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Measuring climate change adaptation policy output: Toward a two-dimensional approach

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Abstract

As jurisdictions across the globe step up their efforts to adapt to climate change, it is important to assess progress by taking stock of and comparing adaptation policy. However, scholars and practitioners are struggling to conceptualize and measure adaptation policy. In this article, we propose a new two-dimensional framework to measure public adaptation policy output, namely, the *Climate Adaptation Policy Index (CAPI)*. The index combines multiple indicators from two core interdependent dimensions, namely, an *institutionalization dimension* focusing on strategic plans and administrative capacities for adaptation; and a *measures dimension* capturing concrete adaptation measures in relevant action areas such as in green and open spaces, transport infrastructure, buildings, public education, and disaster management. Our approach is extensive but feasible and may be adjusted for use in different contexts and policy areas. We probe our approach at the local level using original survey data from a diverse sample of 211 municipalities located in the state of Hessen in central Germany. A factor analysis suggests that the two dimensions constitute a meaningful measurement of municipal adaptation policy output. A cluster analysis identifies five groups of municipalities representing different stages of adaptation policy progress in Hessen. Finally, a regression analysis examines

potential determinants of local adaptation policy making such as the size and wealth of municipalities. The results highlight the potential of the CAPI for analyzing both the state and the making of municipal adaptation policy.

KEYWORDS

climate change adaptation, Germany, index, institutions, measurement, municipalities, public policy

INTRODUCTION

Accelerating climate change has underlined the need for adaptation to avoid serious consequences resulting from climate impacts such as heat waves, heavy rainfall, droughts, storms, and floods. As governments and jurisdictions across the globe initiate and intensify efforts to adapt to climate change (henceforth "adaptation"), the assessment of progress in and possibilities for advancing adaptation are coming into focus. In this process, it is important to enable stocktaking and comparison of adaptation policy within and across jurisdictions. However, scholars and practitioners are struggling to conceptualize and measure adaptation policy, which means that comparison and knowledge accumulation remain challenging. As extant scholarship has pointed out, how we conceptualize and measure adaptation policy has important implications for both understanding adaptation policy change and for preparing advice for policy makers on how to improve adaptation (Berrang-Ford et al., 2019; Lesnikowski et al., 2019; Purdon & Thornton, 2019).

Against this background, there are manifold and persistent challenges in the conceptualization and measurement of adaptation policy. Adaptation is a complex, cross-sectoral endeavor touching upon many different aspects of human and nonhuman life, which makes it difficult to gauge the totality of (potential) adaptation policies. Existing studies have analyzed central strategic planning documents (Reckien et al., 2018; Shi et al., 2015), how public administrations approach adaptation (Roggero & Thiel, 2018), and which policy instruments (Mees et al., 2014) and concrete measures (Bausch & Koziol, 2020) governments employ in adaptation. While these contributions offer valuable insights, they also remain surprisingly detached from one another, which means that there is a risk of missing out on important interdependencies. For example, adaptation planning is certainly important, but without concrete measures, it is unlikely to substantially reduce vulnerabilities to climate change and its impacts (Dupuis & Biesbroek, 2013; Woodruff & Stults, 2016). What is missing is a measurement framework for adaptation policy that organizes and combines these existing perspectives in a more systematic way.

In this article, we aim to address this gap. To do so, we propose a new two-dimensional approach to conceptualize and measure adaptation policy, namely the *Climate Adaptation Policy Index (CAPI)*. The index captures *public adaptation policy outputs*, which are the adaptation decisions and activities of public actors, typically governments, and excludes those of private actors such as nongovernmental organizations (NGOs) or firms. It also excludes the (potential) effects of adaptation policy outputs, that is, adaptation policy outcomes and impacts. The CAPI conceives of adaptation policy as a strategic and integrated cross-sectoral endeavor that manifests along two core interdependent dimensions: (1) an *institutionalization dimension* that includes

strategic plans and administrative capacities for adaptation and (2) a *measures dimension* comprising concrete adaptation measures in relevant action areas such as green and public spaces, transport infrastructure, buildings, public education, and disaster management. In this way, our approach offers a comprehensive measure capturing the interdependent and cross-sectoral nature of adaptation policy while providing clear conceptual contours of its component parts.

We illustrate our measurement framework empirically at the local, that is municipal, level, which is one of the most important loci of adaptation policy making as adaptation issues and solutions tend to be highly localized and context-specific (Dolšak & Prakash, 2018). We use original survey data from a sample of 211 municipalities located in the state of Hessen in central Germany. The sample includes many smaller cities and towns with fewer than 50,000 inhabitants and therefore provides a rather good approximation of the diverse settlement structure in Hessen and Germany. Existing studies have thus far typically focused on larger cities, for example, those with at least 50,000 inhabitants (e.g., Araos et al., 2016; Grafakos et al., 2019; Lesnikowski et al., 2019; Otto, Göpfert, & Thieken, 2021; Otto, Kern, et al., 2021), which neglects smaller municipalities, even though the latter are home to a substantial share of the world's population (but see, e.g., Bausch & Koziol, 2020; Buschmann et al., 2022; Campos et al., 2017; Reckien et al., 2018; Wood et al., 2014). We conduct a factor analysis to validate the CAPI, followed by cluster and regression analyses to explore the patterns revealed by our measurement approach and their potential determinants. Our findings indicate that the CAPI is a valid two-dimensional approach to measuring adaptation policy and that institutions and concrete measures are two distinct dimensions of municipal adaptation policy, which do not necessarily advance in tandem. They also indicate that differences along the two dimensions might be linked to varying municipality characteristics and contextual factors.

The remainder of the article proceeds as follows. First, we discuss existing approaches to measuring adaptation policy and then go on to introduce the CAPI's concept. In the subsequent section, we present our data and construct the index. Finally, we analyze index patterns and correlates, before concluding the article with a discussion of our approach and possible future extensions.

EXISTING APPROACHES TO MEASURING ADAPTATION POLICY

There are many different approaches aimed at conceptualizing and measuring the multifunctional and cross-sectoral nature of adaptation policy (e.g., Araos et al., 2016; Biagini et al., 2014; Sovacool, 2011). Existing empirical contributions can be distinguished along at least two dimensions. First, there is important work focusing on institutional adaptation, that is, how governments plan and organize adaptation. Institutional adaptation approaches include the study of high-level adaptation documents such as plans and strategies, particularly in terms of their existence and contents, such as their maturity and ambitiousness, the inclusion of monitoring provisions, or the integration of mitigation and adaptation (Aguiar et al., 2018; Biesbroek et al., 2010; Grafakos et al., 2019; Klostermann et al., 2018; Otto, Kern, et al., 2021; Rai, 2020; Shi et al., 2015; Woodruff & Stults, 2016). Others have addressed administrative and organizational aspects of institutional adaptation. For example, Roggero and Thiel (2018) focus on how integrative and segregative organizational structures in German municipalities link with their approaches to adaptation. Moreover, multiple scholars have acknowledged the crucial role of administrative resources in adaptation planning and policy (Amundsen & Dannevig, 2021; Biesbroek et al., 2018).

Second, in an effort to depart from the initial focus on adaptation plans, which fails to register policies that are not included in such documents, research has increasingly used additional data sources recognizing the diversity of the (potential) adaptation policy portfolio. For example, scholars have looked into specific adaptation policies and measures in different areas (Amundsen et al., 2010; Bausch & Koziol, 2020) or the different types of available solutions, for example, in terms of regulatory, economic, and informational adaptation policy instruments and their mixes (Henstra, 2016; Mees et al., 2014; Lesnikowski et al., 2019).

These contributions offer important insights. However, they also remain surprisingly detached from each other as they have typically focused on only one of the two dimensions, that is, either on institutions such as adaptation plans and administrations or on (various) policy instruments and measures. There are, however, important interdependencies between these dimensions; this suggests that to further adaptation, institutionalization and concrete measures need to be advanced together. For example, strategic adaptation planning without dedicated measures, or an "action component" (Krause, 2011, p. 52), could remain rather symbolic and eschew vulnerability reduction (Dupuis & Biesbroek, 2013, p. 1481). Conversely, adopting policy measures without a dedicated strategic focus may generate a patchwork of incoherent or even contradictory activities. Finally, adequate administrative and organizational capacities are necessary to implement adaptation plans and concrete measures (Amundsen & Dannevig, 2021; Purdon & Thornton, 2019).

