Yang and Maxwell, 2011)
	SUPPORT: Establish a supportive working environment that motivates to share information and to engage in learning and experimentation with appropriate ways of constructively dealing with mistakes or failure.	(De Angelis, 2013, p. 167; Probst et al., 2012; Shalley and Gilson, 2004; Yang and Maxwell, 2011)
	ROLES: Stay aware of the influence of roles and power positions within organizational units or across scales that may facilitate or block communication channels and the sharing of information.	(Fazey et al., 2013; Preisinger-Kleine, 2013; Probst et al., 2012: 168; Yang and Maxwell, 2011)
Knowledge forms and types		
Forms	FORM: Focus on and cultivate knowledge forms according to the problems to be solved and particularly consider the value of tacit knowledge.	(Lam, 2000; Raymond et al., 2010)
System, target, transform-ational	CONSISTENCY: Built system, target, and transformational knowledge consistently in a soft hierarchy from basic to more aggregated types, e.g., from descriptive over causal to system knowledge. This hierarchy is soft because types can be developed in parallel. Important is the consistency of the final structure of knowledge.	own consideration inspired by literature (Chandrasekaran et al., 1999; Forrest and Wiek, 2014; Preisinger-Kleine, 2013)
Target	VISION: Update and share an organizational vision based on multilevel participation for creating accepted target knowledge	(Nonaka, 1994; Preisinger-Kleine, 2013; Senge, 2006, pp. 5−12)
Transform-ational	USABLE: Create usable knowledge, not only useful knowledge.	Lemos et al. (2012)
Knowledge processes		
Input	COORDINATE: Coordinate information flows and avoid information overload in the input processes across scales, e.g., by bundling or finding synergies.	Eppler and Mengis (2004)
Conversion and Creation	COMBINE: In conversion processes, (re-)combine knowledge from different contexts to innovate and to create new knowledge, e.g., by engaging in open-ended experimentation.	(Fazey et al., 2013; Mulgan et al., 2007; Nonaka and Toyama, 2003; Shalley and Gilson, 2004)
	EXPERIENCE: Make use of practical experience and operational knowledge, e.g., via communities of practice, best practices, or lessons learned during knowledge creation.	(Fazey et al., 2006; Raven et al., 2008; Wenger, 2000; Wenger and Snyder, 2000)
Storage	PRESERVE: For enabling storage of and steady access to knowledge, prepare, encode, and preserve it for practical use in collective open repositories or ensure continuity of staff carrying relevant tacit knowledge.	(Pentland, 1995; Probst, 1998)
Output	TRANSLATE: For the output process, translate knowledge in suitable processes (linguistic, networking, etc.) to reach potential receivers and coordinate dissemination of information across scales.	(Holden and von Kortzfleisch, 2004; Liyanage et al., 2009; Probst, 1998)

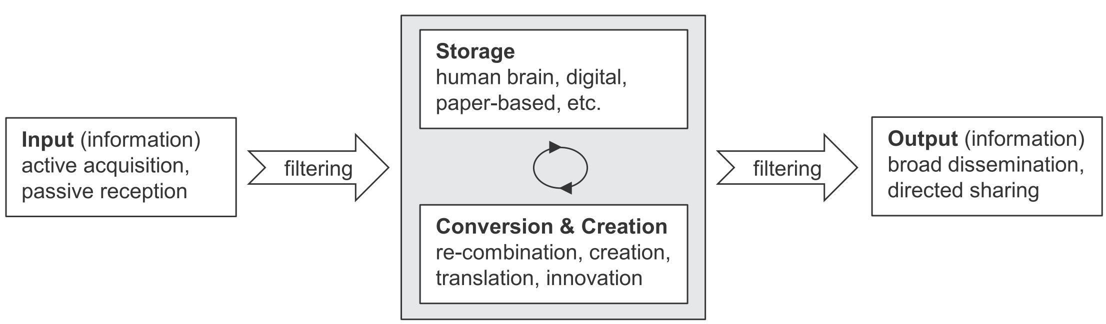

Fig. 2. Knowledge processing steps of an organizational unit; in practice, these steps are interlinked and may coincide (coincidence not shown in the figure).

clear consciousness for causal knowledge and using it for argumentation in local discussions. This indicates the relevance of causal knowledge.

Regarding the content of knowledge that CAMs need in their daily work, they stated a lack of usable knowledge in newly emerging domains and domains of communication. They assured that they carry the required traditional techno-economic or environmental domain knowledge themselves or have sufficient access to appropriate explicit knowledge sources. However, the availability of usable explicit knowledge in new domains such as e-mobility was not satisfactory. Although higher institutional levels make related explicit knowledge available, e.g., via national platforms, the latter is only partly usable for implementation. Furthermore, CAMs were aware of a knowledge gap in the domains of communication and psychology, e.g., operational transformational knowledge for actor-specific strategic communication, storytelling, or actor-network analysis. Only one CAM from an advanced municipality has systematically been acquiring knowledge in these domains. The fact that this has supported achieving the advanced status indicates the value of this kind of knowledge.

Turning to forms of knowledge, the interviews show that operational knowledge for MUCA is dominantly personal tacit knowledge of individual CAMs while encoding seems to be delayed or incomplete. Therefore, it is understandable that CAMs

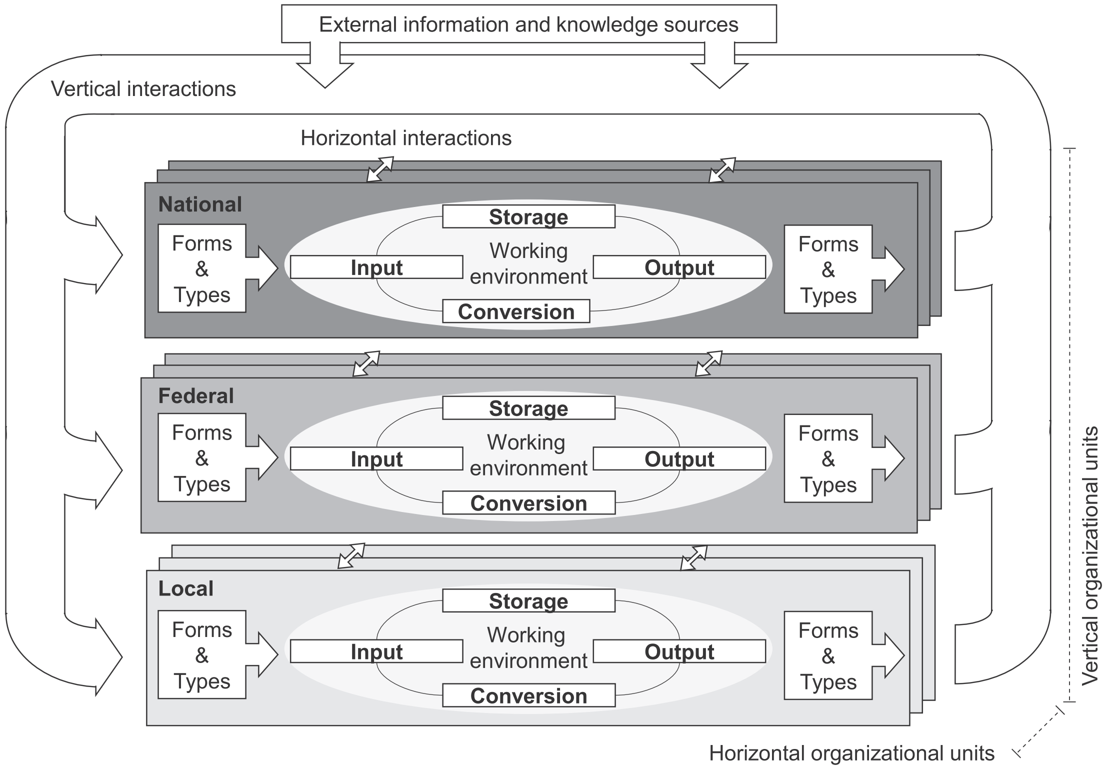

Fig. 3. Scheme of a highly interconnected multilevel knowledge system.

Table 3
Summary of results from interviews with CAMs in Lower Saxonian regional centers describing the knowledge system from their local perspective.

