



Drivers and barriers to municipal climate change adaptation: a comparative analysis of selected measures and different implementation stages

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Abstract

Municipalities play a crucial role in climate change adaptation and can be sites for a diverse range of structural and non-structural adaptation measures that exhibit varying planning and implementation conditions. However, comparative insights into the drivers and barriers influencing various kinds of adaptation measures across different stages of implementation remain limited. This study addresses this gap by combining a survey of municipal administrations in Germany ($n = 101$ from 59 cities) with qualitative methods in three cities, focusing on both general climate change adaptation measures and five specific measures: (1) urban climatic maps, (2) pluvial flood hazard maps, (3) checklists for integrating climate change adaptation into urban land-use planning, (4) municipal bans on gravel gardens, and (5) façade greening of public buildings. Our analysis identifies key factors such as (scarce) resources and (lack of) administrative support that facilitate or impede the implementation of measures in general. While these factors are also reported to be crucial for the five specific measures, the degree of relevance of these and other factors varies across the specific measures and the cities that have already or have not yet planned or implemented them. For regular use or maintenance after implementation, scarce resources remain a key limiting factor, while legal issues become more critical. The article concludes that the drivers and barriers for specific actions and stages of the implementation process vary, and that a more profound understanding of the influencing factors can be used to support local action more effectively.

Keywords Adaptation measures · Influencing factors · Urban planning · Post-implementation evaluation · Germany

Introduction

Cities and their inhabitants and assets face increasing exposure to hazards projected to intensify with climate change in the coming decades. Therefore, local authorities are critical in implementing adaptation policies (IPCC 2022). Municipalities can integrate these measures into traditional policy areas, such as urban land use and landscape development (Dodman et al. 2022). They can take various actions within their field of expertise, including non-structural adaptation measures such

as developing strategies (e.g., Reckien et al. 2018), compiling knowledge for urban development and planning, for example, in urban climatic maps (e.g., Ren et al. 2011), enforcing regulatory measures in urban land-use planning, such as prohibiting gravel gardens (e.g., Ferber 2021), and offering financial incentives (e.g., Wamsler 2016). Additionally, structural measures can be taken in public areas to enhance urban resilience. These may include planting trees (e.g., Demuzere et al. 2014), greening the façades of public buildings (e.g., Alexandri & Jones 2008; Knifka et al. 2023), creating natural retention areas (e.g., Kõiv-Vainik et al. 2022), or increasing the albedo of buildings and streets (e.g., Synnefa et al. 2012). Even though many cities, particularly larger ones, are already implementing (more or less isolated) policies, the measures taken at the local level are generally insufficient to protect and prepare urban populations and assets for current and future hazards. There is a gap between what needs to be done, what local authorities (and other stakeholders) intend to do, and what they implement (IPCC 2022).

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These deficits form the basis for a research strand identifying the barriers preventing local authorities from taking action on climate change adaptation and seeking ways to overcome these obstacles. Various analyses of barriers and drivers offer valuable insights into the factors that facilitate or hinder local climate change adaptation, including, for example, the availability of financial and human resources, the use of synergies between different policies, or the existence of exchange and cooperation (Biesbroek et al. 2013, 2014; Burch 2010; Eisenack et al. 2014; IPCC 2022; Rogers et al. 2023; Simonet & Leseur 2019). Typical lists of influencing factors, however, generalize across different policy domains, measure types, locations, and stages of implementation. To gain a more nuanced understanding, several analyses explore the similarities and differences in influencing factors between case studies (e.g., Lehmann et al. 2015; Lonsdale et al. 2017) or, less frequently, between policy stages (Moser & Ekstrom 2010) and policy domains (Patterson 2021). Further studies focus on single measures (e.g., Knifka et al. 2023). However, there is little comparative knowledge on the factors that help or hinder specific types of measures, despite the vast diversity of climate change adaptation measures with very different planning and implementation conditions (but see EEA 2024) for the limitations of various types of measures; Table 1).

In this article, we aim to provide detailed findings on the key factors that facilitate or hinder the implementation of climate change adaptation, both in general and for five specific urban measures, i.e., urban climatic maps, flood hazard maps, checklists for integrating climate change adaptation into urban land-use planning, municipal bans on gravel gardens, and façade greening of public buildings. We also compare the perceived barriers for cities that have not yet adopted these five specific measures with those municipalities that have already adopted or are preparing to adopt them to examine the experiences of local authorities after the implementation of specific measures.

To this end, we draw on empirical evidence from interdisciplinary and partly transdisciplinary environmental social science research in Germany. Environmental social science research “focuses on humans, our social systems, and the natural environment surrounding us” with a multi-, inter-, and/or transdisciplinary character (Theis & Light 2024 p. 2). In our research presented in this article, we combine primary quantitative data from various cities with primary qualitative and secondary data from three mid-sized municipalities on influencing factors on climate change adaptation.

Background

Municipal climate change adaptation policies

Adaptation actions can generally be categorized into structural and non-structural measures (Schanze et al. 2008). Structural measures involve technical constructions or nature-based approaches to address the risks associated with extreme weather events and climate change. Non-structural measures focus on reducing risks through institutional, regulatory, awareness-raising, or financial approaches (a similar categorization can be found in EEA (2024) and Leitner et al. (2021)). Table 1 provides an overview of these types of climate change adaptation measures, their prevalence based on an open database, their limitations according to the EEA (2024), and some common examples at the municipal level.

Local approaches to adapting to a changing climate are diverse, as both the impacts of climate change and the characteristics of local contexts, such as governance structures, socio-economic conditions, and environmental vulnerabilities, vary (IPCC 2022; Sharifi 2021). For Germany, in addition to a gradual rise in temperature, more intense heat, drought, and heavy precipitation events are projected as changes that need urgent attention (Kahlenborn et al. 2021). Adaptation to climate change as a stand-alone policy area was first addressed in the mid-1990s, for example, in nationally funded local projects. Since then, municipal adaptation to climate change has remained a non-mandatory task (Kern 2023).¹ A recent representative study of 1062 responding municipalities in Germany found that 41% of municipalities were already implementing adaptation measures, and a further 39% reported plans to take action (Friedrich et al. 2024). Against this background, we analyze the factors that municipal administration officials perceive as facilitating or hindering climate change adaptation measures.

Drivers and barriers

A review on climate change adaptation identified 43 drivers in 112 articles, while 19 papers did not mention any facilitators (Rogers et al. 2023). Particularly in countries without an obligation to implement adaptation measures, such as Germany, other factors need to motivate local authorities to take action in this policy area. Typical drivers for implementing adaptation measures in the literature include personal and institutional commitment, synergies between different policies, broad knowledge and good communication, multi-level political and legal support and coordination, internal

¹ However, the first Federal Climate Adaptation Act from 2024 requires the federal states to enable municipalities to prepare local climate analyses and climate adaptation plans (KAng, 2023).