Most existing measurement approaches for adaptation policy ignore such interdependencies. However, Patterson and Huitema (2019) have developed a multidimensional concept of *institutional adaptation* that captures adaptation governance including policy, instrumental, organizational, and coordination aspects (see also Patterson, 2021). The concepts of *adaptation capacity* and *adaptation readiness* also include multiple dimensions and, to some extent, policy indicators. Adaptation capacity is a rather broad concept that is mainly concerned with conditions influencing the potential to adapt, including economic and human resources, technology, information, infrastructure, and institutions (Engle, 2011; Siders, 2019; Smit et al., 2000). Adaptation readiness, by contrast, is a narrower concept meant to capture governance structures and policy processes that can affect adaptation (Ford & King, 2015). Existing empirical accounts of adaptation readiness include policy (output) indicators such as adaptation plans and measures (Otto, Göpfert, & Thieken, 2021). However, they also include governance and policy process indicators such as political leadership and public support, which may be considered potential determinants rather than part of adaptation policy. In the next part, we build on these previous efforts to propose a new two-dimensional framework for conceptualizing and measuring adaptation policy.

A TWO-DIMENSIONAL MEASURE OF ADAPTATION POLICY

Our proposed framework, the CAPI, starts from the background concept of public adaptation policy, which denotes decisions and activities by governments and public actors dealing intentionally with new climate conditions to moderate adverse impacts on communities, infrastructure, and the environment (adapted from Dupuis & Biesbroek, 2013, p. 1480; Patterson, 2021, p. 2; Schoenefeld et al., 2022, p. 2). Based on this background concept, we understand public adaptation policy as a strategic and integrated cross-sectoral endeavor that can be measured along two dimensions: (1) *institutions* and (2) *measures* (see also Krause, 2011). In so doing, we assume that there are important interdependencies between these dimensions, suggesting that both are important for advancing adaptation. For example, the development of institutions such as strategies

or administrative resources for adaptation may stimulate policy measure development and vice versa. Moreover, institutions are expedient in coordinating and implementing adaptation measures, while institutional development alone will not reduce vulnerability.[1]

Regarding the sequenced evolution of public policy (see, e.g., Thomann, 2018), the CAPI measures policy *outputs* such as the adoption of an adaptation strategy or the creation of green spaces and excludes (potential) policy effects. More precisely, we do not assess adaptation policy *outcomes*, that is behavioral changes associated with outputs, for instance, how citizens respond to subsidies for roof greening or information campaigns. We also put aside adaptation policy *impacts*, that is, how the vulnerability of citizens, the natural environment, or physical infrastructure may have changed as a function of adaptation policy outputs and outcomes.[2] Hence, the CAPI represents a starting point for analyzing adaptation policy processes, including their potential drivers, barriers, and effects, which have been a major research focus thus far (Adger et al., 2005; Biesbroek et al., 2015; Eisenack et al., 2014; Vogel & Henstra, 2015). To enable such analyses, we also excluded externally oriented activities such as participation in climate governance networks (e.g., Benz et al., 2015; Lee & Koski, 2014; Schulze & Schoenefeld, 2022) because they may be considered potential drivers of climate policy outputs (e.g., Busch et al., 2018; Fünfgeld, 2015; Kemmerzell & Hofmeister, 2019; Krause, 2012).

Moreover, the CAPI deliberately focuses on the decisions and activities of *public* actors and excludes those of *private* actors. Of course, because public policy emerges from complex governance arrangements, private actors may still partake in and influence public adaptation policy making and implementation (Dovers & Hezri, 2010; Glaus, 2021; Klein et al., 2018). We center on public adaptation policy for three main reasons. First, we aim to keep our measurement approach feasible. Private actors and their adaptation policies are more difficult to identify and sample than public actors and their policies because the former typically comprise many different types (e.g., households, firms, NGOs, etc.), which may produce a large variety of policies. Second, we aim to enhance the comparability of the units of analysis (Ford & Berrang-Ford, 2016), given that private and public actors are very different. Third, we wish to enable future theoretical and empirical analysis of whether and how different actors and governance arrangements, including private actors and their adaptation activities, influence public adaptation policy.

Finally, it must be noted that the CAPI concentrates on *intentional* adaptation policy, that is, policies that have been explicitly designed in response to climate change and its effects. Doing so keeps our measure consistent and feasible (Ford & Berrang-Ford, 2016); however, it is of course a narrower view than the alternative, which would consider any policy that contributes to reducing risks and seizing opportunities related to climate change, including, for example, economic and social policies (Dupuis & Biesbroek, 2013; Smit et al., 2000; Tompkins et al., 2010). The next sections introduce the two dimensions of the CAPI in more detail.

Institutionalization

Adaptation needs to become institutionalized within political systems to coordinate and support adaptation policy making and implementation. Institutions generally refer to the formal and informal "rights, rules, and decision-making procedures" guiding social behavior (Patterson, 2021, p. 2). Our framework considers only formal institutions focusing on the strategic and organizational activities of governments because they can be readily observed. A widespread strategic activity of governments, and arguably one of the most visible policy processes in adaptation, concerns the preparation of adaptation plans, which have been a considerable research focus at

the national (Biesbroek et al., 2010; Russel et al., 2020), subnational state (King, 2022; Rai, 2020), and municipal levels (Aguiar et al., 2018; Koski & Siulagi, 2016; Shi et al., 2015).

Adaptation plans come in many different shapes and forms, but typical elements include an analysis of the situation, that is how vulnerable a jurisdiction is (or will be) to different (future) climate impacts and what to do about it. Therefore, adaptation plans usually contain adaptation goals, options, and priorities. More precisely, adaptation plans may be understood as comprehensive, strategic policy instruments spanning and linking different adaptation goals and measures within and across different sectors. They thus aim to coordinate adaptation activities and foster the acceptance of adaptation among different actors, including policy makers, bureaucrats, citizens, firms, and other stakeholders. Therefore, plans are expedient to provide an integrated answer to the interdependent and cross-sectoral challenge of adaptation, and they likely play an important role in the production and implementation of adaptation measures, as well as with a view to determining ultimate adaptation impacts (Siders, 2017). The extent to which plans cover different goals, sectors, and adaptation process steps and measures is therefore an important indicator of their quality and ambitiousness (e.g., Aguiar et al., 2018; Aylett, 2015; King, 2022).

Administrative capacity is another important institutional aspect of adaptation policy, which can be expected to play a role in adaptation policy making and implementation (Dovers & Hezri, 2010; Hinkel & Bisaro, 2015; Patterson, 2021). Adaptation plans and measures may be notably less effective when they meet insufficient administrative and organizational backing than when such backing is present (Amundsen et al., 2010; Biesbroek et al., 2018; Birchall & Bonnett, 2021). Thus, to acknowledge these interdependencies, it is important to consider administrative capacity for adaptation. Our framework focuses on two concrete manifestations of administrative capacity for adaptation, namely resources and collaborative organizational structures.

First, adaptation policy making and implementation need to be supported by an appropriate level of resources. Providing (new) resources for adaptation within administrations may include additional funds, personnel, and/or reorganization. The importance of such resources for climate and adaptation policy making and implementation is widely acknowledged (Pollitt, 2015; Purdon & Thornton, 2019). For example, financial and human resources, as well as expertize, have been instrumental for Chilean municipalities in adapting to extreme weather events (Valdivieso et al., 2021), while a lack of resources for planning has been identified as a barrier to municipal adaptation in Norway (Amundsen & Dannevig, 2021). Our framework focuses on the establishment of new staff positions and units dealing with adaptation as a proxy for administrative resources. Other relevant data, in particular spending on adaptation, are very difficult to collect and compare because adaptation measures are usually funded through diverse sources and included in many different budget lines (see also Otto, Göpfert, & Thieken, 2021).

Second, the interdependent and cross-sectoral nature of adaptation suggests that additional efforts are needed to coordinate adaptation policies and actions. Policy integration scholars have repeatedly highlighted the merits of collaboration among actors from different policy domains to integrate goals and policies (e.g., Tosun & Lang, 2017). Adaptation policy integration means that adaptation needs to take place in existing and long-standing policy sectors, such as energy policy, health, agriculture or transport. A plethora of studies have analyzed adaptation policy integration (or mainstreaming), for example, in national adaptation strategies such as those in Switzerland (Widmer, 2018), in EU marine policy (Russel et al., 2018), or in municipal fisheries policy in Nova Scotia (Khan et al., 2018). Adaptation policy integration is therefore a widespread and growing phenomenon across the globe.