System element	Result
Working environments across horizontal and vertical levels	
	- Low formal position impairs involvement in administrative knowledge processes
	- Setting up informal personal information channels often is an interim solution
Knowledge forms and types	
Form	- Operational knowledge for MUCA is largely tacit
Type	- Constraints for creating transformational knowledge are vague target knowledge, limited usability of available methods, and limited focus on causal knowledge
	- Traditional techno-economic knowledge mostly available, but lack of usable knowledge in newly emerging domains
Multilevel knowledge processes	
Horizontal input	- Key knowledge fragments can usually be acquired, but data acquisition is challenging due to weak formal legitimization towards externals
Conversion	- Open-ended learning processes and transcending organizational or disciplinary boundaries are key for creating knowledge
	- Bureaucracy and disciplinary thinking insufficiently support this kind of environment
Storage	- Storage of local knowledge is a bottleneck; it is rather unsystematic and limited to descriptive knowledge, continuity of tacit knowledge is at risk
Horizontal output	- Only limited professional knowledge of communication strategies available despite frequent communication activities in daily work
Vertical Input	- Information overload regarding practice examples
	- Gaps in the coordination of information flows at the federal level
Vertical Output	- Local output reaching higher levels generates an incomplete and over-optimistic picture

highlighted personal communication as the best way to exchange information and creating knowledge. They deemed the available codified knowledge, e.g., best practice examples, a good starting point. However, it is often not sufficiently usable in practice. In consequence, for acquiring the core usable knowledge, CAMs usually try to establish personal communication, which initiates turning tacit to explicit knowledge.

3.5. Multilevel knowledge processes

3.5.1. Horizontal processes at local level

Looking at the input process, CAMs stated that they usually manage to acquire the required key explicit knowledge fragments. However, they also stated that they have to deal with incomplete information input from external sources and several constraints regarding internal coordination. The acquisition of knowledge from external stakeholders depends on their willingness to share since there are few formal rules for such exchange. CAMs highlighted that this limits the input of information, e.g., for reliable CO_2 accounting, and the creation of, e.g., causal knowledge. In part, CAMs work on a fragmentary basis regarding external descriptive knowledge. However, when investing sufficient efforts, CAMs usually achieved to establish an information exchange with stakeholders that is just sufficient as a working basis. Especially CAMs of the advanced municipalities emphasized that, for a fruitful exchange, continuously showing presence and regular personal exchange is crucial.

Considering knowledge conversion and creation, CAMs described various projects from their work that they deemed creative. In these projects, overcoming organizational or disciplinary boundaries and the willingness to participate in open-ended learning processes was the most important way to create new knowledge. Yet, CAMs experienced that the current bureaucratic nature of administrations and adherence to disciplinary thinking, e.g., of external stakeholders, insufficiently support such conditions. CAMs in the few advanced municipalities stressed that creativity further needs individuals acting as a constant driving force, especially in situations when project teams experience a phase of discouragement. They also emphasized that teams need suitable constellations for triggering creativity. Therefore, it is crucial to know the local landscape of stakeholders for identifying and connecting appropriate combinations.

Storage of local knowledge is a bottleneck since the continuity of knowledge is at risk and storage is mostly limited to descriptive rather than causal knowledge. Knowledge of MUCA largely remains individual tacit knowledge of CAMs with limited-time contracts. Establishing suitable modes to handover knowledge personally, e.g., to successors, is difficult on this basis. Handovers can sometimes be realized merely in explicit form through written reports with limited possibilities for passing on relational knowledge, local network connections, or practical lessons learned.

In several cases, lessons learned were also stored in a generalized format as best practice examples for the use in other municipalities. However, CAMs highlighted that, beyond being a source of inspiration, such examples are usually not useful for concrete implementation. Their transferability is limited since they are often based on special financing or depend on site-specific local contexts. Hence, an important observation regarding storage is that the focus lies on descriptive explicit knowledge. The interviews show that documentation of context variables or even the impact of projects is unsystematic and that the idea of building causal knowledge is rarely present. Of course, basic evaluations of local projects are stored and used as a basis for argumentation already. However, municipalities hardly document real problems and success factors. This might be one reason why all CAMs emphasized that primary sources for this kind of knowledge are other CAMs met at networking events organized, e.g., by regional energy agencies. Again, this indicates that crucial parts of relevant knowledge are largely stored in tacit form.

The final part concerning horizontal knowledge processes deals with the local output of CAMs and shows that they mostly had limited knowledge of communication strategies available but often engaged in bilateral communication or municipal-wide campaigns. The interviews suggest that the most important strategy of CAMs is identifying advantages of policies or planned operational activities in the field of climate action for different stakeholders and, on this basis, convincing them to participate. They apply this strategy on various occasions such as internal administrative meetings, citizen campaigns, or roundtables with stakeholders from the industry. Some CAMs who achieved to position themselves well within their municipalities started to take a service-orientated role. Thereby, they consolidate and broaden the dissemination of their knowledge.

3.5.2. Vertical processes between local level and federal or national level

Regarding vertical aspects of the input process of CAMs, on the one hand, they face information overload; on the other hand, gaps in the coordination of information flows. CAMs generally appreciate available national or federal publications supporting implementation, e.g., of best practice examples. However, they criticize the overwhelming number of reports that complicate, e.g., the identification of truly best practices related to their local contexts. The input required by CAMs is coordinated to a certain extent, e.g., via regional energy agencies. However, for compiling codified knowledge, CAMs need to refer to many different (regional) agencies. Furthermore, CAMs stated few coordinated approaches for identifying synergy potential between municipalities or collective needs.

Concerning the output of the local level, an incomplete picture of the local situation arrives at higher levels. The majority of the local level reports that reach higher levels focus on innovative projects or best practices demonstrating general feasibility. However, these information flows concentrate on flagship projects that have benefited from special funding or conditions. They are not representative of the average situation. Since knowledge of CAMs is primarily individual tacit knowledge and personal contact to higher levels - especially the national level - in structured dialogues is seldom, relevant local operational knowledge reaches higher levels only in a few instances.

4. Discussion

The interviews on the knowledge system of MUCA indicate that (i) the working mode of the administrative system is often opposed to the requirements of advanced climate action, (ii) the vertical synchronization of local and national levels is incomplete, and (iii) the storage and transmission of CAM's operational knowledge are often not ensured. The following sections discuss challenges and opportunities for the German context in detail. Table 4 summarizes them and, in addition, Fig. 4 visualizes the opportunities and required conditions.

4.1. Working environment of CAMs at local level

4.1.1. Challenges

The interviews show that it is challenging for CAMs to fully leverage the cross-cutting potential of climate action at the local level. Their low position in administration weakens their legitimization and results in impaired information exchange. Their environment, which resembles a "machine bureaucracy" (Lam, 2000), amplifies this effect. Formal structures shape their environment and evoke divisive thinking and the tendency towards maintaining the status quo. This leads to various "knowledge barriers" (Probst et al., 2012, p. 168).

4.1.2. Opportunities

A more actionable or practice-orientated "organizational vision" (Nonaka, 1994) that is "co-produced" (Jasanoff, 2010) with relevant actors would support establishing the required working environment. Beyond abstract targets, e.g., regarding emission reductions, an advanced national vision should include practice-orientated descriptions of goals and pathways that organizational units at different levels can easily adopt for operational work. This would appeal to a broad range of operational administrative staff and

Table 4
Challenges and opportunities for the knowledge system of MUCA in Germany.

System element	Challenges	Opportunities	Related principles (see Table 2)
Working environments across horizontal and vertical levels			
Working Environment	- Bureaucratic environment leading to structural knowledge barriers	- Providing a practice-orientated organizational vision beyond abstract goals for shaping supportive working environments and efficient horizontal and vertical workflows	VISION, ROLE, RULE, SUPPORT, STRUCTURAL OPENNESS
Knowledge forms and types			
Form	- Local tacit knowledge and information on local knowledge requirements receive insufficient attention in national processes	- Synchronizing knowledge processes vertically by structured personal exchange from local to the national level, e.g., via local mandates from communities of practice	STRUCTURAL OPENNESS, USABLE, FORM
Type	- Incomplete conversion between local contextual and generalized knowledge - Local system knowledge is fragmentary	- Supporting an evidence-based transition grounded in connected local databases accompanied by standardized reporting procedures - Emphasizing building of causal knowledge via qualitative and quantitative methods for creating reliable transformational knowledge - Identifying usable best practice examples by proven methodologies	CONSISTENCY, PRESERVE, USABLE
Multilevel knowledge processes			
Input	- Horizontally disconnected knowledge fragments across municipalities - Information overload regarding downstream information flows	- Providing a clear framework for operationalizing MUCA in terms of information flows - Closing knowledge gaps by extended duties for stakeholders to disclose environmentally relevant information - Strengthening the coordinating role of energy agencies as intermediaries and bundling information at federal level	VISION, COORDINATE, RULE, CONSISTENCY
Con-version	- Bureaucratic and disciplinary thinking hamper innovative knowledge creation	- Leveraging local innovations by supporting experimentation environments and valuing tacit knowledge	COMBINE, VISION, FORM, STRUCTURAL & FUNCTIONAL OPENNESS
Storage	- Structured storage of operational knowledge with proven usability is limited	- Connecting local knowledge processes and establishing collective storing approaches - Focusing on usability when storing operational knowledge from local project experience - Planning for handover procedures that enable sharing tacit knowledge	PRESERVE, FORM, EXPERIENCE, USABLE
Output	- Unclear how to organize vertical upward information flows for making local knowledge usable at higher levels	- Establishing efficient vertical upward information flows by using federal agencies as knowledge translators	COORDINATE, TRANSLATE, USABLE, STRUCTURAL OPENNESS
	- CAMs need to justify MUCA towards local stakeholders and may face obstacles when trying to initiate change	- Developing social skills of CAMs for effective knowledge integration and dissemination as institutional change agents	TRANSLATE, ROLE

would, thereby, serve as a bridge in horizontal and vertical knowledge processes, e.g., between different departments. Practice orientation would also require highlighting and defining the necessary communication channels across different levels to establish seamless workflows. Therefore, policies should define additional “communication rules” (Dyer and Nobeoka, 2000) that increase the integration of CAMs in information flows and facilitate knowledge dissemination by CAMs.