Table 1 Overview and examples of types of municipal adaptation measures

	Categories ^a	% ^b	Barriers according to EEA (2024)	Examples
Structural	Nature-based, ecosystem-based (“green” and “blue”)	26.6	p. 98 • Missing “evidence of effectiveness” • Costs, particularly for maintenance • Limited technical capacity • “Climate impacts” on greenery • “Health concerns” (e.g., allergens) • “Competition for space” • Unintended consequences (e.g., gentrification)	• Maintaining and creating green spaces • Tree planting • Roof/façade greening • Natural retention basins
	“Grey”	19.0	p. 78 • “High cost of implementation” • Maladaptation; trade-off with mitigation • “Limited ability to deliver co-benefits” • “Lack of flexibility”	• Retention cisterns • Increasing the albedo of buildings and streets • Passive heating and cooling of buildings
	Technological	16.5	p. 84 • Costs and related questions of justice • “New governance-related requirements” for use	• Smart cooling/watering • Measurement, modeling, and mapping • Early warning systems
Non-structural	Coordinating, strategic, and planning	20.3	p. 59: Lack of... • “Resources and capacities” • “Political commitment and support” • “Expertise or interdisciplinary knowledge” • “Institutional capacity”	• Climate adaptation plans • Urban climatic maps^c • Pluvial flood hazard maps^c • Checklist for integrating adaptation into planning
	Regulative		p. 59 • “Resistance [...] by relevant stakeholders and residents”	• Prohibitions in planning • Preservation of green areas
	Awareness-raising, capacity building	14.3	p. 109–110 • Missing evidence of impact • “Must be tailored to [...] participants” • Challenges in reaching target group • Costs “to develop and maintain” services • Effectiveness might depend on other measures	• Risk communication campaigns • Education of nursing staff regarding heat
	Financial	3.4	p. 68 • Lack of financial resources • Lack of “knowledge, technical capacity, and staffing” • Bureaucracy; “specific requirements” • “Legal restrictions” at various levels • Hesitancy in working with the private sector	• Incentives such as municipal funding for the greening of private buildings • Stormwater or rainwater fee

^aThe categories are based on the key type measures for adaptation to climate change (EEA2024; Leitner et al. 2021) with a few changes.^bShare of adaptation actions reported to CDP (Carbon Disclosure Project, 2022) by European cities, analyzed and published by EEA (2024)^cWhile the mapping and modeling of hazards belong to the technological measures, we categorize the production of urban climatic maps and pluvial flood hazard maps in the measure type “coordinating, strategic, and planning,” as these maps go beyond the geospatial representation of risks and often involve recommendations and provide the strategic groundwork for urban land-use planning.

and external exchange and cooperation, access to sufficient resources, and stakeholder participation (Biesbroek et al. 2011; Desthieux & Joerin 2022; IPCC 2022; Lehmann et al. 2015; Lonsdale et al. 2017; Rogers et al. 2023; Simonet & Leseur 2019; van der Heijden 2019). Two recent surveys from Germany focused on motivations for local authorities to engage in climate change adaptation. They found that the most frequently reported motivating factors include being affected by climate change impacts, aiming at improvements in citizens' quality of life and health, and the desire to set a good example (Friedrich et al. 2024; Schoenefeld et al. 2023).

Biesbroek et al. (2013) identified more than 200 barriers in 81 articles, and Rogers et al. (2023) detected 65. In short, these reviews and further literature often identify insufficient political support, competing interests and priorities, limited human and financial resources, lack of knowledge and skills, difficulties in translating knowledge into action, and legal issues, among other barriers (Aylett 2015; Biesbroek et al. 2011; Dodman et al. 2022; Fila et al. 2023; IPCC 2022; Measham et al. 2011). Two surveys in Germany identified a lack of human resources as the most critical barrier to planning and implementation, mentioned by about 80% of municipalities (Friedrich et al. 2024; Schoenefeld et al. 2023), followed by a lack of financial resources (73% by Friedrich et al. (2024); 66% by Schoenefeld et al. (2023)). These high figures seem reasonable, as municipalities tend to allocate human and financial resources to mandatory tasks first. In a survey of municipalities across Germany, more than a quarter of all respondents selected the following barriers alongside a lack of resources: lack of qualified personnel, lack of a sense of urgency, lack of acceptance in the administration, lack of cooperation, unclear responsibilities, uncertainties regarding planning law, and limited perceived pressure to act (Friedrich et al. 2024). In municipalities in the German state of Hesse, at least one-fifth of all respondents cited

conflicting views and interests, local political problems, unclear responsibilities, and uncertainties about climate impacts as further obstacles (Schoenefeld et al. 2023). With a focus on façade greening, Knifka et al. (2023) identify lacking acceptance and ambitions in politics and administration, lacking resources or willingness to use them, and practical or technical challenges as main barriers based on a literature review and case study in a German city.

These findings offer valuable insights into the factors that support or hinder municipalities in adapting to climate change, which can lead to improvements in this area. However, these findings often do not distinguish between different types of measures or the experiences of municipalities at various stages of implementation. A report by the EEA (2024) identifies limitations affecting key types of measures. A comparison of these constraints reveals that the costs and a lack of resources pose significant challenges for all types of measures (although they seem to be less critical for regulatory measures). Additionally, a lack of technical capacity is mentioned for various kinds of measures. Alongside these two factors, there is a wide variety of constraints, as shown in Table 1. Given the diversity of climate change adaptation policies, this article elaborates on common and divergent influencing factors related to five selected measures.

Data and methods

This study utilizes a multi-method approach (see Fig. 1). We combine a survey covering a wide range of cities with desk research, qualitative expert interviews, and information gathering during meetings with council employees and other stakeholders to evaluate the drivers of and barriers to adaptation measures.

In this study, we explore a selection of five measures (see Fig. 1; Table 2):

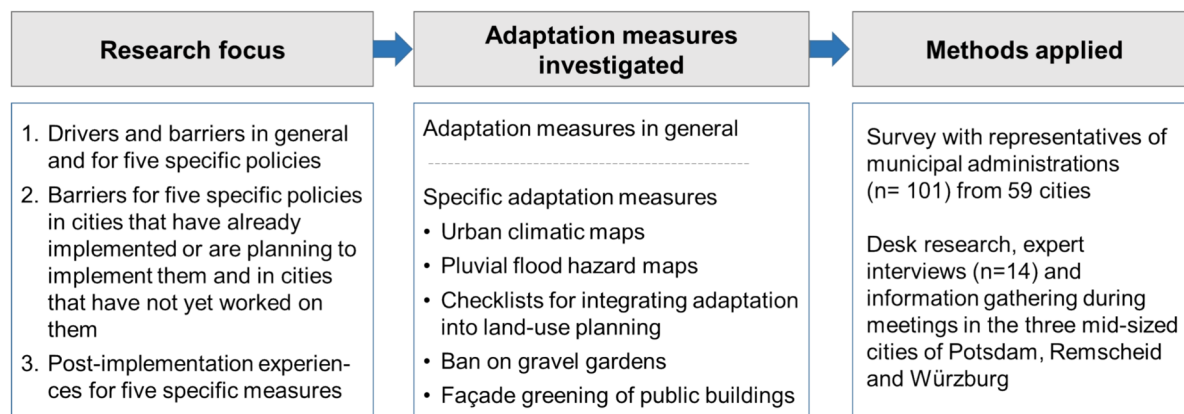


Fig. 1 Overview of the research design of this study

Table 2 Overview of selected measures and their state of implementation in German municipalities based on a survey from 2023