A related literature deals with integrating adaptation concerns into public organizations and municipal administrations. For example, Hagedorn (2015) argues that integrative institutions are more suitable than fragmented institutions to address governance problems of high complexity and high functional interdependencies such as those relating to sustainability transitions. Roggero and Thiel (2018) support this view explicitly for the case of adaptation. By comparing 19 local administrations in Germany, they find that integrative institutions, as opposed to segregative institutions, may be better suited to drive adaptation to expected climate impacts. Other scholars have dealt with the integration of mitigation and adaptation efforts in city administrations, for example, through city advisory committees (Göpfert et al., 2019).

It is important to note that while our framework highlights the need for integrated organizational structures to address the cross-sectoral nature of adaptation, it deliberately excludes participatory and collaborative arrangements between public and private actors (e.g., from civil society, science, or business). Rather, we consider such collaborations as (potential) determinants of public adaptation policy outputs. Research suggests that realizing the benefits of public–private collaboration for adaptation may depend on the presence of additional, favorable conditions such as the recognition and meaningful engagement of all relevant actors at all stages of decision-making (Cattino & Reckien, 2021; Few et al., 2007; see also Newig et al., 2018). Wamsler et al. (2020) even show how a lack of capacities and diverging interests between municipalities and citizens can contribute to undesirable adaptation outcomes.

Measures

The institutions discussed thus far comprise an important variable shaping adaptation by guiding and incentivizing policy making and implementation (Hughes & Sarzynski, 2015; Patterson & Huitema, 2019). However, to generate effects, concrete adaptation measures are needed. Therefore, adaptation requires adopting and carrying out many concrete measures or actions in different areas, such as in green and open spaces, transport infrastructure, buildings, disaster management, information, and education (Amundsen et al., 2010; Bausch & Koziol, 2020). For example, to advance adaptation in green and open spaces to increasing heat and drought, local governments may create/alter watering schemes and promote more climate-resilient tree and plant species (e.g., Siders, 2019). In developed or developing areas, they may specify new development limits, create retention areas, and pursue surface unsealing to address more frequent heavy rainfall. We thus argue that the number or density of measures in different areas is an important indicator of adaptation policy and its ambitiousness, which comparative research can exploit (see also Knill et al., 2012; Schaffrin et al., 2015; Schulze, 2021).

Moreover, in line with Krause (2011), we argue that adaptation measures are an important indicator of substantive follow-up activity to strategic and organizational components of adaptation policy. Without the adoption and implementation of concrete measures, adaptation plans likely remain rather symbolic, and the expansion of administrative capacities is an ineffective practice. Along these lines, Bausch and Koziol (2020) argue that the ability of municipalities to adopt and implement appropriate measures is directly related to their ability to shield local populations from the negative consequences of climate impacts. Otto, Göpfert, and Thieken (2021) also include adaptation measures in their multidimensional index of adaptation readiness, attesting to the importance of this dimension.

Existing studies concerned with a larger adaptation policy portfolio have typically focused on functional types of adaptation actions, such as capacity building or management (Araos

et al., 2016; Biagini et al., 2014; Ford & King, 2015), or the policy instrument types and their mixes that governments employ in adaptation, such as regulatory, economic, organizational, and informational instruments (Henstra, 2016; Howlett & Rayner, 2007; Lesnikowski et al., 2019; Mees et al., 2014). These approaches offer important insights, but they are also more interested in *how* governments deal with adaptation, whereas our measures dimension focuses on *how much* governments do in terms of concrete (on-the-ground) measures. Despite these differences, there are also overlaps between both perspectives, such as the assumption that adaptation requires addressing multiple goals and sectors, which can only be achieved through many different activities.

DATA AND MEASUREMENT

Case selection

We probe our measurement framework at the local level, which is a crucial arena of adaptation policy where comparative work is urgently needed (Dolšak & Prakash, 2018; Javeline, 2014; Vogel & Henstra, 2015). To do so, we use a diverse sample of 211 municipalities located in the state of Hessen in Germany (see Table 1 for sample details). Hessen is a land-locked state in central Germany comprising only five large cities (of more than 100,000 inhabitants) and 417 small- to medium-sized cities, towns, and rural municipalities organized into 21 counties and three governing districts (see also Figure A1 in the Appendix). Approximately, two-thirds of Hessen's population lives in municipalities with fewer than 50,000 inhabitants (compared to approximately 60% for all of Germany), which underlines the importance of including smaller municipalities in adaptation policy research.

TABLE 1 Sample structure.

		Hessen		Sample		
		N	**%**	***N***	**%**	**% (RR)**
Spatial distribution	Districts (NUTS II)					
	Darmstadt (South)	184	43.6	95	45.0	51.6
	Giessen (West)	101	23.9	46	21.8	45.5
	Kassel (North)	137	32.5	70	33.2	51.1
	Total	422	100.0	211	100.0	50.0
	p-value of Pearson chi-square = .7723					
Demographic distribution	Population size					
	≥100,000	5	1.2	5	2.3	100.0
	50,000–99,999	7	1.7	6	2.8	85.7
	20,000–49,999	47	11.1	31	14.4	66.0
	10,000–19,999	111	26.3	57	26.5	50.9
	5,000–9,999	133	31.5	68	31.6	51.2
	<5,000	119	28.2	44	20.5	37.3
	Total	422	100.0	211	100.0	50.0
	p-value of Pearson chi-square = .06.					

Abbreviation: RR, response rate.

Hessen has already been subjected to a range of climate change-related impacts such as drought and heavy rainfall and is expected to face more impacts in the future. For example, Hessen has repeatedly experienced unusually high temperatures during summer months (e.g., in 2003, 2006, 2015, 2018, and 2019), leading to massive drought and heat-related environmental damage. Hessian authorities such as the Hessian Agency for Nature Conservation, Environment and Geology (HLNUG) under the Hessian environmental ministry predict that such events will become more frequent and more intense over time.[3] The state government has responded, for instance, by creating a Center on Climate Change and Adaptation[4] within the HLNUG and by providing incentives and support for municipal climate change adaptation. These include, for example, funding programs for climate mitigation and adaptation projects, consulting services through the State Energy Agency, and the establishment of a municipal climate network, the so-called Klima-Kommunen[5] (Schulze & Schoenefeld, 2022). These characteristics make Hessen a suitable test site for probing our measurement approach.

Data collection

To measure the two dimensions of the CAPI (namely institutionalization and measures), we conducted a survey between November 2020 and January 2021, by sending a questionnaire, including an online and offline (pen and paper) option, to all 422 Hessian municipalities. We sent the questionnaires directly to the mayor's offices, with the suggestion that they be forwarded to the responsible administrative units and employees if needed. Overall, 227 municipalities returned questionnaires. Deleting those with very few responses yielded 211 useable questionnaires, which reflects a response rate of 50%.[6] Moreover, in constructing the CAPI, we also researched municipal websites and adaptation plans and made additional inquires to verify and add data. This also led to some data changes, mostly with regard to the classification of plans (see below).

Table 1 reveals that the sample represents the Hessian municipalities in terms of their spatial distribution, that is by the three governing districts of Hessen, rather well. However, because the smallest municipalities with fewer than 5000 inhabitants remain underrepresented and the largest ones are overrepresented,[7] the sample's demographic distribution is somewhat skewed. A chi-square test returned marginally significant differences between the demographic distribution of municipalities in the sample and the true distribution in the state of Hessen. However, while the response rate declines as a function of municipality size, a remarkable 37% of the smallest municipalities with fewer than 5000 inhabitants still responded. The skewed response nevertheless suggests that we cannot easily generalize our results to all of Hessen. More precisely, because larger municipalities tend to be more active in adaptation than smaller ones (including in our sample), our data probably somewhat overestimate the average level of adaptation policy among Hessian municipalities. Moreover, self-selection may add to this overestimate to the extent that more active municipalities were more likely to respond to our survey than less active municipalities.

Index construction

The construction of the CAPI involves three main steps: selecting indicators, scoring cases, and aggregating the information. Table 2 summarizes the CAPI's indicators and subindicators, their operationalization, and aggregation rules. Figure A2 in the Appendix provides a graphical

TABLE 2 Operationalization of the Climate Adaptation Policy Index (CAPI).