For successfully establishing an advanced organizational vision with the above features, this vision needs to be updated continuously in participatory processes across vertical levels (Preisinger-Kleine, 2013; van den Heiligenberg et al., 2017). This way, administrative staff would potentially not depreciate it as abstract goals but use it as a means to achieve consensus during transition efforts (Joas et al., 2016).

4.2. Knowledge types and forms

4.2.1. Challenges

This study suggests that, in the German context, incomplete vertical alignment of knowledge processes has led to a lack of usable knowledge at the local level. A local process, parallel to national activities, is necessary for translating the orientation and methodologies provided along with high-level policies into actionable procedures for operationalizing MUCA. At the local level, this kind of process does not seem to have taken place thoroughly. Municipalities are expected to implement measures, especially of technical nature, which the national level has only sketched. Municipalities have not been equipped sufficiently with usable knowledge for defining actionable pathways. A similarly unsynchronized communication regarding the national provision of climate change information and local needs was observed, e.g., in the United Kingdom (Demeritt and Langdon, 2004). The interview results suggest that, on the one hand, the explicit knowledge provided by the national level is too abstract and focuses on techno-economic domains, while domains for initiating change, e.g., communication, are underrepresented. On the other hand, the knowledge of municipalities about their local dynamics is limited since local empirical data for assessing impacts is often fragmentary.

4.2.2. Opportunities

Synchronizing multilevel knowledge processes by a more personal exchange would increase the practical usability of knowledge.

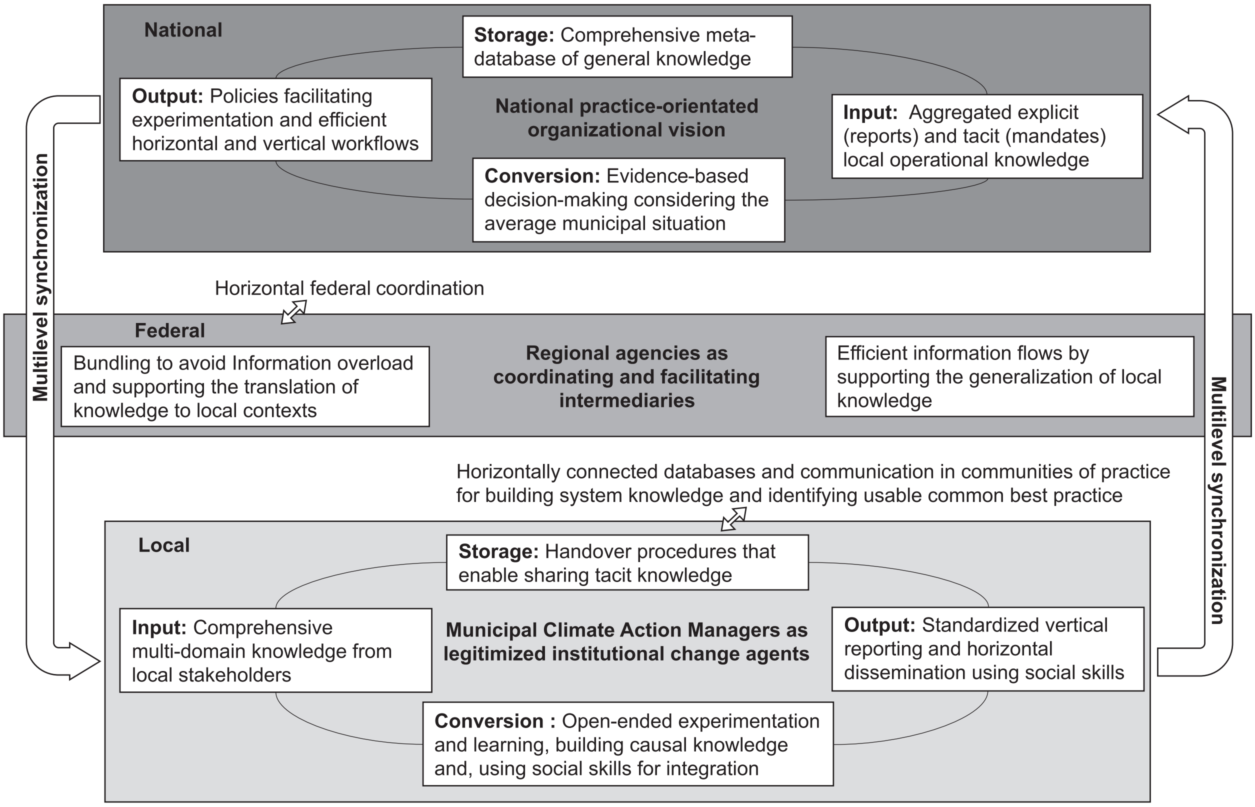

Fig. 4. Opportunities and required conditions that facilitate knowledge processes for MUCA in the mulitlevel knowledge system of Germany.

Already in early steps of policy-making, national knowledge processes ought to involve more structured interpersonal exchange with the local operational level by "strong ties" (Hansen, 1999). This increases the mutual understanding of current considerations and concerns (Homsy and Warner, 2013) and increases the bandwidth of information considered and disseminated for approaching local operational tasks. An option for realizing closer vertical exchange could be meeting procedures involving local mandates, e.g., from local communities of practice, who introduce local operational knowledge concisely and act as reviewers of national processes. For climate adaptation, research has already proposed institutionalized review processes at city level (Muñoz-Erickson et al., 2017). Multilevel approaches with review elements have already been successful, admittedly not frictionless, in the field of resource or ecosystem management by installing co-management arrangements (Berkes, 2009).

Another aspect that ought to receive higher emphasis is the potential of evaluations for building causal knowledge consistently for supporting a more evidence-based transition. Grounding the designs of local pathways on evidence more clearly increases the potential for success (Forrest and Wiek, 2014; Preisinger-Kleine, 2013). Several public sector studies have illustrated the importance of supporting policies and decision-making by "organised systematic empirical enquiry" (Davies et al., 2000, p. 6) using a broad spectrum of methods such as regression analysis, impact analysis, randomized experiments or, more generally, transition experiments (Davies et al., 2000; Luederitz et al., 2017; Millard-Ball, 2012). One option to achieve such enquiry in the context of MUCA is a more detailed compulsory reporting procedure in funding schemes that asks for project data and information on local developments (see also in Section 4.3.3). A drawback is that this would require allocating resources for the documentation. However, improved reporting allows for establishing comprehensive connected local databases. Such a database can be used for analyzing project data via best practice management methodologies (Dani et al., 2006; Zairi and Whymark, 2000) for revealing truly usable best practice and, also, for learning from failure (Borins, 2001). Furthermore, an advanced local database enables applying mixed qualitative and quantitative analytical methods broadly for drawing (causal) inferences and creating reliable transformational knowledge.

4.3. Multilevel knowledge processes

4.3.1. Input

4.3.1.1. Challenges. The combination of incomplete information exchange and insufficient vertical coordination leads to horizontally disconnected knowledge fragments across municipalities. The limited legal basis of municipalities (Karg, 2017) hampers acquiring environmentally relevant explicit knowledge from local stakeholders, e.g., companies. Duty of disclosure such data partly exists, e.g., through the German Federal Emission Control Act, but does not cover the full range of explicit knowledge required for comprehensive climate protection. In contrast to this gap, the incomplete vertical coordination of downstream information flows towards CAMs creates "information overload" (Eppler and Mengis, 2004). The fragmentary and insufficiently coordinated input seems to be a reason for the situational step-by-step workflow often adopted by CAMs. This discontinuous workflow hampers identifying synergies between CAMs or municipalities regarding operational tasks.