Five selected measures	Share of German municipalities according to Friedrich et al. (2024)	
	...that has already implemented the measure	...that plan to implement the measure
Urban climatic maps	No data	No data
Pluvial flood hazard maps	38%	26%
Checklists for integrating climate adaptation into urban land-use planning	21%	No data
Reduction of gravel gardens (using awareness-raising or regulatory methods)	26%	29%
Green roofs and/or façades, e.g., on public buildings	18%	31%

- 1) Urban climatic maps, which show, among other things, the modeling results of the heat load in a city or its parts and often include recommendations for further urban development.
- 2) Pluvial flood hazard maps (also known as rainfall-based flooding maps or stormwater flood hazard maps), which spatially represent the flood hazards in a city or its parts.
- 3) Checklists for administrations to integrate climate adaptation (and often also mitigation) into urban land-use planning through a systematic review of development projects.
- 4) Bans on gravel gardens on private land in development plans for new construction projects to develop green and open spaces in private gardens.
- 5) Greening the façades of public buildings.

We limited our analysis to these five measures to ensure a reasonable response rate and avoid overburdening respondents with questions. We specifically chose these five measures for three reasons. First, we aimed to cover different types of adaptation measures and compare various policies within one policy type, focusing on urban development and land-use planning measures. Second, we selected measures already common in German municipalities (see Table 2) and the three cities where we conducted the expert interviews (see Table 4), enabling us to identify similarities and differences in the factors influencing their implementation. Third, in this interdisciplinary environmental social science research, we focused on measures related to our expertise in urban, landscape, and land-use planning, geography, and environmental science.

Surveying various cities

The survey targeted employees in the city administrations of 104 German cities. This included all cities with more than 100,000 inhabitants and those with 50,000 to 100,000 inhabitants not belonging to a county. A total of 611 individuals

working on climate issues, urban planning, urban land-use, or landscape planning² in these cities were identified through internet searches on municipal websites. They were contacted via e-mail and invited to participate in the online survey from the 7th of September, 2021, until the 5th of October, with a reminder e-mail sent in between.

The questionnaire included questions on general adaptation measures, the five specific measures (see Fig. 1), and various adaptation-related topics. The structure, the wording of the questions and answer options, and the filtering were consistent for all measures (see Table 3 and SI1a/b for the wording in German). Questions assessing the post-implementation phase were only asked for the five selected measures. Additionally, the survey asked for voluntary information about the respondents' field of work and the city itself, such as federal state, city size, and city name.

A total of 101 completed questionnaires were received from 59 cities, representing a response rate of 56.7% for cities. For 21 cities, more than one person completed a questionnaire. Five questionnaires lacked information on the city name. With multiple responses possible, most respondents reported working mainly on climate adaptation (61%), climate mitigation (44%), urban planning (37%), and urban land-use planning (36%). The survey responses were analyzed for each person and not for each city, as this suited the research questions on the drivers and barriers experienced by the participants. Statistical analyses were carried out using Microsoft Excel and IBM SPSS 28. The open-ended responses were categorized manually according to their content.

² In our context, urban planning (*Stadtplanung*) concerns itself with the strategic design and organization of cities to meet the needs of residents, such as housing, transportation, and public infrastructure. Land-use planning (*Bauleitplanung*), a subset of urban planning, provides the legal framework for specific land uses, regulating developments through instruments like zoning and building plans. Landscape planning (*Landschaftsplanung*) focuses on conserving and enhancing natural ecosystems and biodiversity within a spatial context.

Table 3 Overview of the relevant questions in the questionnaire (■ for measures in general; □ for the five selected measures; see SI1a/b for the German original)

Initial Question		
	■ Have measures to adapt to climate change already been implemented in your city, or are they being planned?	
	□ Does your city already have a [specific measure]?	
	No follow-up question if the answer was: “Do not know”	
	No follow-up question if the answer was “No, the responsibility for this lies with the federal state” in the case of the ‘municipal bans on gravel gardens’	
Follow-up questions on drivers and barriers for general and specific measures		
Drivers	Answer to initial question: “Yes” or “In progress or planned”	Answer to initial question: “No”
	What factors have occurred or are occurring that have significantly favored the planning or implementation of the...	No additional questions regarding drivers.
	■ measures you have implemented or planned?	
	□ [specific measure]?	
	Please list up to five critical factors. [List of 17 answer options + “None”, “Other, namely:...”, “Do not know” (see Fig. 1)]	
Barriers	Answer to initial question: “Yes” or “In progress or planned”	Answer to initial question: “No”
	What major obstacles have arisen or are arising...	What are, or have been, the main obstacles preventing...
	■ in the planning or implementation of measures?	■ the planning and implementation of climate adaptation measures to date?
	□ in the planning or implementation of [specific measure]?	□ the creation or implementation of [specific measure] to date?
	Please list up to five critical factors. [List of 15 answer options + “Other, namely...”, “None”, “Do not know”]	Please list up to five critical factors. [List of 15 answer options + “Other, namely...”, “None”, “Do not know”]
Follow-up questions on the assessment of success for specific measures		
Assessment of success	Answer to initial question on specific measures: “Yes”	Answer to initial question on specific measures: “No” or “In progress or planned”
	□ How successful do you think [specific measure] is for climate adaptation in your city?	No additional questions regarding the assessment of success.
	[1 not at all successful – 5 very successful; + “Do not know”]	
	□ Please give brief reasons for your assessment: [open question]	
	□ In your opinion, what changes would be necessary so that [specific measure] can be (even) better utilized? [open question]	

Qualitative methods applied in three cities

We complemented the quantitative survey results with insights from Potsdam, Remscheid, and Würzburg. All three cities are located in different federal states and are expected to be affected by a warmer climate (Kahlenborn et al. 2021). Potsdam and Würzburg are expected to experience a drier (continental) climate, while Remscheid has a low mountain climate with more rainfall. The cities have already implemented various adaptation measures, including some of those discussed in more detail in this article (see Table 4).

To gain background information, we analyzed available documents on climate change adaptation and the specific measures for all three cities (see Table 4). In addition, we interviewed representatives from the administrative units of landscape planning, urban planning, and land-use planning in the three cities in 2020, focusing on climate change adaptation measures in urban planning instruments, precisely non-structural measures. In addition, we conducted

four semi-structured interviews with stakeholders on implementing façade greening projects in the cities of Remscheid and Würzburg in 2020. The interviews focused on the planning, construction, and maintenance phases of façade greening and included the municipal climate department and the department responsible for the respective public building. In 2023, we conducted follow-up interviews with local stakeholders in one of the two cities, focusing on the maintenance status and progress towards the original targets. In the second city, no one was available for a new interview in 2023. We analyzed the transcribed interviews using deductive content analysis to identify drivers and barriers to adaptation.