Dimension	Indicator	Operationalization	Score	Weight
Institutionalization	(1) Plans	Sum of three subindicators	7/7	1/3
		1. Existence of three types of adaptation plans or strategic activities (only the most advanced type is scored):		
		(a) Adaptation strategy, (integrated) climate mitigation concept including adaptation, and intercommunal adaptation strategy	5	
		(b) Other concepts (e.g., urban development plan) including adaptation, climate action plan including adaptation, and guidelines/recommendations on adaptation	3	
		(c) Administrative stock-taking of need for action, political decision to develop a climate analysis/concept/strategy	1	
		2. Share of 15 sectors covered by a municipality's central adaptation plan (human health; planning; construction; transport, mobility, and communication; water management, flood control; soil; biological diversity, nature and environmental protection; agriculture; forestry; energy economy; finance; disaster management; industry; tourism; and education)	15/15	
		3. Share of 11 adaptation process steps and measures covered by a municipality's central adaptation plan (preliminary studies of climate change [impacts]; impact studies, risk analyses; [public] participation of citizens, businesses, civil society groups, and others; adaptation measures in land-use planning or urban development; mainstreaming in administrative processes; adaptation measures to extreme precipitation; adaptation measures to extreme heat; adaptation measures in green and open spaces; educational measures; monitoring of adaptation measures; and evaluation of adaptation measures)	11/11	
	(2) Resources	Establishment of new staff positions dealing with adaptation	1	1/3
	(3) Collaboration	Existence of an interagency working group dealing with adaptation, weighted by the number of up to 10 departments involved (environment, urban development, urban planning, building construction, transport; green space, civil engineering, water disposal, water supply, and health)	10/10	1/3

Dimension	Indicator	Operationalization	Score	Weight
Measures		Share of adaptation measures adopted in seven equally weighted action areas (up to 39 measures in total)		
	(1) Green and open spaces, forestry and agriculture	Open air-corridors; new and near-natural restructuring of green spaces (e.g., parks); connecting green spaces and green strips; watering of public green spaces and/or farmland during heat periods; support of mixed forest and diversity of species (e.g., in forests and parks); climate-resilient tree and plant species; and support of climate-ready water governance	7/7	1/7
	(2) Public spaces	Creation of drainage and retention areas; planning of multifunctional areas as "water plazas" (e.g., play-, sports-, and parking grounds as temporary precipitation storage); creation of "green oases"/shading in public space; creation of public drinking water fountains; creation, maintenance or raise of dams, dikes or flood protection walls; creation or maintenance of flood retention basins, barrage dams, and polders; and ecological flood control (e.g., through renaturation of water bodies or pasture land)	7/7	1/7
	(3) Transport infrastructure	Protection of underpasses (e.g., with drainage or seepage ditches); greening of streets; greening of railway tracks; climate-ready public transport stops (heat protection etc.); light surfaces for traffic areas; and shadowing of parking spaces	6/6	1/7
	(4) Developed or developing areas	Greening of brownfields; setting development limits; creation of retention areas within settlements; surface unsealing; coloring of traffic routes and plazas; and creation of open water surfaces and streams	6/6	1/7
	(5) Buildings	Greening of roofs and facades; thermal insulation; cooling of buildings; shadowing of buildings; shadowing elements on buildings; and backwater protection	6/6	1/7
	(6) Public education and leisure opportunities	Creation of new, sustainable leisure activities (e.g., in case of reduced snowfall); creation of new educational offers related to sustainability/nature; sensitization and information of citizens about climate change and climate adaptation in general; and sensitization and information of citizens about specific topics/hazards (e.g., handouts about heat-related behavior, information about heavy rainfall, and brochure for builders or farmers)	4/4	1/7
	(7) Disaster management	Expansion of technical capacities (e.g., vehicles, equipment, etc.); expansion of personnel capacities; and creation of early warning system (e.g., in collaboration with hospitals and care facilities, retirement homes, housing companies, and other social service providers)	3/3	1/7

Note: The score column shows the potential maximum score for each (sub)indicator, and the denominator used to scale variables between 0 and 1. The weights column refers to each dimension separately. In the final composite CAPI, both dimensions are also weighted equally.

representation of the index construction. Due to lack of priors, we weighted both dimensions and all indicators equally. All indicators and subindicators are based on the responses to our survey, complemented by desktop research and additional inquires for adaptation plans and staff positions. Table A4 in the Appendix contains all survey questions.

The first indicator of the institutionalization dimension captures characteristics of advanced municipal adaptation planning (e.g., Aguiar et al., 2018; King, 2022; Reckien et al., 2018). It consists of three subindicators. The first subindicator denotes what kind of, if any, adaptation plan or strategic adaptation activity exists in a municipality. The gold standard may be a full-fledged adaptation strategy. However, municipalities may also pursue other, less advanced, strategic approaches such as urban development plans with specific adaptation provisions. We rank these plans and activities from more to less advanced, placing municipalities on an ordinal scale ranging from 0 to 5. Accordingly, municipalities with adaptation strategies, integrated climate mitigation and adaptation concepts, and intercommunal adaptation strategies receive a score of 5; those with other concepts such as urban development plans including adaptation and climate action plans with adaptation receive a score of 3; and those with administrative stock-takes of adaptation needs or decisions to develop a climate analysis, etc., receive a score of 1. If a municipality reported that several of these plans or activities exist, we only counted the most advanced type. Municipalities without any adaptation planning activities are scored as 0.

While the above ranking captures different degrees of municipal adaptation planning, there are still important differences within each category. We therefore use two additional subindicators based on two additional survey questions to refine our measurement. The second subindicator captures a municipality's plan's efforts to integrate adaptation across different municipal agencies and processes (Aylett, 2015). To this end, it calculates the share of 15 predefined sectors, such as human health, planning, construction, water management, etc., that are covered by the plan (dividing the number of covered sectors by the total number of potential sectors). The third subindicator assesses how systematically and comprehensively a municipality's plan addresses adaptation by calculating the share of 11 typical adaptation process steps and measures that are included, ranging from preliminary studies to policy development to monitoring and evaluation. To reach the final planning indicator score, the three planning subindicators are added up and divided by the maximum possible score of 7. This aggregation rule maintains the original rank order between the three types of plans while adding further nuances within these types (see Table 2 for details).

The second institutionalization indicator captures administrative resources devoted to adaptation. More precisely, we use a dedicated question from our survey to obtain a binary variable indicating whether or not a municipality has established new staff positions or units dealing with adaptation. Establishing new administrative positions can be considered an important organizational change and resource to address increasing adaptation needs and to accommodate the cross-sectoral nature of adaptation (Patterson, 2021). Moreover, new positions can also be considered an acceptable proxy of municipal spending on adaptation given the difficulty of defining, identifying, and comparing municipal budgets for adaptation.

The third institutionalization indicator focuses on specific coordination and collaboration efforts in organizing adaptation. More precisely, it measures efforts to integrate adaptation concerns in municipal administrations and to coordinate adaptation policy goals and activities across different departments and agencies. To this end, we asked whether an interagency working group exists in a municipality's administration and, if so, how extensively it integrates different administrative departments. We expect that administrations with such working groups are better equipped to deal with the complex and cross-sectoral nature of adaptation (Roggero & Thiel, 2018). The third indicator first identifies the existence of interagency working groups

dealing with adaptation and then weights this binary variable by the number of 10 predefined departments that are involved in the working group (see Table 2 for details). We assume that incorporating more municipal departments in adaptation indicates more ambitious integration efforts. To reach the final score for the institutionalization dimension, all three indicators were scaled between 0 and 1 and then summed up by applying equal weights (1/3 each).

The second dimension of our index captures concrete adaptation measures, which crucially complement adaptation institutionalization to reduce vulnerability. The measures dimension denotes the adoption of up to 39 different adaptation measures, which we identified based on academic literature and existing surveys, especially those that are regularly conducted by the German Institute of Urban Affairs (Difu) to assess progress in municipal climate mitigation and adaptation in Germany (e.g., Rösler et al., 2013). This includes a large variety of measures such as the creation of open-air corridors and green spaces; surface unsealing; the creation, maintenance, or raising of dams, dikes or flood protection walls; thermal insulation of buildings; and informing citizens about climate impacts. We used a finite number of common, predefined measures from which respondents could choose because the universe of potential adaptation measures is hard to define. Therefore, asking municipalities to self-identify their measures may have generated additional problems because of differing understandings of what constitutes an adaptation measure and how to count them.