4.3.1.2. Opportunities. A more precise framework for operationalizing MUCA, particularly considering the vertical and horizontal exchange, would foster leveraging existing potentials. Climate action requires advanced options for gathering data from stakeholders to build comprehensive local system knowledge. Policies, e.g., at national level, ought to introduce extended duties to disclose environmentally relevant data. At the same time, finding suitable ways to ensure data protection is crucial. The tension between data protection and provision will require increased attention in the context of climate change.

Another measure for improving information flows is strengthening the coordinating role of energy agencies as cohesive "intermediary organisation[s]" (Matschoss and Heiskanen, 2017). Bundling their outputs horizontally across the federal state level reduces information overload towards CAMs. Moreover, coordinating the municipal inputs to these agencies helps to detect synergies or innovations of greater relevance. These organizations can further play an important role in communicating local needs towards the national level. However, as a study on Manchester, United Kingdom, shows, such intermediaries need to understand themselves as representatives of and for the municipalities; otherwise, they just reinforce the national agenda (Hodson and Marvin, 2012).

4.3.2. Conversion

4.3.2.1. Challenges. The bureaucratic environment CAMs face in local administration is not only a challenge in the input process but also during knowledge conversion and creation. The administrations tend to disciplinary specialization and aim at the stability of existing structures. In this context, the integration of disciplines and innovative knowledge creation is demanding.

4.3.2.2. Opportunities. Allowing for more creative freedom and exchange in administrative rules and structures supports leveraging the available local innovation potential. CAMs require a working mode closer to an "operating adhocracy" (Lam, 2000) that values explicit knowledge but also supports developing tacit knowledge and open-ended experimentation. A case study on Malmö, Sweden, highlights that structured continuous interdepartmental communication can lead to policy innovations (Lenhart et al., 2014).

In the German context, administrative rules should be modified to support the emergence of a moderate experimental transition atmosphere. In the first step, not all municipalities can establish wide "epistemic networks" (Dobson, 2019) or comprehensive "transition arenas" (Loorbach, 2010) that support different working modes and institutional change. Therefore, starting with moderate steps creates preconditions for more comprehensive approaches. Administrative procedures ought to incorporate more elements allowing for flexible project development and, e.g., through additional communication rules and opportunities, a gentle integration of less innovation orientated organizational units or disciplinary thinking stakeholders. A study on 100 European cities showed that, for instance, involving rather traditional public sector organizations can be beneficial for experimental approaches (Dignum et al., 2020). Furthermore, fostering social ties and informal communication significantly supports innovative approaches (Pelling et al., 2008). This has been discussed, e.g., for climate action in Durban, South Africa (Leck and Roberts, 2015).

Facilitating communication triggers (re-)adjusting or transcending organizational and disciplinary boundaries as well as the relations between the involved perspectives and interests. Such a communicative basis facilitates empathic multilogues, increases the willingness to invest efforts in open-ended learning processes, and can lead to a fruitful collaboration in networks.

4.3.3. Storage

4.3.3.1. Challenges. Since several CAMs have limited-time contracts, local transformational knowledge that has already proven its value in operational work is volatile. Although CAMs partly document best practice examples, obstacles for the documentation process are missing coordination and standardization across municipalities. This leads to the unstructured storage of explicit knowledge and complicates targeted and efficient searching for best practice examples. Various examples are also documented at higher organizational levels, e.g., on national platforms. However, they serve to establish a positive public image rather than for providing usable knowledge for broad application. Beyond these deficiencies, the current modes of storing explicit knowledge hamper creating causal knowledge, which would support building reliable transformational knowledge (see also Section 4.2).

4.3.3.2. Opportunities. Improved structuring of the storage of operational knowledge supports the continuity of operational transformational knowledge and the efficiency of the transition process by accelerating collective learning processes. A step into this direction would be advancing the project database provided in the national meta-platform for climate action (BMU, 2018b). For ensuring "usability" (Lemos et al., 2012), the database needs to incorporate operational project experience from municipalities considering the local contexts and influencing factors beyond basic project descriptions. For the case of the United Kingdom, one study also argued that more direct communication between the local level and the national level would increase the usability of nationally issued climate change information (Demeritt and Langdon, 2004).

A recommendation that applies but is not limited to Germany is to store the best common practice examples in the sense of actionable solutions to MUCA created from projects under average conditions. This is different from storing, e.g., best practice emerging from prestigious projects based on special funding. Furthermore, CAMs highlighted that a usable database should entail information on contact persons as the basis to initiate sharing tacit knowledge on impediments and solutions. This kind of advanced empirical basis regarding local solutions should be incorporated into high-level decision-making for enabling conditions that create solutions to everyday operational problems. Setting up a comprehensive database might not be possible in the short-term. An initial compromise would be to consider, ahead of time, how to realize suitable handover modes allowing for a personal exchange between different generations of CAMs.

The proposed approach of establishing a cross-municipal database and exchange of experience is challenged by the fact that transferring local knowledge between municipalities is a sensitive and not always feasible process (Williams, 2017). However, connecting isolated local knowledge processes through collectively storing knowledge is an opportunity for triggering comprehensive learning processes that accelerate local transition processes as a whole.

4.3.4. Output

4.3.4.1. Challenges. It is not clear yet, how knowledge processes at the national level can integrate local knowledge in a better way. The output of CAMs is not standardized. Their vertical information output is weakly structured and often of limited usability at the national level. Therefore, at the national level, awareness tends to be higher for non-representative prestigious examples involving, e.g., the use of new technologies, than for realistic pictures on municipal developments. In this situation, several innovative approaches for advancing MUCA beyond using innovative technologies remain within local networks as tacit knowledge and do not reach a wider audience.

Regarding CAMs' output towards other administrative units and local actors, their low position requires them to use various "social skills" (Fligstein, 1997) for justifying MUCA and initiating institutional change. Other studies, e.g., in Scandinavia, also addressed such difficulties in disseminating transition knowledge in hierarchical contexts (Hauge et al., 2019; Lenhart et al., 2014). For overcoming such barriers, CAMs use "issue re-labelling" (Heinelt and Lamping, 2015) as one of the key strategies. This means taking different perspectives, e.g., of the economic departments, and highlighting advantages of MUCA from these perspectives without emphasizing MUCA but, e.g., economic advantages.

4.3.4.2. Opportunities. Incorporating a higher amount of local operational knowledge at the national level by advanced multilevel coordination allows for designing policy frameworks towards more effectiveness and innovativeness at the local level. A study on national adaptation plans of 13 countries also points out the need for similar bottom-up approaches (Alves et al., 2020). For the climate change adaptation context in Norway, a study showed, in specific, that representatives of the national level can benefit from the direct personal exchange with the local level (Hauge et al., 2019). In addition to sharing local tacit knowledge through a vertical exchange (see Opportunities in Section 4.2), vertical upward information flows need to be efficient. CAMs need to document their experience and innovations usable form for the national level, e.g., how to activate stakeholders from different fields. Intermediary regional agencies should then support the necessary knowledge translation (Matschoss and Heiskanen, 2017).

Apart from the above-mentioned strategic aspects of vertical knowledge output, the administrative system ought to support the operational role of CAMs as institutional "change agents" (Battilana et al., 2009) or "boundary spanners" (Goodrich et al., 2020) more clearly. Strengthening the set of social skills that can foster knowledge integration (McGuire, 2006) requires more systematic support for the communicative competences of CAMs. This kind of support increases the efficiency of routine operation and knowledge creation processes in general. In a few of the studied cases, CAMs have successfully applied such skills and developed MUCA in a way that local stakeholders acknowledge the advantages of MUCA beyond merely reducing emissions. In these cases, CAMs could adapt their role towards more service-orientation and shift efforts from challenging the old institutional logic towards mainstreaming the new logic (Battilana et al., 2009). This indicates the beginning of a potential institutional change and that MUCA can be part of an integrated transition process more broadly.

5. Conclusions and recommendations

This study combines design principles for knowledge systems and insights into the local operational level of MUCA in Germany based on 14 interviews. This section concludes, first, by summarizing the challenges encountered in the cases studied and, second, by highlighting general opportunities and recommendations for policy-making. Furthermore, the final section highlights limitations of this study and future research needs.

This study shows that many organizational units for knowledge management are available for MUCA in the context of the German energy transition but that their dynamic interactions need to be enhanced. The bureaucratic working mode of German administration is often opposed to the flexibility required for advanced MUCA. This also impedes integrating a sustainability orientation in local administrations more generally (Kirst and Lang, 2019). Furthermore, the vague organizational vision regarding the operationalization of MUCA has partly led to an incomplete synchronization of local and national knowledge processes. Therefore, local needs are only partially fulfilled and the national level has only fragmentary knowledge about the local operational conditions. In this context, CAMs have the potential to act as institutional "change agents" (Battilana et al., 2009), who carry and create valuable operational knowledge. However, their cross-departmental integration in administrative workflows is limited. Therefore, they cannot fully leverage the available innovation potential, e.g., of interdepartmental collaboration. Another critical issue is the volatility of operational knowledge since it concentrates in individual CAMs with limited-time contracts and handover modes are not clearly defined.