Furthermore, we gathered information during meetings with city administration employees and further stakeholders of all three cities about their general climate change adaptation policies and the selected measures, where available. In Potsdam, we participated in workshops and discussions on developing their urban climatic maps and

Table 4 Overview of the three cities and the applied methods

	Potsdam	Renscheid	Würzburg
General information			
Inhabitants (as of 31-12-22)	185,750	112,613	127,810
Federal state	Brandenburg	North Rhine-Westphalia	Bavaria
Existence of specific adaptation measures			
Urban climatic maps	Published in 2022	Published in 2018	Published in 2016 (updated 2018)
Pluvial flood hazard map	Published in 2022	Published in 2017	Published in 2025
Checklist for integrating climate adaptation into land-use planning	Non-existent	Developed in 2017	Non-existent
Implementation of a ban on gravel gardens (on the municipal level)	Non-existent	First case of the ban through a development plan in 2020	Non-existent
Facade greening of public buildings	Unknown	Established in 2020	Established in 2020
Methods applied			
Desk research	Analysis of policy documents such as climate change adaptation (or mitigation) plans, landscape plans, and documents related to the five specific measures, if available, for background information		
Interviews on climate adaptation measures in urban planning instruments	Three interviews in each city with representatives of landscape planning, urban planning, and land-use planning in 2020		
Interviews on facade greening of public buildings	/	Two interviews: municipal climate department and local actors involved in greening building façades in 2020	Three interviews: municipal climate department and local actors in greening building façades in 2020 and 2023
Gathering information during meetings with city administration employees between 2018 and 2024	...on climate change adaptation in the municipality in general, as well as the usage, opportunities and obstacles of checklists for integrating climate adaptation into land-use planning and a ban on gravel gardens and ...on the development of the urban climatic maps and pluvial rain hazard maps	...on the development of the facade greening of a specific public building	...on the development of the facade greening of a specific public building

pluvial flood hazard maps and provided scientific input to these maps through mobile temperature measurements. In Remscheid and Würzburg, we participated in meetings on greening a public façade and contributed to its evaluation by conducting interviews and microclimatic measurements.

Findings

Overall, almost all survey respondents reported that adaptation measures had either already been implemented (67 out of 101 respondents) or were currently planned or underway (30 respondents) in their city (see Fig. 2).

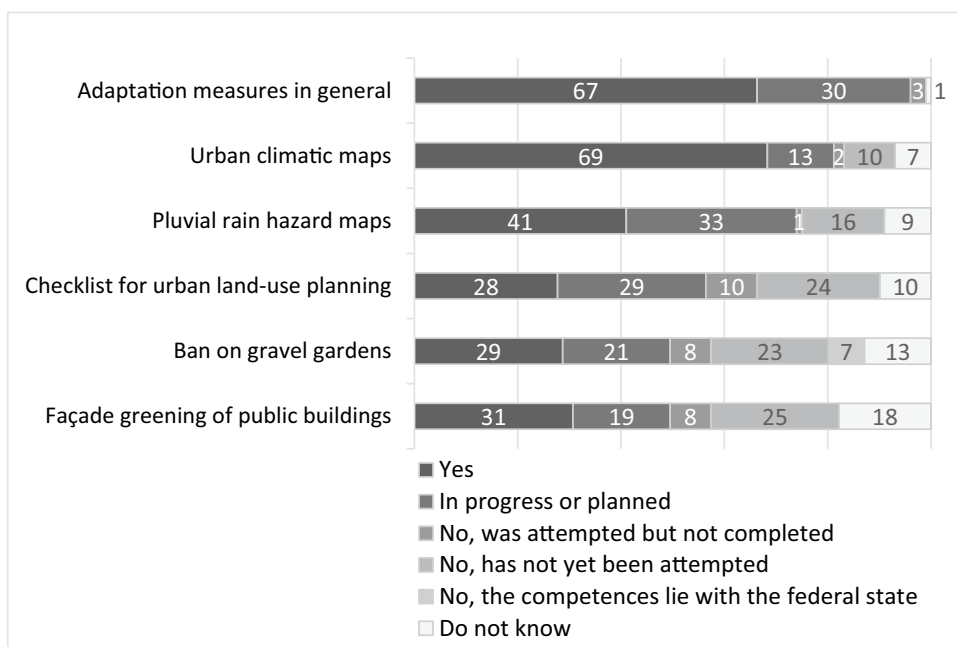
The survey found that 69 out of 101 respondents reported that their city had an urban climatic map, a slightly higher number than those reporting on adaptation measures in general. Pluvial flood hazard maps were less commonly reported, with 41 respondents mentioning these. Around 30 respondents each stated that their cities had obtained checklists for integrating adaptation into land-use planning, issued regulations banning gravel gardens, and implemented façade greening of public buildings (Fig. 2). Interestingly, for all five selected measures, there were cases where respondents asserted that the specific measure had been implemented in their city, but at the same time said that adaptation measures, in general, were only underway or being planned. This may indicate that these people had different types of measures in mind when answering the question on general adaptation measures.

Comparison of drivers for different climate change adaptation measures

Support from local policies and administrations was the most important driver for general adaptation policies and for four of the five selected measures (see Fig. 3). With regard to general adaptation measures, 52% of respondents chose political support and 48% administrative support as facilitating factors. Support from the local administration received comparatively high numbers (45–51%) among the five selected measures and was perceived as particularly important for façade greening. Support from local politicians was mentioned across a slightly wider range (42–61%). This factor was considered particularly important for implementing regulations banning gravel gardens. The need for support from local administrations and politicians was also confirmed in the interviews about façade greening and banning gravel gardens. Furthermore, the interviews highlighted that the commitment and experience of a key person in the local administration were crucial to initiating these measures.

External funding, elected as the second-most crucial driver for general adaptation measures (49%; see Fig. 3), seems to be of less and varying importance for the five selected measures. This factor was mentioned by 31 to 35% of respondents for the maps and façade greening of public buildings. At the same time, it was not considered an essential facilitator for obtaining checklists for integrating adaptations into urban land use and for regulatory bans on gravel gardens. Financial or human resources were not considered necessary for the latter measure either. In contrast, for all other selected measures (and measures in general),

Fig. 2 Existence of adaptation measures in general and of the selected measures in the cities according to the respondents (the numbers are not equivalent to the number of cities, as there was more than one answer from a quarter of the 59 cities; absolute numbers; $n = 101$)