The 39 municipal adaptation measures are organized into seven action areas, including (1) green and open spaces, forestry, and agriculture, (2) public spaces, (3) transport infrastructure, (4) developed and developing areas, (5) buildings, (6) public education, and (7) disaster management.[8] We focus on the extent to which these seven action areas are covered by adaptation measures rather than the total number of measures because the number of potential action areas for adaptation is more limited than the number of potential measures and thus easier to define. In so doing, we assume that the overall level of municipal adaptation policy or ambition correlates with the density of measures in the identified action areas (see also Schaub et al., 2022). Aggregation involved calculating the share of measures in each action area. The area scores were then added up to reach the measures dimension score with equal weight (1/7) given to each area.[9]

We conducted an exploratory factor analysis with principal component factors and varimax rotation to probe the plausibility of our framework and to check whether the two dimensions emerge from the indicator variables outlined earlier. Two factors reach eigenvalues greater than 1 and amount to a cumulative explained variance of 0.54 (see Table 3).

TABLE 3 Factor eigenvalues.

Factor #	Eigenvalue	Difference	Proportion	Cumulative
Factor 1	3.98537	2.61121	0.3985	0.3985
Factor 2	1.37416	0.51826	0.1374	0.5360
Factor 3	0.85590	0.11639	0.0856	0.6215
Factor 4	0.73951	0.04036	0.0740	0.6955
Factor 5	0.69914	0.13688	0.0699	0.7654
Factor 6	0.56226	0.03357	0.0562	0.8216
Factor 7	0.52869	0.04459	0.0529	0.8745
Factor 8	0.48410	0.06677	0.0484	0.9229
Factor 9	0.41732	0.06378	0.0417	0.9646
Factor 10	0.35355		0.0354	1.0000

TABLE 4 Factor weights.

Variables	Factor 1	Factor 2	Uniqueness
Adaptation plans	0.2084	**0.6972**	0.4705
New staff positions	−0.0053	**0.7195**	0.4824
Interagency working group	0.1804	**0.6935**	0.4865
Green and open spaces, forestry, and agriculture	**0.6815**	0.2598	0.4681
Public spaces	**0.7417**	0.2140	0.4041
Transport infrastructure	**0.5892**	**0.4038**	0.4897
Developed or developing areas	**0.7671**	0.2221	0.3623
Buildings	**0.6865**	0.1210	0.5141
Public education and leisure opportunities	**0.4804**	**0.5162**	0.5028
Disaster management	**0.7016**	−0.2185	0.4601
$N = 211$, varimax rotation			
KMO = 0.8541			
Cronbach's α	0.8183	0.5701	
0.8118 (all variables)			

Note: Loading matrix from exploratory factor analysis with varimax rotation method extracting two factors from 10 indicators of municipal adaptation policy. All indicator scores range from 0 to 1. KMO: Kaiser–Meyer–Olkin statistic of sampling adequacy. Factor loadings >.4 in bold.

Retaining these two factors for the rotation analysis produces the results presented in Table 4. The KMO test of sampling adequacy (0.85) generally suggests that extracting factors from the data is worthwhile. The results show that our variables correlate in expected ways (see also Table A1 in the Appendix). The first factor clearly reflects the density of policy measures in the seven adaptation action areas while the second factor includes the three variables from the institutionalization dimension. However, most variables are left with relatively high unexplained variance (uniqueness scores above .4). Hence, interpreting relationships between the institutional variables and between the different densities of measures requires a cautionary approach. The Cronbach's α coefficient for the measures dimension (0.82) is satisfactory, but it is rather low for the institutionalization dimension (0.57). Alpha for all indicators (0.81) signals an acceptable level of reliability regarding the composite CAPI. In sum, these findings support the existence of a pattern and the conclusion that institutions and measures constitute two distinguishable constructs of municipal adaptation policy. However, given the amount of unexplained variance and reasonably similar factor loadings, we prefer to use the unweighted linear combination of averages rather than the factor scores to construct our index. In this way, we retain the full variance in our variables and follow a generally more intuitive approach to index creation.

ANALYSIS AND RESULTS

Descriptive statistics

Table 5 presents summary statistics for the final index, its two dimensions, indicators, and subindicators. To ease interpretation, we multiplied the fractional scores for each dimension and the combined

TABLE 5 Summary statistics.

	Mean	SD	Min	Max
Climate Adaptation Policy Index (CAPI)	*2.04*	*1.62*	*0*	*8.96*
Institutionalization score	*1.24*	*2.01*	*0*	*9.90*
(1) Adaptation plans	0.19	0.28	0	0.99
Adaptation strategies	0.08	0.27	0	1
Other concepts	0.17	0.38	0	1
Preparatory activities	0.18	0.39	0	1
Sectors	0.14	0.23	0	0.93
Process steps	0.12	0.23	0	1
(2) New staff positions	0.12	0.32	0	1
(3) Interagency working groups	0.06	0.21	0	1
Measures score	*2.84*	*1.82*	*0*	*8.16*
(1) Green and open spaces, forestry, and agriculture	0.39	0.28	0	1
(2) Public spaces	0.32	0.25	0	1
(3) Transport infrastructure	0.14	0.17	0	0.67
(4) Developed or developing areas	0.31	0.27	0	1
(5) Buildings	0.33	0.28	0	1
(6) Public education and leisure opportunities	0.27	0.30	0	1
(7) Disaster management	0.21	0.28	0	1

Note: $N = 211$. Composite CAPI and dimensional scores in italics (multiplied by 10).

index by 10. This places all municipalities on a scale ranging from 0 to 10, with higher values indicating more adaptation policy output (see also Nohrstedt & Nyberg, 2015). CAPI scores range from 0 to 8.96 with a mean of 2.04. Four municipalities in the sample received scores of 0 on the composite CAPI, indicating that they had not (yet) adopted explicit adaptation policies by the time of our survey.

The results generally suggest that the institutionalization of adaptation is less common among Hessian municipalities than the adoption of concrete measures. A total of 111 of the sampled municipalities (approximately 52%) have scores of 0 on the institutionalization dimension while this is only the case for six municipalities (approximately 3%) on the measures dimension. A total of 44% of the municipalities have adopted some kind of adaptation plan but only 8% have a fully developed adaptation strategy in place. By comparison, Otto, Kern, et al. (2021) report that 59% of 104 German cities with at least 50,000 inhabitants have an adaptation strategy. In our sample from Hessen, approximately, 45% of the cities with at least 50,000 inhabitants have such strategies. Across the whole sample, other, less advanced, adaptation concepts (17%) and preparatory activities (18%) are approximately twice as common as comprehensive strategies. New positions dealing with adaptation were only reported by 13% of the municipalities, and interagency working groups existed in only 8%. Larger municipalities were once again more active regarding these institutionalization indicators than smaller ones. Approximately 36% of larger municipalities with at least 50,000 inhabitants reported having established new positions compared to only 12% among those municipalities with fewer than 50,000 inhabitants. Interagency working groups existed in 45% of these larger municipalities but only in 6% of the smaller ones. On aggregate, these numbers produce an average institutionalization score of 1.2.

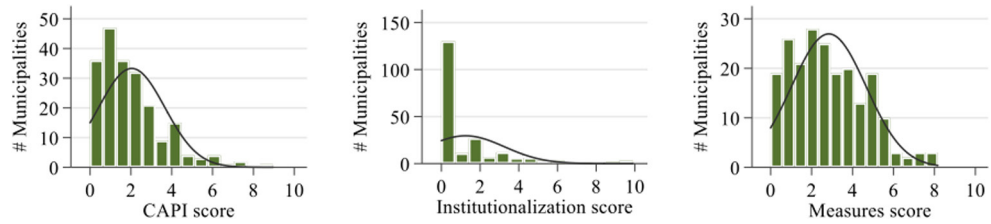

FIGURE 1 Distribution of CAPI, institutionalization, and measures scores for 211 Hessian municipalities.

With a view to the measures dimension, we find the highest average measures density in green and open spaces, forestry, and agriculture (39%) and the lowest in transport infrastructure (14%). The average measures density score is 2.8, implying that the mean density of measures across all action areas is approximately 28%. However, there is substantial variation across municipalities. Notably, all action areas, except transport infrastructure, reach maximum densities of 100%, meaning that, in each of these action areas, at least one municipality reported to have adopted all surveyed measures.