For approaching the challenges described above, the knowledge system perspective of this study offers various policy recommendations. Designing and implementing structured multilevel learning processes for establishing a highly interconnected knowledge system increases the efficiency of the routine operation of MUCA and supports innovations that are usable and more transferable. A fundamental prerequisite for learning is to understand the elements and dynamics of the system in which climate action takes place. As part of a comprehensive organizational vision for MUCA, national policies should support multilevel learning processes that consider both explicit and tacit forms of knowledge. The inclusive multilevel character of these systems is pivotal since tackling climate change requires new ways of co-producing knowledge (Frantzeskaki and Rok, 2018; Jasanoff, 2010; Mach et al., 2020).

Policies should emphasize the collection of data using practicable standards, categorization schemes, and archiving rules, which can be used to build a comprehensive database of explicit knowledge. Such a database allows for applying advanced analyses for inferring causal knowledge, which can be used, e.g., for detecting common or even failed patterns of action versus successful innovative patterns (David and Gross, 2019; Derwort et al., 2019). In turn, the resulting analytical conclusions directly enhance the operational work. For successfully steering transition processes in MUCA, it is crucial to generate and store system knowledge that is not abstract but instead taps into the broad empirical basis of local knowledge from different stakeholders. Establishing open and consistent exchange of causal system knowledge, developed from the local context across horizontal and vertical levels, is required if we want this knowledge to become the basis for analyses and decision-making at the different levels.

Further, policies ought to promote institutional arrangements facilitating collaboration that support the sharing of operational tacit knowledge, e.g., within local communities of practice or public administration. Encouraging the exchange of tacit knowledge requires fostering personal exchange, also in informal settings (Nonaka and Konno, 1998; Pelling et al., 2008). In addition, policies should facilitate the exchange between staff from the local operational level and the national decision-making level. Such an exchange raises awareness for operational conditions at upper organizational levels and, thereby, increases attention to issues of feasibility when developing targets and designing transition pathways. For an efficient exchange of both explicit and tacit knowledge, it is crucial to coordinate and, where possible, bundle knowledge processes both horizontally and vertically. In this way, the multilevel learning processes benefit from data and human experience and generate actionable transformational knowledge.

In a transition context, policies should support the creation of innovative transformational knowledge. In practice, establishing supportive working environments enables the creative potential (Shalley and Gilson, 2004; Yang and Maxwell, 2011) of administrative staff that needs to engage in open-ended learning or experimentation. To a certain extent, policies can justify the need for and benefits of experimentation (Caniglia et al., 2017; Luederitz et al., 2017). They ought to support knowledge integrators such as

CAMs in leveraging the potential of collaboration for innovation. A few of the municipalities studied here managed to integrate MUCA into municipal life successfully and enabled a more service-orientated role of CAMs. This was possible because knowledge integration during MUCA achieved conceivable benefits for various municipal stakeholders. Motivated by such examples, a new official task of administrations could be dynamically creating innovative transformational knowledge and providing transition services.

In summary, for supporting effective responses to climate change and sustainability transitions in general, national policies can help to establish efficient multilevel knowledge systems by (i) supporting the generation of causal system knowledge that relies on local knowledge for effective decision-making, (ii) establishing efficient multilevel exchanges and integration of explicit and tacit knowledge for implementation, and (iii) allowing for flexibility in administrative structures to enable open-ended learning processes that leverage local innovations and create usable transformational knowledge. In this way, national policies can contribute, from the top down, to creating the conditions for and supporting the establishment of highly interconnected multilevel knowledge systems and learning processes that are rooted, from the bottom up, in local knowledge and expertise. Such orchestrated interplay of knowledge leverages the transformational potential of cities and supports integrated actions that contribute to the broader transformation towards sustainability.

5.1. Limitations and future studies

This section acknowledges four limitations of this study on the knowledge system of MUCA and points out research needs.

First, as pointed out in Section 2.1.1, the number of cases and geographical coverage limit the representativeness of this study. To a certain extent, it can still indicate some general patterns of MUCA in Germany due to the various commonalities regarding the conditions for MUCA in German municipalities (Kern et al., 2005). Furthermore, this study focuses on the average municipal situation. Future studies might conduct more comparative studies, e.g., between forerunner municipalities and the municipalities with average or even poor performance regarding MUCA for better understanding municipal dynamics. The goal of this research direction would be to develop a comprehensive roadmap of diverse municipal transition pathways with a high resolution of individual transition states. All kinds of municipalities could then link these generic states to their current own states and use the roadmap as a guide for accelerating their sustainability transitions.

Second, the knowledge management literature is the main basis of the compilation of design principles in Section 2.2.2, which is, thus, focused on organizational and managerial aspects. This is only one of the many possible perspectives for analyzing knowledge systems (Muñoz-Erickson et al., 2017). With reference to one of the “knowledge system analysis” (Muñoz-Erickson et al., 2017) frameworks recently proposed, the present study focuses on “functions” and “complexities” (Muñoz-Erickson et al., 2017) of knowledge systems by applying a multilevel knowledge management approach. In future work, it would be useful to compare this study with works applying complementary perspectives that look, for instance, more at epistemic aspects (Dobson, 2019; Frantzeskaki and Rok, 2018). Beyond the need to integrate different perspectives on knowledge systems and the nature of knowledge itself, a rewarding task of future research will be to understand which frameworks or perspectives are best suited to facilitate sustainability transitions in a given context. This requires transdisciplinary research projects that have applied or will apply different frameworks and provide insights into knowledge processes in practice. Accompanying meta-studies could analyze the different project settings from a second order perspective in order to gain valuable insights into the interaction of practice with different frameworks or theories.

Third, there are various other factors and contexts to knowledge systems that have not been considered explicitly such as available resources (Hegger et al., 2012; Nonaka, 1994) or the political and economic context (Feagan et al., 2019; Jasanoff, 2010). Future research might reveal the influence of these factors and contexts on the configuration and dynamics of knowledge systems in order to clarify limitations of applying a mere knowledge system perspective.

Fourth, the interview-based methodology also has its limits. Interviews are situational events influenced by various factors such as age, gender, or professional background (Qu and Dumay, 2011; Steinar and Brinkmann, 2009, pp. 123–124). The professional background of the interviewer, i.e., environmental engineering, is related to the one of most CAMs interviewed. This might have influenced the “follow-up” or “probing” questions (Steinar and Brinkmann, 2009, p. 135). Interviewers with different backgrounds might have posed other questions. Furthermore, the interviews focused on how to make MUCA more efficient from the perspective of CAMs. Interviewees might have downplayed potential personal deficiencies.

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Role of the funding source

The role of the funding bodies was limited to the provision of funding.

Data statement

Due to the sensitive nature of the questions asked in this study, survey respondents were assured raw data would remain confidential and would not be shared.

CRediT authorship contribution statement

Manuel W. Bickel: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft. **Guido Caniglia:** Writing - review & editing. **Annika Weiser:** Writing - review & editing. **Daniel J. Lang:** Supervision. **Thomas Schomerus:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix E. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.123628.

Appendix A. Population statistics of Lower Saxony

Table A.1
Population Statistics – Lower Saxony and regional centers

State/City	Population in 2016
Federal State of Lower Saxony (total)	7.990.991
Hannover	536.055
Braunschweig	248.528
Oldenburg	168.301
Osnabrück	164.622
Wolfsburg	124.247
Göttingen	119.182
Salzgitter	104.441
Hildesheim	101.789
Delmenhorst	77.546
Wilhelmshaven	76.001
Lüneburg	75.333
Celle	69.225
Hameln	57.497
Lingen (Ems)	54.465
Langenhagen	54.457
Nordhorn	53.579
Emden	49.977
Sum of population of regional centers	2.135.245
Sum without Hannover	1.599.190
Sum without Hannover in percent of population of Lower Saxony	20%

Source: Federal Statistical Office of Lower Saxony, https://www1.nls.niedersachsen.de/statistik/, Accessed 12 November 2019.