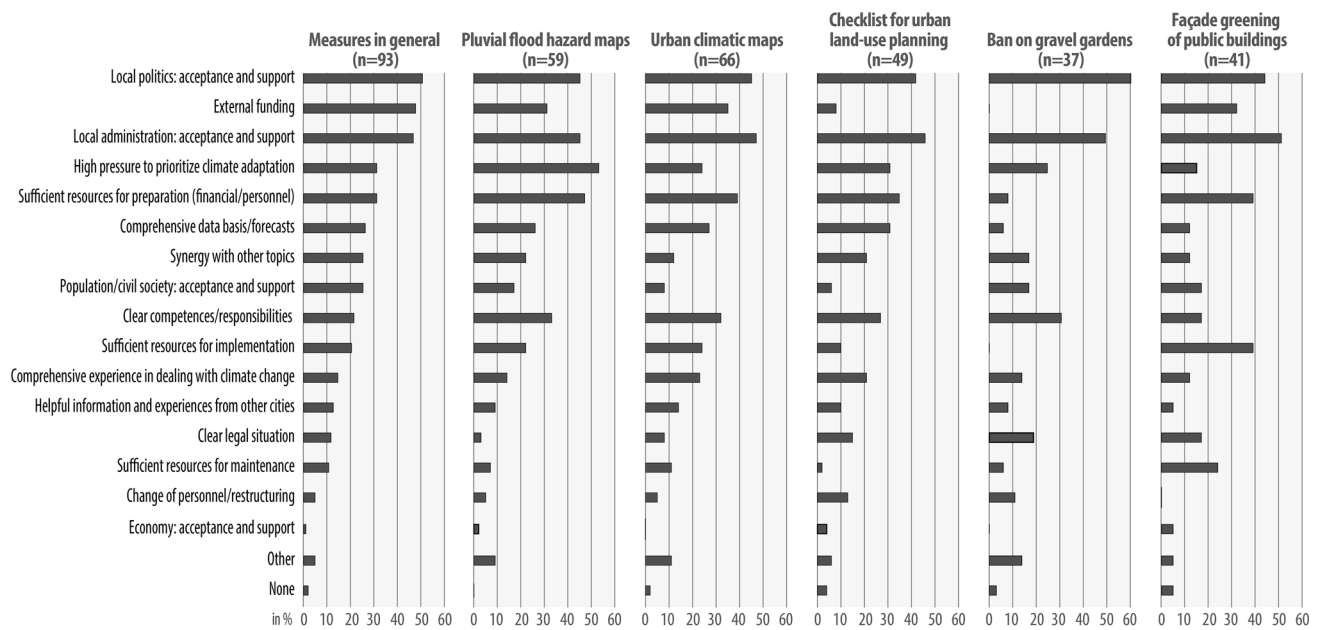


Fig. 3 Drivers of varying climate change adaptation measures

sufficient resources were considered an essential factor by 32% (general measures) to 47% (pluvial flood hazard maps) of respondents. Understandably, the importance of having sufficient resources to implement the measures was highest for the selected structural measure (39%), lower for the maps (22–24%) and measures in general (21%), and of little to no importance for the checklists and the ban on gravel gardens. Furthermore, for façade greening of public buildings, sufficient maintenance resources were more critical than for the other selected measures (24% compared to 11% for measures in general and urban climatic maps and less for the different measures).

In the survey results, a quarter of respondents (26%) mentioned public acceptance of measures as a driver for adaptation measures in general. However, for selected measures, the percentage of respondents indicating this factor was (much) lower (6–17%). Notably, the checklist for integrating adaptations into urban land-use planning and the urban climatic map were hardly influenced by this factor. While public acceptance of façade greening (17%) played a relatively minor role in the survey, its importance was highlighted in the interviews. For example, interview partners stated that façade greening should be promoted through best-practice examples and innovative projects, as this helps to bring theoretical concepts to life.

For pluvial flood hazard maps, the essential enabling factor (53%) was the high pressure to prioritize climate adaptation, for example, due to experienced impacts. This factor was less important for general adaptation measures

(32%) and all other specific measures, especially for façade greening (15%). In contrast, the interviews revealed that in one of the three cities, there was high pressure to act on gravel gardens as there was a development area where almost every house had a gravel garden.

Notably, clear responsibilities within the administration were considered most important for non-structural measures (27–33% of respondents; see Fig. 3), more critical than for general adaptation measures (21%). For façade greening, these played only a minor role (17%). A clear legal situation was most important for the regulatory measure (ban on gravel gardens, 19%) and the structural measure (17%).

More than a quarter of respondents (26–31%) emphasized the need for a comprehensive database to support general measures and the development of climate-related planning basics such as maps and checklists. Respondents considered comprehensive data less critical for the selected structural and regulatory measures (6–12%).

Around a quarter of respondents (26%) mentioned that synergies with other issues were important for enabling general measures. Synergies were deemed crucial for the checklist on integrating adaptations into urban planning (21%) and the pluvial flood hazard maps (22%), but to a lesser extent for the other three selected measures. Other contributing factors were mentioned less frequently.

The number of respondents who indicated that no factor supported the implementation of specific adaptation measures or measures in general was relatively low, ranging between 2 and 5% (Fig. 3).

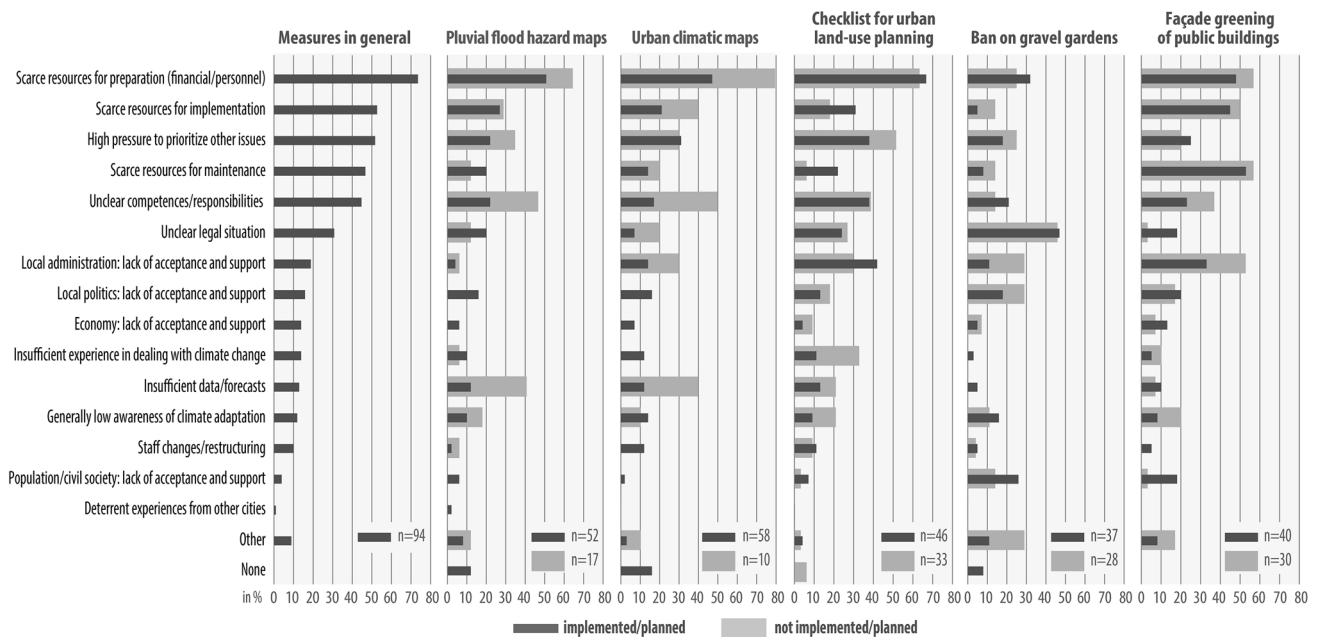


Fig. 4 Barriers to different climate change adaptation measures, considering the stage of implementation