Figure 1 reveals that the distributions of the CAPI and both of its dimensions skew to the right. The composite CAPI's skewed distribution is strongly driven by the many municipalities lacking any institutionalization. We believe that these distributions are characteristic of the relative novelty of adaptation as a policy domain, and we would expect them to normalize over time once more municipalities engage in adaptation.

The relationship between institutionalization and measures

This section explores the relationship between adaptation institutionalization and measures. The Pearson's correlation between the two dimensions is .4, indicating a positive relationship. Figure 2 plots the two dimensions against each other, revealing that high institutionalization typically coincides with higher measure densities but not necessarily vice versa. In other words, many municipalities have adopted and implemented measures but have not (yet) made as much progress in institutionalizing adaptation.

To further explore differences and similarities between the two dimensions of adaptation policy, we conduct a hierarchical cluster analysis based on Ward's method with squared Euclidian distances. The resulting dendrogram (not shown) suggests a solution that places municipalities into five groups. We label these groups *policy leaders, measures leaders, policy followers, institutionalization latecomers, and policy laggards*. These results are also reflected in Figure 2, which also reflects municipal population sizes. Table 6 additionally describes the different clusters with their mean index scores as well as the mean municipality size and wealth indicators.

The first cluster situated in the upper right quadrant of Figure 2 is the smallest and includes only six municipalities, which qualify as *adaptation policy leaders* with very high institutionalization and high measures scores. Three of them are large municipalities with more than 100,000 inhabitants, including Frankfurt am Main, the by far largest city in Hessen with approximately 760,000 inhabitants, and Darmstadt, which is the capital of Hessen's southern governing district. Notably, all six members of this group are located in the Darmstadt district.

The second cluster includes 20 municipalities, which have typically not adopted the full range of adaptation institutionalization options but which are very active in adopting and implementing concrete measures. This characteristic makes them *adaptation measures leaders*. Giessen,

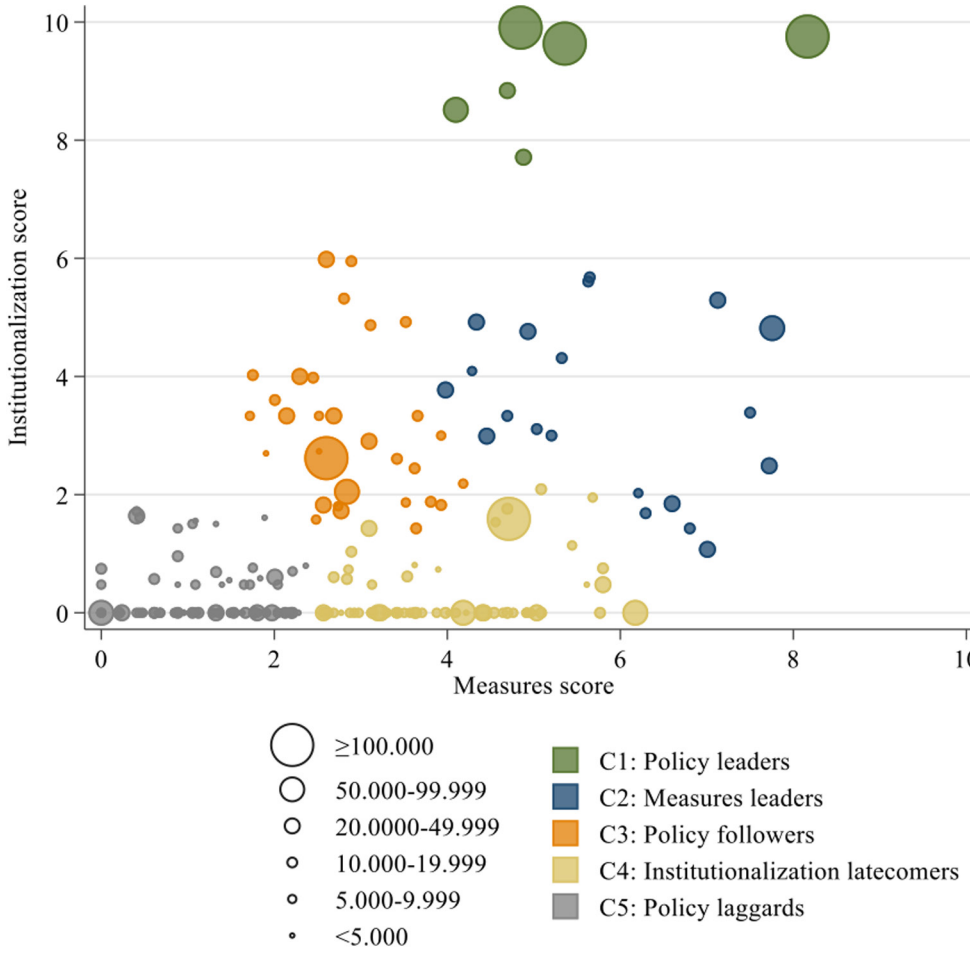

FIGURE 2 Scatterplot of adaptation institutionalization and measures for 211 Hessian municipalities.

which is a university city with approximately 90,000 inhabitants and the capital of Hessen's western governing district, belongs to this group. The other group members are all municipalities with fewer than 50,000 inhabitants, including 11 with fewer than 20,000 inhabitants.

The third cluster comprises 31 municipalities with medium scores in terms of both institutionalization and measures, which makes them *adaptation policy followers*. The group includes Kassel, which is a university city and the capital of Hessen's northern governing district, and, in contrast to the second cluster, a relatively high number (approximately 30%) of small municipalities with fewer than 10,000 inhabitants.

The municipalities in cluster four returned low institutionalization scores but medium scores on measures and can therefore be labeled *adaptation institutionalization latecomers*. More than half of the municipalities in this cluster have fewer than 10,000 inhabitants. However, this cluster also includes larger cities, such as Hessen's capital of Wiesbaden, with approximately 280,000 inhabitants, which is currently undertaking further institutionalization steps including developing a heat action plan, as well as the university city of Marburg in the center-west of Hessen, which is currently developing an adaptation strategy. This explains both cities' low institutionalization scores at the time of the survey.

TABLE 6 Cluster typology and mean values of municipal adaptation policy output, size, and wealth.

Cluster #	Number of municipalities	Mean CAPI score	Mean institutionalization score	Mean measures score	Mean number of inhabitants	Mean tax revenue per capita (€)	Cluster characterization
1	6	7.20	9.06	5.34	203,840	1488	*Policy leaders:* Very high scores on institutionalization and high scores on measures
2	20	4.65	3.48	5.83	24,133	714	*Measures leaders:* Medium scores on institutionalization and high scores on measures
3	31	3.00	3.11	2.89	22,870	671	*Policy followers:* Medium scores on institutionalization and medium scores on measures
4	65	2.12	0.29	3.95	17,306	870	*Institutionalization latecomers:* Low scores on institutionalization and medium scores on measures
5	89	0.72	0.26	1.18	8781	527	*Policy laggards:* Low scores on institutionalization and low scores on measures

Cluster five includes municipalities with low scores on both institutionalization and measures, making them *adaptation policy laggards*. Approximately, 75% of the municipalities in this group have fewer than 10,000 inhabitants. Rüsselsheim am Main, with approximately 65,000 inhabitants, constitutes by far the largest municipality in this group. It is an industrial city (headquartering Opel Automobile) southwest of Frankfurt am Main and has only begun to systematically develop more adaptation policies.

Finally, Figure 2 also confirms that smaller municipalities tend to be weaker adaptation policy adopters than larger municipalities. However, the figure also illustrates that both small and large municipalities appear in each cluster. A large diversity in size exists, particularly with regard to the measures dimension. This finding suggests that many smaller municipalities may focus on developing and implementing specific adaptation measures rather than institutionalization, for instance, if they lack the resources to develop full-fledged strategies or hire new staff.

Determinants of adaptation policy

Finally, we probe the utility of the CAPI for analyzing drivers of and barriers to adaptation policy making. To this end, we regress the CAPI and its dimension scores on potential determinants from common models of local policy making, including municipal development, fiscal capacity, and interest group indicators (Lubell et al., 2009). More precisely, we examine associations with population size and growth, municipal tax revenue and debt per capita, as well as percentage industrial employment and green party seats in municipal councils. We retrieve data for all explanatory variables from the statistical offices of the state government of Hessen.[10] We log transform the population size and tax revenue variables to address outliers and potential nonlinear effects. We expect larger, growing, wealthier, and less indebted municipalities to be more active adaptation policy makers. More industrial municipalities may hesitate to adopt adaptation policies if such policies are considered an additional burden on industrial production, while a stronger representation of the green party in municipal councils may reflect higher political pressure and popular demand to deliver adaptation policy. Due to the nonnegative right-skewed distributions of our dependent variables, we estimate generalized linear models with a log link and robust standard errors. These models can handle zero outcomes and avoid dependent variable transformation (Wooldridge, 2010, pp. 723–767).