Appendix B. Interview Guideline

Table B.1
Set of initial questions asked during the interviews

Role and professional experience	
Professional experience and current position	Describe your education and professional background. Describe your current position and tasks.
System, Target Transformation Knowledge	
Target Knowledge	How clear is your picture about the target state of the municipality in the individual sectors industry/commerce, trade and services/ mobility/private households/education? Is there something like a vision that goes beyond target states in form of CO_2 reduction targets? How detailed is it concerning the structures in the individual sectors?
System Knowledge	How is your knowledge situation regarding the current state in these sectors?
Transformation Knowledge	How is your knowledge situation regarding the required actions to approach the target state?
Local information sources	
Missing (transformation) knowledge	Regarding the pathway, what is the knowledge that you are missing? At which points do you have difficulties to proceed and what knowledge would you need?
Information sources	Do you generally have all the contact persons among the local actors? Do you encounter difficulties in approaching them?
Quality of information sources	Concerning the quality of information exchange with these stakeholders, what could be improved?
Information sources in general	
Information sources	Considering all societal levels, what are you most important sources of information and knowledge for the successful climate action?
Sources for legitimization	Do you have any sources available aiding you in your legitimization in the municipality?
Best Practice databases	Which role do best practice databases and project examples play for you?
Improvement of Best Practice	How could the use or reporting of Best Practice examples be improved?
Specific information sources	
	You have already mentioned some of the following actors as information sources. Could you please describe more in detail which role the following actors play for you?
Difu as source	The Difu (national service centre for municipal climate action) at the national level?

Table B.1 (*continued*)

Role and professional experience	
KEAN as source	The KEAN (Lower Saxonian energy agency) at the federal state level?
Science as source	How does science contribute to your operational work? -You might think of science concretely as universities or research institutes but also as science in a general sense.
Knowledge conversion	
Examples of creative projects	Describe two to three examples or projects of your work, in which you used creativity to create own solution strategies or innovation. If available, one of the examples should be from an industry or economy context.
Definition and emergence of creativity	What was the creative or innovative moment in these projects? How did it evolve?
Synergy	When you approach new projects, to what extent do you consider aspects of synergy and transfer from the outset?
Storage	
In general	How do you store your knowledge and make it so to speak available forever?
Tacit	What is the knowledge that remains stored in your mind? How easy or difficult would it be for a temporal substitute for your position to access your knowledge?
Impacts	Concerning impacts of your activities, which knowledge about impacts do you store? To what extent to you document a “before and after” perspective?
Lessons learnt	To what extent do you document your “lessons learnt”, i.e “what works and what does not work”?
Causal knowledge	To what extent do you use statistical models?
Output	
Boundaries	To whom and how do you disseminate your knowledge including formal and informal ways? Particularly consider how you disseminate knowledge outside of your municipality.
Quality	Have you received feedback to the knowledge you disseminated?
Openness	Which opportunities do you have to communicate grievances, e.g., internally within local administrations and to external units?
General situation	
Negative aspects	From your perspective, which institutions at which level could improve the framework conditions for municipal climate action?
Positive aspects	In your position, that is in many situations not directly empowered for decision making, how are you successful anyway to bring forward the implementation of local climate action? What are your success strategies?
Assessment of situation	In summary, how would you assess the knowledge situation concerning local climate action in your municipality, e.g., in comparison to other municipalities?
Sustainable climate action	
Integration	What would have to be done to make local climate action more sustainable? Consider the degree of integration of the various relevant knowledge domains in particular.

Appendix C. Education and Background of CAMs

Table C.1
Overview of the education and professional background of CAMs interviewed

Category	Feature	Number of interviewees
Education	University degree	12
	Degree for the higher administrative service	2
Discipline	Engineering or technical background	1/3
	Mixed background involving geography, spatial planning, environmental and resource management	2/3
Years of working experience	Less than 3	2
	Between 3 and 7	8
	More than 7	6

Appendix D. Codes and exemplary interview statements

The following tables provide the codes, their ID labels, and the code frequencies that emerged from the interviews and, in addition, exemplary statements from the interviews. Frequencies appear in the following formats: (i) The percentage of cases that a code applies to appears as C-percentage. For example, 7 cases were counted that a code applies to/total of 14 cases = C-50; (ii) Given a certain code with sub-codes, the frequency of citations that a sub-code applies to in relation to the frequency of all sub-codes, on average over all municipalities, appears as F-percentage. For example, if code X had 2 sub-codes, in one case X-1 was mentioned 3 times, X-2 was mentioned 6 times, the resulting total mentions would be 9; in a second case X-1 was mentioned 5 times, X-2 was mentioned 10 times and the resulting total mentions would be 15. The average frequency of sub-code X1 for the two cases would be $(3/9 + 5/15)/2 =$ F-33, and for sub-code X-2 it would be $(6/9 + 10/15)/2 =$ F-67; (iii) Some codes were created from mixed statements from all interviews; these aggregated codes only partially apply to each municipality and, therefore, appear as M without a number.

Table D.1
Results regarding the role and power position of CAMs

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
RWE1	CAMs are generalists and deal with many different knowledge domains. They call for more integrative thinking in decision-making.	"Climate action management is not green – it is all colors." „Achieving long-term effects is one of the most difficult challenges. I see the urgency to focus on the long-term effects of the projects that we initiate." "Acting sustainably means to bring together the diverse perspectives and approaches to achieve a higher efficiency, instead of letting them run in parallel."	C-93
RWE2	They initiate and keep alive projects that involve various topics and stakeholder networks.	„We are the motivator or project pusher and try to bring on board the relevant institutions." „We have to keep several balls in the air, which is often difficult considering the numerous projects that run in parallel."	C-86
RWE3	CAMs have faced uncertainty concerning legitimization in their direct working environment.	„Eventually, you are working for a voluntary service when you are working for municipal climate action. This is the point somehow, since climate protection is not always well-respected in the administration." "It is always a good idea to obtain confirmation or acknowledgement from externals and not only from internals, since administration is not necessarily happy that we are there."	C-79
RWE4	Almost all CAMs are responsible for climate action as single person without direct colleagues working for climate protection. About a quarter have limited-time contracts.	–	
	Limited time contract (NKI funding)	–	C-29
	Unlimited contract	–	C-71
	Single person without team	–	C-71
RWE5	Position of CAMs at lower level of administration.	–	
	Position within specialist department of administration	–	C-79
	Advisory unit for specialist department of administration	–	C-7
	Advisory unit or agency for top level of administration	–	C-14

Table D.2
Results regarding system knowledge

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
SYS1	Availability of descriptive knowledge particularly in form of sectoral CO2 accounting	–	C-100
SYS2	Use of European Energy Award process for monitoring	–	C-21
SYS3	Carbon footprints considered controversial due to missing or impracticable standards for municipal emission accounting, missing or incomprehensive data, or mistrust in the data.	"Apart from the initial accounting, we have not prepared an interim accounting, because we face difficulties to draw the right boundaries. A renewed accounting might have created numbers that would make the credibility appear questionable. […This] might ruin the work that we have already achieved." "[Apart from CO_2 accounting,] there is a lack of suitable systemic indicators. As in the case of the ecological footprint, this is linked to the problem of defining the right system boundaries."	C-71
SYS4	State-of-the-art knowledge from the domain of technology is available as own embodied knowledge, from internal specialist departments, or external experts in particular.	"Technical knowledge is not really a problem. We have our specialists for buildings, traffic, etc. Of course, there is backlog in single cases, but in general this is not a problem."	C-100
SYS5	Electric mobility is a new technological topic associated with uncertainty due to missing overall transition pathway and insufficient multilevel alignment regarding provision of useable knowledge.	"Politics demands us to act, although a lot of knowledge is missing, [… which] still has to be transferred into the administrative body. […] And there are many companies who want a slice of the cake, […] and praise their products […] by saying 'look, we have all these bonus schemes and subsidy programs, now please just buy our electric cars.' […] I finally have to get an overall picture and feel uncertain in this situation."	C-36
SYS6	Detailed knowledge in the domain of technology sometimes required to start communication with stakeholders through naming potential options that are usually not part of municipal climate action literature but, e.g., process engineering literature.	"As long as I haven't talked to experts from the field of this specific production sector I don't know which options exist and cannot contact the individual companies by saying: You don't make us of this option, but it is still possible." (statement by an interviewee from a municipality with an advanced status of climate action)	C-7
SYS7	Unstructured approaches or ad-hoc information exchange prevailed concerning building causal or procedural knowledge about potential target groups for campaigns	Only one interviewee mentioned detailed studies on values and symbols of target groups.	C-93
SYS8	Descriptive and relational knowledge for the identification of suitable contact persons is available	"Identifying contact persons is usually no problem."	C-79

TableD.3
Results regarding target knowledge

ID	Code		Frequency
TRG1	Rough qualitative vision of target states or highly aggregated descriptive numbers concerning emission targets	The quality of the visions differed, for example, from "I have a figurative imagination how the city should change as a whole" to "I have a relatively clear personal imagination how the target state looks like concerning the sectors and key terms".	C-79
TRG2	Only municipalities with structured learning processes (see Table, TRF2) have more detailed structural goals for individual sectors	"We have developed strategic goals for the city."	C-14