Comparison of barriers to different climate change adaptation measures considering different stages of implementation

Barriers in cities already implementing or planning adaptation measures

None of the respondents reported encountering any barriers to general climate change adaptation measures that had already been implemented or were currently planned (see Fig. 4). For specific measures, 16% of respondents in the case of urban climatic maps and 12% or fewer for the other particular measures indicated that they experienced no barriers during the planning or implementation of the measures (see Fig. 4).³

According to the respondents, the main obstacle to the implementation or planning of adaptation measures in general was the lack of resources at different stages of the process: preparation (74%), implementation (53%), and maintenance (47%). Lack of financial or human resources in the preparation phase was also the most frequently reported obstacle for the three specific measures aimed at supporting climate-relevant planning (with, e.g., 67% of the respondents

identifying this barrier in the case of checklists and 47–51% in the case of both kinds of maps). Still, almost half of the respondents (48%) reported that this barrier was hindering façade greening. A third of respondents (32%) said they had faced this barrier when implementing the ban on gravel gardens.

Limited resources for implementation were also considered a significant barrier for specific measures, especially for structural measures (façade greening 45%) and, to a lesser extent, for checklists (31%) and pluvial flood hazard maps (27%). Façade greening faced the greatest challenges due to limited maintenance resources (53%), while non-structural measures were less affected (8–22%). Interviews and discussions with stakeholders in Würzburg and Remscheid highlighted the challenges related to the long-term maintenance of green façades for public buildings. Long-term maintenance was not funded with the establishment of the green façades and relied on the commitment of local stakeholders. Therefore, early discussions about efficient maintenance were considered necessary.

In addition to limited resources, the survey identified high pressure around other topics as a significant obstacle hindering general adaptation measures (52%). This factor was also perceived as posing a challenge to specific measures, albeit to a lesser extent, especially for checklists (38%) and urban climatic maps (31%). Furthermore, unclear responsibilities within the administration appear to have been an essential factor for adaptation measures in general, with 45% of respondents mentioning it (Fig. 4). This factor seems of medium relevance for most of the specific measures

³ While only 3% of respondents chose the “don’t know” option for adaptation measures in general, this percentage is much higher for specific measures, ranging from 16 to 26%. This suggests that not all respondents may have been involved in implementing or planning these specific measures. To compare percentages, the “don’t know” responses were removed from the samples in Fig. 4.

investigated, with the highest percentages for checklists integrating adaptation into planning (38%). Lack of acceptance and support from the local administration was a significant barrier, particularly for checklists integrating adaptation into planning (42%) and, to a lesser extent, for façade greening (33%). In the case of the other specific measures and general adaptation measures, this was more rarely mentioned as a barrier. Lack of support from local politicians was cited by 16% of respondents for general adaptation measures and comparably often for specific measures (13–20%).

Thirty-one percent of respondents identified an unclear legal situation as a barrier to implementing and planning general adaptation measures. This percentage was higher for the regulatory measure of banning gravel gardens, with 47% of respondents selecting this factor. It was also relevant for the checklist integrating adaptation into planning (24%) and pluvial flood hazard maps (20%), but played a relatively minor role in other measures.

Lack of support from local businesses does not seem crucial, as only 14% of respondents mentioned it as a barrier to general adaptation measures and fewer for specific measures. Additionally, a lack of acceptance from the population regarding general adaptation measures was hardly mentioned (by just 4% of respondents), and this was only relevant for the ban on gravel gardens, with 26% of respondents reporting this barrier.

Insufficient data and experiences in dealing with climate change seem to play minor roles in general and specific adaptation measures, with 14% or fewer respondents mentioning these as hindrances.

Barriers in cities neither implementing nor planning the specific measures

The most critical factor in cities that had already implemented or were planning the specific measures was a limitation of resources for the preparation phase, except for the ban of gravel gardens (see Fig. 4). This factor was even more frequently mentioned by representatives of cities that had not yet implemented the measure in the case of maps (65%/80%) and façade greening (57%). Also, the lack of resources for implementation and maintenance was mentioned more frequently as a challenge by respondents from cities that had neither implemented nor planned façade greening, urban climatic maps, or a ban on gravel gardens.

Notably, insufficient data does not seem to be a substantial barrier. At the same time, a lack of data and unclear responsibilities were mentioned two to three times more often for both types of maps in cities that had not yet implemented or planned them compared to cities that had already published or were working on them. In addition, lack of support from the local administration seems to have been more important for respondents from cities that had not

implemented or planned climate function maps, gravel garden bans, and façade greening. The barrier regarding a lack of acceptance within the local administration was also evident in the interviews. Particularly when it came to implementing façade greening of public buildings, one interviewee from the administration noted that mandating façade greening through requirements in the development plan was viewed critically.

Respondents from cities without pluvial flood hazard maps or checklists to integrate adaptation into urban planning were more likely to see high pressure regarding other issues as a barrier. For both these measures and façade greening, a generally low awareness of climate change adaptation seems to have been more decisive in cities that had neither implemented nor planned these measures.

Figure 4 also shows that respondents in cities not planning or implementing specific measures mentioned some barriers less often. In these cases, the factors seem to have been barriers at the planning and implementation stages. For example, a lack of support from local politics in the case of the maps and a lack of acceptance from the population regarding façade greening and the ban on gravel gardens were less often seen as barriers in cities that had not yet planned or implemented these measures.

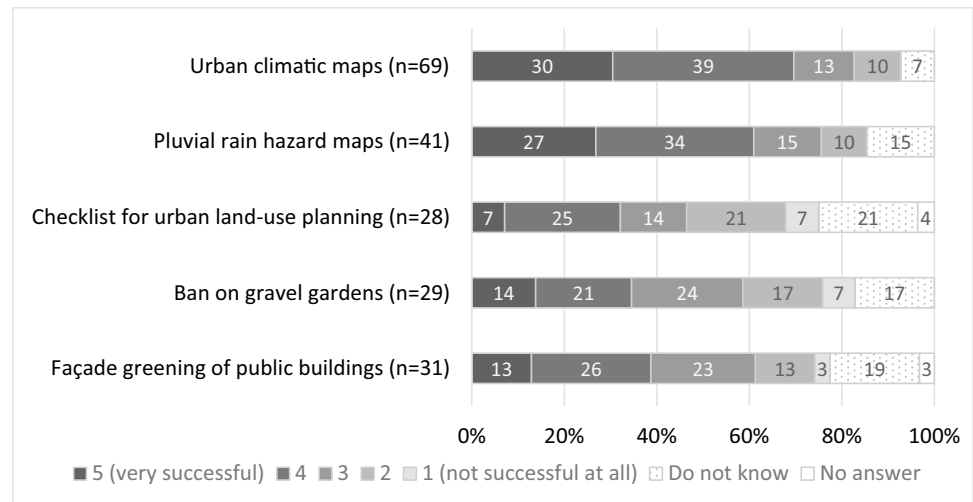
There were frequent answers in the category of “others,” for example, 29% in the case of the ban on gravel gardens. In the open-ended responses, some respondents questioned the general usefulness of this measure and suggested that raising awareness and informing homeowners about the role of gardens in biodiversity and water regulation, instead of creating regulations, would be more effective.