The regression results presented in Table 7 suggest that the development model is generally the best predictor of municipal adaptation policy output. More populous municipalities tend to be more active in adopting adaptation policy than less populous municipalities, possibly due to greater adaptation needs and more available resources in the former. However, while population size is associated with both adaptation institutionalization and measures, population growth only predicts institutionalization. This finding may indicate that municipalities react to higher growth and a need to maintain living or welfare standards mainly with increasing strategic and organizational adaptation capacities. Fiscal capacities are unrelated to adaptation policy in the full models, but municipal income in terms of tax revenue is positively related to adaptation policy in the separate models. The effect of municipal income is thus largely absorbed by municipal size (the correlation between the two variables is .48). Group interests emerge mainly as significant predictors of adaptation institutionalization in our models. Contrary to our expectation, a higher share of industrial employment is associated with more (and not less) adaptation institutionalization. This finding may reflect higher demand for adaptation in more polluted and vulnerable industrial municipalities. A stronger representation of the green party in municipal councils is associated with higher levels of adaptation institutionalization (with more measures

TABLE 7 Regression models predicting adaptation policy output in 211 Hessian municipalities.

	CAPI				Institutionalization				Measures			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Development												
Population size (log)	0.37***			0.36***	0.55***			0.51***	0.27***			0.28***
	(0.05)			(0.06)	(0.08)			(0.13)	(0.04)			(0.05)
Population growth	0.01			0.01	0.03*			0.04**	−0.00			−0.01
	(0.01)			(0.01)	(0.02)			(0.02)	(0.01)			(0.01)
Fiscal capacity												
Tax revenue p.c. (log)		0.38***		0.02		0.65***		0.03		0.25***		0.01
		(0.09)		(0.08)		(0.17)		(0.23)		(0.07)		(0.07)
Public debt p.c.		0.06		0.00		0.21**		0.10		−0.01		−0.06
		(0.05)		(0.05)		(0.09)		(0.12)		(0.05)		(0.05)
Interests												
Industrial employment			−0.00	0.01**			−0.00	0.02**			−0.00	0.00
			(0.00)	(0.00)			(0.01)	(0.01)			(0.00)	(0.00)
Green seats			0.04***	0.01			0.06***	0.02*			0.02***	0.01
			(0.01)	(0.01)			(0.01)	(0.01)			(0.01)	(0.01)
N	211	211	211	211	211	211	211	211	211	211	211	211
Log likelihood	−334.09	−361.72	−360.35	−331.62	−326.87	−377.73	−377.55	−318.80	−392.83	−408.70	−407.79	−391.22
AIC	674.17	729.44	726.71	677.23	659.74	761.45	761.10	651.60	791.66	823.40	821.58	796.45

Note: Unstandardized coefficients. Robust standard errors in parentheses.

*$p < .10$; **$p < .05$; ***$p < .01$.

only in Model 11). This pattern may reflect government reactions to the demands of green voters, which emphasize the consolidation of adaptation policy making beyond individual measures. It should also be noted that the green party effect disappears once we exclude municipalities with 50,000 and more inhabitants from the analysis, reflecting the typically higher shares of green voters in larger cities. Moreover, the population growth effect seems to be substantially driven by these larger cities (see Table A3 in the Appendix).

DISCUSSION AND CONCLUSIONS

As jurisdictions adapt to a changing climate, keeping track of adaptation policy becomes ever more important. In light of persistent difficulties and fragmented existing work, we propose the novel *Climate Adaptation Policy Index (CAPI)* to conceptualize and measure adaptation policy more systematically along an institutionalization and a measures dimension. These dimensions emerge from the relevant adaptation and climate policy literature, and they also find empirical support in our first plausibility probe using data on municipal adaptation in the state of Hessen in Germany. The empirical results show that institutions and concrete adaptation measures represent distinct dimensions of municipal adaptation policy, which may also relate to different contextual drivers and barriers. Measuring adaptation policy should therefore incorporate both dimensions. Missing out on one dimension might result in inaccurate conclusions concerning municipal adaptation efforts and a limited understanding of influential factors in the adaptation policy process. The CAPI therefore offers an opportunity to advance our understanding of adaptation policy characteristics, processes, and effects from various perspectives.

To this end, our approach remains flexible, inviting improvements and adjustments regarding the exact variables in each dimension based on specific context and research needs. The results of our factor analysis generally suggest that there is room for removing measurement error along these lines. In particular, given that the Cronbach's α is somewhat low for the institutionalization dimension, adding suitable institutionalization indicators might improve the reliability of the dimension. Similarly, the number of action areas and measures may be adjusted to the relevant national and/or subnational context.

The CAPI may also be extended to include additional policy characteristics. To keep our approach feasible, we have focused on common local institutions and the density of adaptation measures. However, future extensions could, for instance, add information on different instrument types and their mixes or the calibrations of instruments such as the target groups and levels of subsidies for roof greening, the size of green spaces, or the amount of funds spent on educational activities.[11] As the adaptation policy field matures, such finer distinctions might gain increasing relevance, and the CAPI could incorporate them as the need arises.

Moreover, our approach is in principle scalable to different governance levels and policy areas. For example, at the EU level, the EU's 2021 Adaptation Strategy[12] and its directorate on adaptation and resilience[13] within the dedicated Directorate-General on Climate Action correspond to the institutionalization of adaptation, while the EU Floods Directive represents a type of legal measure.[14] We also believe that our framework may be adapted to measure policy output in other areas, including but not limited to climate mitigation and sustainability (e.g., Christen & Bornemann, 2021; Krause, 2011).

Finally, our framework's strengths derive not only from its conceptual flexibility but also from its distinct openness to different data collection methods and triangulation, including, for

example, document analysis, interviews, and surveys. Surveys are particularly useful when public records are insufficient or unavailable. In our case, for example, it would have been impossible to obtain sufficient data on administrative capacities and concrete measures from municipal websites. Of course, a potential disadvantage of survey data may be its reliance on the knowledge of those completing the questionnaire and the possibility of social desirability and response biases. However, it should also be noted that survey questions on municipal adaptation policy outputs such as ours are typically of factual nature, meaning that the information provided may be checked and verified if public records are available.[15]

Moving forward, the framework may enable a range of future analyses to assess and explain adaptation policy patterns in different places and at different governance levels. It may therefore be useful for researchers engaging with different theoretical approaches to adaptation policy, for example, policy diffusion and scaling (Kern et al., 2023; Schoenefeld et al., 2022) or administrative organization (Biesbroek et al., 2018; Krause et al., 2016). Moreover, the CAPI may be valuable for researchers from different methodological backgrounds. For example, it may be a useful starting point for detailed qualitative analyses of individual adaptation institutions and measures, which may then, eventually, also inform future refinements of the index. For practitioners from different levels of governance, the CAPI may offer a useful way to assess adaptation policy efforts and their elements to identify potential strengths, weaknesses, and interventions.

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ENDNOTES

[1] Multidimensional concepts have also been developed to measure municipal sustainability policy and governance (Christen & Bornemann, 2021), institutional adaptation in urban water governance (Patterson, 2021), and adaptation readiness (Otto, Göpfert, et al., 2021).

[2] In contrast to climate mitigation, where progress in policy outcomes and impacts can be expressed in terms of greenhouse gas emissions reductions, there is no straightforward common metric to gauge progress in adaptation policy outcomes and impacts. The latter involves assessing reductions in vulnerability or climate risks, which is at least as challenging as measuring adaptation policy outputs (e.g., Cai et al., 2018).

[3] https://www.hlnug.de/fileadmin/dokumente/klima/extreme_wetterereignisse.pdf.

[4] https://www.hlnug.de/index.php?id=10335.

[5] https://www.klima-kommunen-hessen.de/.

[6] The exactly 50% response rate is pure coincidence.