Table D.4
Results regarding transformation knowledge

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
TRF1	Incremental case by case way of action	„There is no manual. It is like SCRUM*: where are we, where do we want to go, what are the next steps." *SCRUM: used in industry as a manner of agile incremental product development. "It is rather an evolution than a revolution."	C-100
TRF2	Structured goal-orientated learning and adaptation process that provides confidence about the envisaged pathway although working incrementally.	„We prepare an annual work program that includes proposals of our department but also of politicians concerning the next steps. It also sheds light on ongoing measures."	C-14
TRF3	The reasons named for the step-wise approach are manifold among the interviewees. • complexity of the problem and solution strategies • missing guidance and commitment of higher institutional levels • (local) politicization of climate protection instead of rational long-term approaches • volatility of human resource capacities	• "for the German Energy Transition or the Great Transformation we basically do not have a master plan" • "if you want to eat an elephant, you need to do this a bit at a time" • Steady need for quick integration of new and innovative topics that on the one hand are not yet comprehensively prepared (see e.g. e-mobility example in • Table) and on the other hand appear complex towards citizens • Dependency on the economic cycle that sometimes disrupts continuous approaches • Instable legislative framework and political back and forth • "Municipal climate action is a still voluntary task, voluntary commitment doesn't work. Making municipal climate action compulsory by federal state laws has been discussed for years, however, this has not been transposed." • Climate action sometimes gets "mangled on the local political battlefield that is often based on short-term thinking". The local discursive process does not always end in favour of climate action since other municipal concerns might opposed. • Irregular availability of resources in the education sector, so that long-term approaches are difficult to establish • Capacity of local administrative is often insufficient to fulfil the high expectations from envisioning pathways. This would lead to "working for the drawer."	M
TRF4	Importance of procedural and relational knowledge for comprehensive municipal-wide communication campaigns and its use to the extent available was highlighted	"The highest priority is the dialogue with the stakeholders that has to be maintained and cultivated continuously." "In any case, it would be falling short to only focus on 'energy' for winning 'clients' and generating motivation — I feel like I am the service providers and have to win clients." „You need to know about the hobbyhorses of the people."	C-79
TRF5-7	**Required or missing knowledge for the work**		
TRF5a	Knowledge from the domain of communication and psychology to: • encounter irrational argumentation • build communication bridges and establish dialogues • consciously use one's role	CAMs faced, e.g., • Arguments such as "We do not want that; we do not need that. We still have enough gasoline. Climate change is not real.", "If my neighbor doesn't do that, why should I?", or "Ventilation systems blow out false air, I do not want that." • "Reluctance to accept advice" • "Half- or quarter-knowledge" CAMs pointed out some success factors to cope with above situation: • "You need to pick them up via everyday topics." • "Layperson are often not interested in technical details, but how individual measures affect them personally. You need to argue towards them, for example, with positive experiences of other users from the same user group at a different but still spatially close location." • "Human aspects, psychology, also matter a lot. You need to know how to approach others. This is certainly easier for a 50-year old than for a 20-year old."	F-42
TRF5b	Descriptive and relational knowledge about sectors and individual people	This includes knowing "trendsetters", "decision-makers", "hobbyhorses", "interests", "working conditions and available capacity of people", or preferences concerning the mode of communication.	F-30
TRF6	Organizational set-ups and working processes	"Collaboration with the public utilities", "public relations work and campaigns", "collaboration with the consumer advice centre", etc.	F-20
TRF7	Technical knowledge	"In the end, technology is the really interesting part."	F-1

Table D.5
Results regarding knowledge input from information sources in general, internal sources within administration and external sources such, i.e., (local) stakeholders

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
Information sources in general			
INP1	Knowledge sources used by CAMs rather provide knowledge from traditional domains of climate protection, especially technology, than from domains such as communication or psychology.		
	Knowledge from the domain of communication and psychology	Examples of named sources or application fields are: seminars to improve rhetoric; companies that can set-up and conduct education projects or campaigns; scientific insights in terms of methods for public relations, e.g., storytelling, marketing, etc.	F-11
	Knowledge from the domain of organizational management, e.g., in terms of organizational set-ups or working processes	Examples of named sources or application fields are: networking events with other CAMs to exchange on how projects are handled successfully; energy agencies or national service centre for climate protection for organizational drafts or frameworks to initiate campaigns or projects	F-22
	Technical knowledge and knowledge from other traditional climate protection disciplines	Named sources are, e.g.: technology institutes, individual energy experts, energy agencies, environmental NGOs, federal institutions such as the German Federal Environmental Agency or the Service Centre Municipal Climate Action	F-67
INP2	Use of energy and climate action agencies of other federal states as information source	"Considering energy agencies as information source, I prefer the ones of other federal states, especially Northrhine Westphalia."	C-43
INP3	The Internet is a good starting point for overview information at a lower degree of detail, however, the most useful information stems from personal communication.	„The Internet is always nice for identifying initial approaches, however, when it comes to the nitty-gritty, personal contacts are more important."	C-100
INP4	Highly relevant sources are local and partly regional internal and external networks	Named sources are, e.g.: colleagues, disciplinary experts, local institutions, CAMs from other municipalities, local associations of citizens or companies	C-86
INP5	A tacit source of high value are other climate action managers, especially those within the same federal state	Exchange happens regularly during workshops at the federal level initiated by the regional energy agency.	C-64
INP6	Higher institutional levels sometimes fail to provide useable information and stick to providing knowledge in an explicit form.	"The national platform provides a lot of material, e.g., about e-mobility. However, it is so voluminous and text-intensive that you usually do not achieve to read it. You sometimes have the feeling that they are paid for the number of words they use." "[These sources are] good, in principle, however, often too far away and abstract, they sound nice. However how do they imagine the implementation?"	C-36
INP7	Most effective and important mode of communication takes place on a personal level	"The success strategy for data acquisition are open questions and getting to know each other on a personal level." „The interpersonal relationships are the most important thing for the collaboration with stakeholders. "	C-100
External sources			
INP8	Information flows form external are not automatically reaching CAMs, however, once effort is invested, exchange with external stakeholders works	"If information is missing, for example, concerning energy consumption behavior of households, I contact the head of the local energy supply company. During the conversation, the missing information is developed and contact persons are identified."	C-100
INP9	Acquisition of external data strongly depends on the willingness of stakeholders to share information	„What does industry do? They won't tell me about their plans. You simply try to contact the stakeholders and try to find out what they are planning."	C-43
INP10	Consciousness about experiential knowledge to retrospectively evaluate communication processes and recognize the potential volatility of external communication channels and the need to establish long-term cooperation and information processes.	"Setting up clear rules for acquisition and sharing of information, which means to whom do you communicate what in which manner, this is finally one of the central issues." "Knowledge lives on sharing, faces, people. […] For many years, we have three annual working meetings in our regional network, this is quite a good network."	C-29
Internal sources			
INP11	Internal exchange strongly depends on personal contacts and sympathy	From a positive perspective one interviewee stated: "If I would use the usual rigid administrative channels, I would not achieve to acquire information in time".	C-50
INP12a	Smooth internal information exchange	"Internal information exchange works well through a continuous dialogue."	C-43
INP12b	Minor constraints in terms of missing automated integration of CAMs in information flows of other departments	„There are many departments, e.g. building construction, that perform climate action activities on their own without consulting or coordinating with us."	C-29
INP12c	Limited or blocked information flows towards climate action managers	"What I find so worrying, is that the structure is so hierarchical, the groups are side by side, but they actually avoid working together." "Especially the process of information exchange could be improved. In the end, you usually get the required information, but the process is very lengthy and time consuming."	C-29