Assessment of the post-implementation success and challenges of the specific measures

Respondents who reported on specific implemented measures were asked to evaluate how successful they perceived these to be for climate change adaptation in their cities (see Table 3 and Fig. 5). The measures that most respondents (75%) saw as (very) successful were urban climatic maps, followed by pluvial flood hazard maps (71%). Far fewer respondents perceived façade greening of public buildings (50%), the ban on gravel gardens (42%), and checklists for urban land-use planning (39%) as (very) successful.

When asked to explain their assessment (see Table 3; $n=52$) in an open answer, participants described urban climatic maps as valuable for considering the climate aspect when preparing development plans and planning specific projects. They also saw them as helpful in communicating with citizens and investors and increasing the transparency of planning processes. However, they stated that using such maps in planning is problematic because they are not legally binding, and other issues may take priority. This is why

Fig. 5 Success of implemented measures as assessed by survey respondents



the maps are not regularly used in some municipalities. In some cases, they are seen as not detailed enough. Therefore, when asked about changes related to urban climatic maps (see Table 3), survey respondents ($n = 40$) often expressed a desire for an improved database and a more legally binding status. Some respondents wished to combine climate projections and simulations of different interventions regarding climatic effects and better integrate them into their geo-information systems and databases. A few respondents desired clear guidelines for action (e.g., for internal development or unsealing) and interpretations based on the maps. Some respondents believed having sufficient, qualified staff would be necessary to improve the use of the maps.

For pluvial flood hazard maps, 29 respondents justified their positive assessment by highlighting the usefulness of the maps when preparing for extreme precipitation and stormwater inundation. They mentioned that the maps were valuable for (storm-)water management, road drainage, planning construction areas, and protecting the population in at-risk areas. Visualizing hazard-prone regions was particularly appreciated to communicate risk to citizens, property owners, and within the municipal administration. However, data protection concerns have prevented the maps' publication in a few cases, and some respondents indicated the need for precise regulations guiding their publication. It was also suggested that there should be greater public awareness about these maps. Comparable to the findings for the urban climatic maps, pluvial flood hazard maps were said to need a more binding legal character. Respondents further emphasized the need for more financial and personnel resources and clarification of legal requirements, especially for the designation of building areas. Additionally, it was suggested that the maps need to be continuously updated and refined for greater precision. Interviews with representatives from a city administration using a pluvial flood hazard map revealed that the city's current data were inadequate

for reliable planning. Specific data on water levels and rain-water drains during pluvial flood events were identified as necessary. Interviewees emphasized that testing specific development plans and the involvement of technical experts from departments such as parks, water management, and disposal would be crucial for developing long-term standards for heavy rain adaptation.

The success of using checklists to incorporate climate change adaptation into urban land-use planning was assessed differently. Overall, the assessment was less favorable than for the two maps (see Fig. 5). A total of 17 people provided their reasons for their evaluation of the measure, and 14 reported on necessary changes. They positively evaluated their checklists as providing essential guidance, particularly for new development areas considering climate change adaptation, and described them as an accepted tool in administration. However, they said that the checklist results should be given more weight in the assessment process (e.g., regulated by law) and given priority over other objectives. Some critics argued that the checklists were too scientific, time-consuming to process, or too superficial. According to some respondents, the checklist should be used repeatedly before or at the start of the planning process as well as during the various planning steps.

In total, 19 respondents provided reasons for their assessments of the ban on gravel gardens in their city. Overall, prohibiting gravel gardens was seen positively because it allows for specifications during the planning/application stage of new residential homes, thus preventing undesirable developments and promoting the creation of more green spaces. Additionally, extensive media coverage on the topic was viewed favorably, as it helps to raise awareness. The main criticism of this instrument was that the subsequent implementation is not sufficiently monitored, mainly due to a lack of human resources in the city administration, and can be violated without consequences. Furthermore, the bans

only apply to new buildings, meaning a relatively small area is typically affected overall. During one of the expert interviews, a person pointed out that there is insufficient differentiation between rock gardens and gravel gardens, with the former often representing a critical habitat. Some survey respondents desired widespread education among the public and gardening companies. According to some survey respondents, monitoring the ban should be more consistent, which can only be achieved with more staff. There were also isolated calls for legal regulation of already existing gardens.

Survey respondents ($n = 16$) viewed green façades on public buildings positively because they serve as role models for the public and offer positive microclimatic and ecological effects. However, it was noted that the effects will only materialize if green façades become more widespread. Therefore, respondents ($n = 17$) requested clear and binding guidelines for building authorities, nationwide subsidies for property owners, and implementing guidelines in state regulations. The survey also revealed a need for expanded human and financial resources, higher maintenance budgets, and technical and professional standards as well as guidelines for local authorities. In addition to ensuring long-term maintenance, the interviewees identified further factors important for long-term success, including vegetation-related factors such as using site-adapted plant species with specific climate, light, and water requirements and implementing automatic, efficient, and tailored watering systems. The selection of species suitable for extreme weather conditions and engaging in exchanges with experts were also highlighted as crucial aspects for the success of these greening measures during the interviews.

Discussion

We conducted a study combining a survey of municipal administrations with insights from desk research, qualitative interviews, and information from meetings with city administration employees in three cities to analyze the factors influencing the implementation of climate adaptation measures in Germany, where these measures are not mandatory. Our analysis focused on understanding the drivers and barriers to implementing specific climate change adaptation measures. Given the diverse range of adaptation measures, we expected differences concerning specific measures and implementation stages. We aimed to contribute to the existing literature by providing a more detailed understanding of the factors influencing the adoption of such measures.

Our findings regarding general climate change adaptation measures are consistent with recent literature from Germany (Friedrich et al. 2024; Schoenefeld et al. 2023) and other countries (Rogers et al. 2023). According to our research, the most critical drivers for implementing climate change

adaptation measures include support from local politicians and municipal administrations, external funding, sufficient financial resources, and a high sense of urgency. Although we have not statistically explored the links between these factors, they appear to be closely interrelated. For example, external funding provides more financial resources, and a high sense of urgency may increase local support from politicians and administrators, and vice versa. Additionally, factors such as aligning climate adaptation with other political issues, obtaining comprehensive data, and having clearly defined responsibilities were identified as important facilitators.