Table D.6
Results regarding knowledge conversion

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
CNV1	The search for synergy potential in standard and innovative projects is limited to individual sectors or methods and the boundaries of individual municipalities.	„When starting a campaign in one district, we consider if we could transfer it to another, however, we are limited to our municipality and pool of knowledge. If we found a lever in such project, we try to transfer it. However, transfer is still in the back of the head and we do not directly aim to achieve it."	C-86
CNV2	Synergies are usually not planned for a priori and rather emerge in the course of implementation.	Two positive examples of synergies: "We contracted a consulting company to develop a blueprint for emission accounting that we can easily carry on […] without being dependent on assigning follow-up orders". "For our public relations concept […] we demanded an agency to create an overall concept that includes general methods that we can use to address the public in general, but also specific target groups."	C-64
CNV3	Creative solutions involve, e.g., cross-combinations of or collaboration between: • disciplines • departments • sectors • technologies • forms of communication • time horizons • (re-)drawing boundaries of areas • (re-)interpretation of benefits and impediments • flexible (re-)weighing of agenda	Findings on the left side may be derived from projects, that are deemed creative by the CAMs: • IT and open data for visualizing an interactive energy map, • intelligent heat recovery by solely using waste heat of servers for building heating • educative climate bicycle route on the basis of regional cooperation • collaboration with the traditional drilling industry for climate use of ground heat in district heat networks • Integrating climate protection aspects subordinately into a food festival • making house building companies understand to use the perspective of climate action as future marketing added value instead of an impediment	M
CNV4	Creative solutions require, e.g.: • empathy • networks • common language • multilogues • intrinsic motors • open-ended learning	"Empathize with the issue" on the basis of sound knowledge; adopt "networked procedures" with the stakeholders in "structured processes"; find a common "language" to enter open "controversial discussions", that are less dialogues but multilogues, that require a continuous "motor" to keep them alive against "sceptics" and "uncertainty" when breaking new ground and against the aversion to group learning processes with potential "dead ends".	M

Table D.7
Results regarding storage of knowledge in general and storage of experiential knowledge

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
STR1	Storage of knowledge is a bottleneck. Apart from time constraints, a reason for this is the missing encoding of climate action knowledge.	"This might be my weak spot and again depends on the available resources, because systematization and storage of knowledge requires effort. I admit that I do not store all operational knowledge, so that it would be accessible to anyone. Of course, I store a lot at our central storage; but, other than that is difficult to achieve and hold on to in practice." "When a colleague is on vacation, you realize that digital storing and filing is done in totally different ways. That is to say, we are still missing the big key for this issue."	C-79
STR2a	Operational knowledge, especially relational and descriptive knowledge about stakeholders, remains embodied knowledge	Storage of knowledge in individual minds, e.g., about "people", "networks", "lines of argumentation", "working procedures", "knowledge landscape." Statement highlighting the tacit nature of operational knowledge: "If you imagine a handover of the position, this would be very difficult if you would not talk a lot to each other and work together for a certain time."	F-68
STR2b		Storage in form of "interim reports", "activity reports", "guidelines", "flyers", "protocols", etc.	F-36
STR3	Practical lessons learnt remain embodied knowledge and are not documented or discussed internally to get the chance of becoming collective knowledge (in part, they are exchanged between CAMs on workshops at the federal level — see Table, INP5)	„I have not experienced documenting lessons learnt in the administration, at most, issues for me personally."	C-86
STR4	Impacts documented unsystematically; mainly qualitative or quantitative descriptive indicators; no approaches to build sound causal knowledge	CAMs collect descriptive numbers about traditional material measures such as installed renewable power plant capacity, or saved energy after modernization of heating in public buildings. "We do document, e.g., campaigns in terms of the number of consultations performed, however, I cannot really make statements on impacts. I am missing the tools for this purpose." "Concerning impacts, I often have to rely on my gut feeling." Some interviewees stated, that in some cases, shallow evaluations have been performed, especially concerning the triggered investments by incentive programs. Three municipalities try to tackle the task of documenting impacts on a municipal level by participation in the European Energy Award.	M
STR5	No use of inferential statistical models.	Only one municipality has used a chi-square test in one single project as secondary information.	C-100

(*continued on next page*)

Table D.7 (*continued*)

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
STR6	Current forms of best practice databases are mostly used for a first inspiration only and their usefulness was seen critical	"Best Practice examples described in brochures may, at most, serve for inspiration only." "Best Practice examples do not play an important role at the moment. In some cases, there are good examples in specialist journals, however, for there is not suitable database that could support my work."	C-71
STR7	Transferability of best practice examples is often not given since they are often based on special financing or local conditions	"Best Practices are rarely transferable; this is almost demotivating."	C-50
STR8	Many project examples, e.g., examples provided by other municipalities on their website, are labelled as best practice that, however, are state-of-the-art.	"There are too many best practice examples and too few good ones."	C-36
STR9	In some cities, best practice examples may still serve as external reference points to show the potential for success of specific approaches.	"Best practice examples can serve to initiate communication and dialogue".	C-43
STR10	The most important part of best practice examples are the contact persons to find out what the project really was about.		C-57
STR11	Instead of best practice, a general practice database would be more helpful, which would be based on commented bundled descriptive, relational, causal and procedural knowledge.	Combining statements from several interviewees, such database would cover: • "annotations of the implementing persons" • "areas of special attention in single steps of implementation" • "how have cooperation partners been won and how was the issue brought to the decision phase" • "which mistakes have been made" • "what went wrong, what went well and how was the project received" • an efficient "filter function" on the basis of o a sufficient set of variables for covering the "grading about the implementation status of climate action" o quantitative structural data about the municipality to find out "who does something comparable"	M

Table D.8
Results regarding knowledge output

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
OUT1	Knowledge about success factors or constraints of local climate action rather stays local and does not easily reach higher institutional levels.	The complex knowledge about operational climate action is mainly disseminated on a personal basis, e.g., during network meetings. There is, e.g., a punctual half-yearly exchange between CAMs at the federal state level via meetings organized by the regional climate action agency that the interviewed CAMs usually attend. "We operate out of the community into the community". Dissemination of knowledge to organizational units associated with the national level is rare. Considering all statements on knowledge output, there is a gradient from local to national level regarding the reception of knowledge outputs.	
	Tacit to the local level	*Please note: numbers for output to other levels are not shown to focus on or point out the differences between output to local and national level.*	F-45
	Tacit to the national level		F-13
	Explicit to the local level		F-73
	Explicit to the national level		F-13
OUT2	The major strategy for successful dissemination was "issue re-labelling" (Heinelt and Lamping, 2015), i.e., highlighting advantages generated by climate action in various fields beyond climate protection.	Advantages named to bridge to other perspectives are, for example: • Health concerning food, e.g. CO2 and nutrient balance of a burger, • Health concerning air pollution by fossil fueled vehicles • Health by more body movement during cycling • Saving money by saving energy, with relatively short amortization times esp. for public property buildings • Possibilities of networking for local companies when attending an energy roundtable • Using climate friendliness of buildings and as a future selling argument for real estate companies • Using the winning of energy efficiency prizes by individual companies as an image gain in their field of business • Using car sharing or riding bicycles as a mobility mode of low area intensity • Using efficient forms of logistics as a cost saving argument for producers while producing higher comfort for citizens • Local value chain • saving of material resources is also climate action that reduces costs • climate action as a chance and motor for urban town planning • outsourcing of own vehicle fleet to mobility provider reduces internal workload	C-71
OUT3	The second most important strategy was to be neutral and objective in discussions when bringing forward arguments.	"I try to moderate without getting personally involved and try to apply a neutral approach with open ended questions".	C-50
OUT4		"Once we take an offering, once an intimidating role depending on the specific stakeholder type we are talking to."	C-50

Table D.8 (*continued*)

ID	Code	Exemplary statements (or content summary of several statements)	Frequency
	Although neutral, arguments need to be based on sound descriptive and relational knowledge about target groups to be able to find the right words and tone in conversations.	In summary, several statements showed the importance of entering conversations with the right topics, e.g. current topics of daily life such as food, or considering the personal sympathy explicitly when talking to stakeholders.	
OUT5	Networking and finding allies is an important strategy to use advantages such as: • possibility to rely on colleagues that have generally been won for climate action with time in small steps • internal win-win situations based on mutual (immaterial) favours • neutral external argumentative reference points	"Favour for a favour in the sense of mutually putting a good word to specific stakeholders or decisions makers to support each others projects." (it was emphasized that this was not meant in a material sense for clear dissociation from corruption or bribery) "Slowly convincing colleagues to eat more vegetables than meat at lunchbreak so that, if this is successful, one may count on them to a certain extent." "You first have to share, before you can square" (own translation of the proverb like statement: "Du musst erst teilen können, bevor du multiplizieren kannst.")	C-43
OUT6	Thorough preparation of decision situations by preliminary sharing of information to build some kind of justified descriptive or factual knowledge. leads to successful rational decision-making.	"Before the council gathers for decision-making we usually initiate a preliminary information meeting with politicians and administrative staff to inform about our projects or plans." (It should be noted that not all municipalities have administrative rules that allow the direct exchange between politicians and administration.)	C-36
OUT7	Once decisions were made in favour of climate action, public perception of the administrative climate action unit needs to be pushed to a positive direction towards a service unit with an offering role	"We are perceived as an authority. The question is how we can reach the citizens, e.g., by a climate action centre, that is publicly not perceived as authority but as neutral contact unit or partner with opening hours apart from typical administrative opening hours […]. Of course, this is a question of available staff, but we try to develop towards a service unit."	C-21

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