The study identified several barriers to implementing general climate change adaptation measures. These align with recent literature indicating a lack of resources as the most frequently cited issue (Friedrich et al. 2024; IPCC 2022; Schoenefeld et al. 2023). The survey identified essential barriers such as unclear responsibilities, unclear legal situations, limited perceived pressure to act, and lack of support in local administrations. These factors are also considered challenging in the literature (e.g., Friedrich et al. 2024; Schoenefeld et al. 2023).

When looking at specific measures, three groups of factors are crucial for the five measures investigated here. First, administrative and political support is a key driver for all measures and is the most frequently mentioned factor in the literature, according to Rogers et al. (2023). Second, the sufficiency or scarcity of resources is an important driver or barrier for all five measures, but to different extents. Diverse studies emphasize the need for resources, mainly external funding, for municipalities to undertake adaptation measures (Kern et al. 2023; Otto et al. 2021). Third, the perceived pressure to prioritize adaptation also acts as a driver, while the high priority of other (political) issues is a barrier for all five measures. The challenge of different problems competing for limited resources seems much more important than a general lack of adaptation awareness. To overcome this barrier, the literature recommends, for example, taking advantage of windows of opportunity (that open, e.g., after damaging weather extremes), developing synergies with other issues, and mainstreaming adaptation (IPCC 2022).

In addition to these similarities among the five measures, specific factors are more critical to some measures than others. Structural measures involving greenery, such as façade greening, require short- and long-term resources for maintaining vegetation, as also the EEA (2024) and Knifka et al. (2023) indicate. However, external funding and resources are less critical for organizational and regulatory measures, such as checklists and bans on gravel gardens. Instead, a lack of acceptance by the local population and an unclear legal situation are crucial barriers to this kind of measure, as partly also mentioned by the EEA (2024). The ban on gravel gardens seems quite controversial, as shown by our results and

statements from other practitioners (BDLA Bayern 2021). Knowledge factors are more important for the three planning measures (checklists and maps) than others. To ensure the success of these three measures, the respondents and interviewees call for more binding legislation and better data.

Our findings indicate differences in barriers between cities that have already implemented or are planning to implement a specific measure and those that have not. Cities that have not planned or implemented the measures under study seem to face barriers more frequently. At the same time, some obstacles are more specific to certain stages of the implementation process. Therefore, supporters of local climate change adaptation, such as national or federal state governments, need to consider the measures they want to focus on and the specific drivers and barriers at each implementation stage to improve municipal adaptation. This could, for example, improve current funding schemes, as evaluations show that smaller, less experienced municipalities benefit little from funding schemes in Germany (Scheller & Schlegel 2024).

For future studies, we recommend that cities that have not yet implemented or planned specific measures could be asked about the needed driving factors in addition to barriers. Regarding post-implementation experiences, the maps were perceived as more successful than the other three measures. The most frequently mentioned challenges at this stage were having enough resources to apply the planning documents and maintain the measures and dealing with unclear or inappropriate legal conditions that hinder the use of the measures. Post-implementation assessments can also help raise awareness around the need for monitoring and evaluating policies to assess the quality of their application, for example, in addition to just counting the number of completed measures. However, the information covered in our study is limited to the self-reported assessment of the application process. It could be supplemented by further considerations of effectiveness provided in the literature (Owen 2020). Ultimately, further insights from long-term evaluations could enhance practitioners' knowledge of what might work well and what to consider when introducing new measures.

Our approach involved surveying a larger number of cities and desk research, expert interviews, and participation in meetings in three cities. This triangulation provided a better understanding of the issues at stake. The approach also helped us to better understand the drivers and barriers encountered in climate change adaptation. However, our research has some limitations and is partly exploratory. First, the sample sizes are small and include mostly cities with more than 100,000 inhabitants. This means we cannot draw conclusions about smaller municipalities, as the literature (Fila et al. 2023; Fünfgeld et al. 2023) suggests these tend to feature different conditions. Our sample is

also limited to German cities operating in a specific governance, planning, and policy context. While our findings on factors influencing adaptation measures are generally consistent with broader international research (e.g., Rogers et al. 2023), caution is needed when generalizing specific findings to cities in countries with different institutional structures, climate-related exposures and vulnerabilities, or access to resources. Future research should explore how these factors play out in various national settings and at different stages of implementation. Second, we did not include awareness-raising, grey, technological, or financial measures in our research due to the explorative nature of this study, our area of expertise, and our aim of not overburdening the survey respondents and interviewees. Future research should extend the investigation to cover all key measures. Additionally, further research is needed on the types of measures included here to see whether other examples lead to different results, as our results for the two maps differed. Third, it should be noted that we contributed to specific measures in the three cities (both maps in Potsdam and façade greening in Remscheid and Würzburg). This transdisciplinary part of our research led to close exchanges and insights into the processes of implementing climate adaptation. At the same time, it may have influenced interviewees' perceptions of drivers and barriers in the three cities. Fourth, not all factors frequently mentioned in the literature as drivers or barriers were included in our survey. For example, we did not distinguish between human and financial resources or ask about (the lack of) qualified staff as Friedrich et al. (2024) did. In addition, the EEA (2024) reports on further challenges for each key type of measure (see Table 1). To make the results of survey studies more comparable, it would be helpful to, for example, align the response options between surveys.

Conclusion

After analyzing different climate change adaptation measures and their drivers and barriers, four main lessons can be learned: First, as climate change adaptation measures vary widely, our understanding of what drives or hinders them should reflect this. Some drivers and barriers appear critical for (almost) all types of action, such as scarce resources for preparation and administrative support. Other factors seem less important than these but are still essential for specific measures, such as the legal situation for regulatory actions or a lack of data for planning measures. Therefore, future studies, especially surveys, could ask specific questions about measures or differentiate between different types of measures and implementation stages. Furthermore, it is essential to interpret findings on the drivers and barriers to adaptation measures in general with caution, as

they may not represent the influencing factors for different specific measures. Second, not all factors that drive implementation automatically become barriers when they are absent. This suggests that implementation may be more straightforward with these enabling factors, but in some cases, implementation is still quite likely to happen without these factors. Third, some barriers are more common in cities that have not yet planned or implemented measures than in those that have, such as scarce resources, lack of data, and unclear responsibilities in the case of maps. These barriers may prevent the adoption of certain measures and appear particularly important to address in the initial preparation phase. Further investigation could also help to determine which barriers might require more effort to be overcome and how to support municipalities more effectively. Fourthly, as more measures are implemented, monitoring and evaluation of policies will become even more important, and future research needs to address this issue further. The explorative findings presented above contribute to a broad body of literature on influencing factors in municipal climate change adaptation. Future interdisciplinary and transdisciplinary studies could extend this knowledge with a broader set of measures and diverse samples of municipalities, including smaller or rural municipalities. Such knowledge can improve our understanding of (in)action and ways of supporting municipalities.

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Data availability The data from the survey is owned by the authors and can be made available upon reasonable request. The data from interviews and meetings is confidential.

Declarations

Ethical approval Informed consent was obtained by all interview participants as part of the introduction of the interview and was granted anonymity. The University of Potsdam did not require an ethic approval process for this study.

Conflict of interest The authors declare no competing interests.

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