[7] Our size categories correspond to official German city and municipality types formulated by the German Federal Institute for Research on Building, Urban Affairs and Spatial Planning (BBSR). Accordingly, a "big city" has at least 100,000 inhabitants, a "large medium-sized town" at least 50,000, a "small medium-sized town" at least 20,000, a "large small-town" at least 10,000, a "small small-town" at least 5000 inhabitants. The BBSR connotes municipalities with fewer than 5000 inhabitants as "rural municipalities."

[8] We use the term *action areas* to denote spheres of adaptation around which local governments have typically organized their activities, for instance, based on their conventional rights and duties. They are not to be confused with (economic) sectors which may have different boundaries.

[9] Most questions that we used in constructing the CAPI included an open (other) category for adding plans and measures. Since this category was rarely used, the corresponding answers are not included in the analysis.

[10] https://statistik.hessen.de/. Green party seats refer to the last local elections before the survey in 2016. Percentage population growth is measured as the difference between municipalities' 2019 and 2009 populations divided by their 2009 population (Conroy & Berke, 2004). Data for all other variables are from 2019. Summary statistics can be found in Table A2 in the Appendix.

[11] Measurement approaches considering policy instrument types and calibrations (or intensities) have been mainly developed at the national level (see Knill et al., 2012; Schaffrin et al., 2015; Schmidt & Sewerin, 2019). However, assessing and combining the calibrations of different instrument types is particularly challenging, for example, because they are highly context-sensitive (for a critical discussion, see Capano & Howlett, 2020).

[12] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0082&from=EN.

[13] https://ec.europa.eu/info/sites/default/files/organisation_charts/organisation-chart-dg-clima_en.pdf.

[14] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007L0060&from=EN.

[15] While survey respondents may of course give incorrect answers, in our case, we have no indication that such error has been systematic.

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APPENDIX

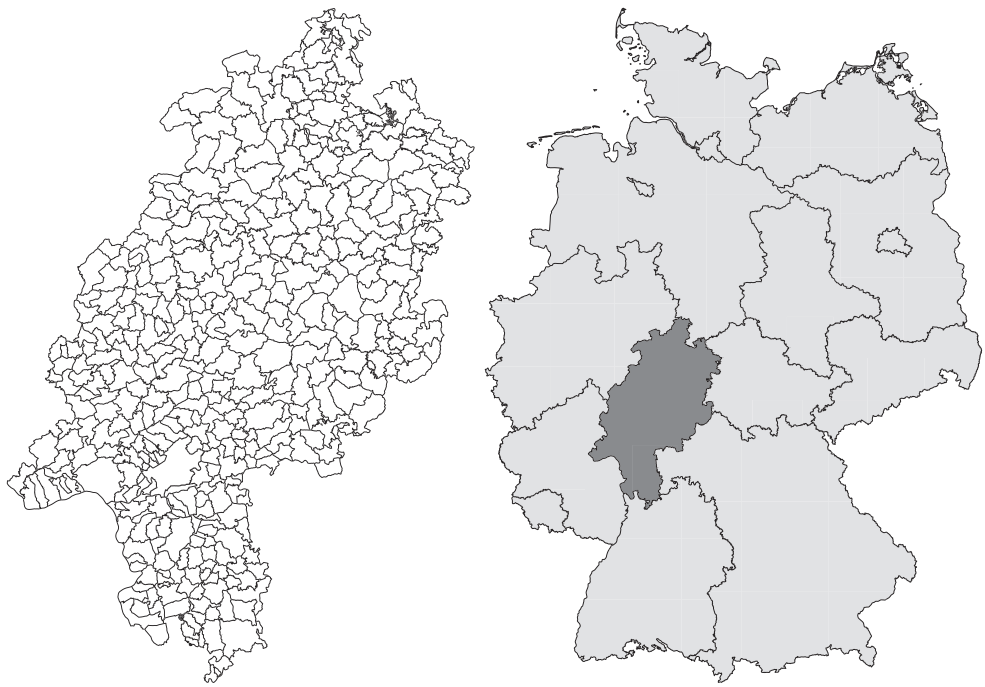

FIGURE A1 Maps of Hessen showing borders for its 422 municipalities and its location in Germany. Shapefile sources: gds-srv.hessen.de/atomfeed/DigVGr-epsg25832-shp.zip; https://www.bkg.bund.de/.

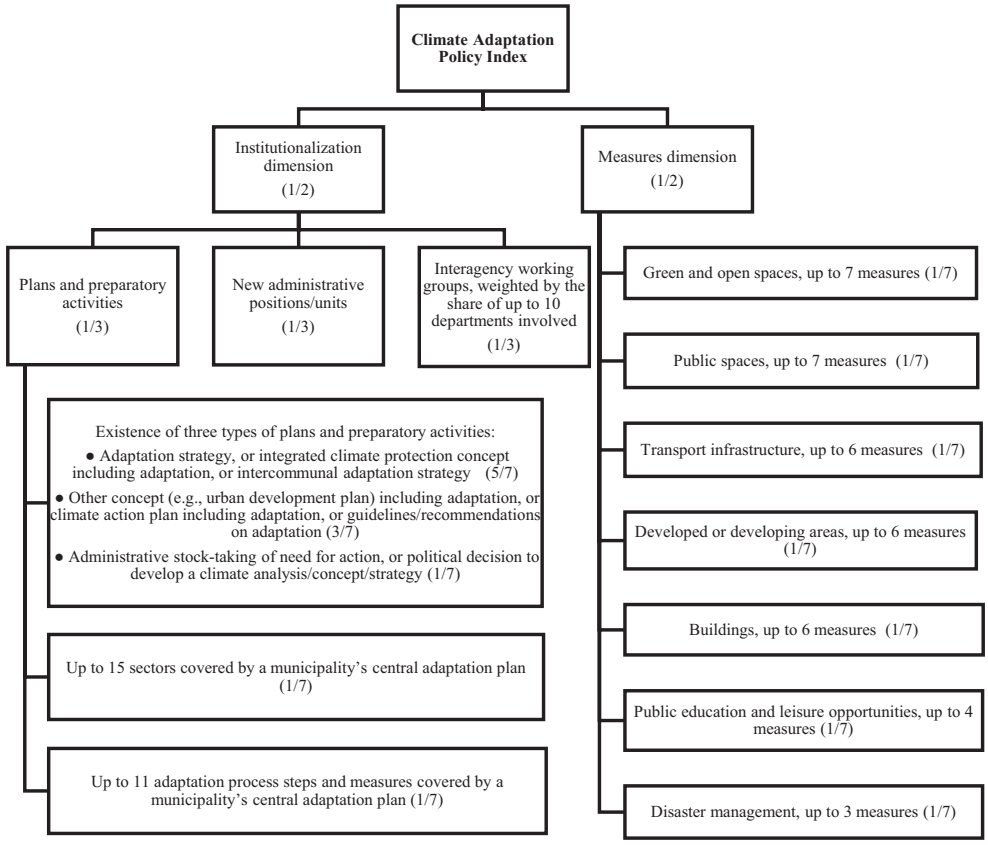

FIGURE A2 Construction of the Climate Adaptation Policy Index (CAPI). Fractions in parentheses are the weights applied to each dimension and indicator.

TABLE A1 Pairwise correlations.

Variables	(1)	*(2)*	*(3)*	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) CAPI	**1.000**														
(2) Institutionalization	***0.860***	1.000													
(3) Measures	***0.826***	0.423	1.000												
(4) Adaptation plans	**0.685**	***0.743***	0.395	1.000											
(5) Sectors in adaptation plans	**0.639**	***0.653***	0.413	0.787	1.000										
(6) Process steps in adaptation plans	**0.691**	***0.714***	0.437	0.769	0.863	1.000									
(7) New staff positions	**0.610**	***0.783***	0.219	0.300	0.285	0.345	1.000								
(8) Interagency working group	**0.623**	***0.651***	0.387	0.385	0.418	0.514	0.269	1.000							
(9) Green spaces, forestry, and agriculture	**0.602**	0.303	***0.735***	0.262	0.273	0.266	0.156	0.309	1.000						
(10) Public spaces	**0.627**	0.321	***0.760***	0.259	0.310	0.368	0.208	0.268	0.460	1.000					
(11) Transport infrastructure	**0.635**	0.431	***0.652***	0.307	0.375	0.376	0.315	0.315	0.490	0.440	1.000				
(12) Developed or developing areas	**0.638**	0.319	***0.780***	0.286	0.319	0.358	0.124	0.384	0.528	0.573	0.490	1.000			
(13) Buildings	**0.539**	0.233	***0.701***	0.217	0.183	0.202	0.162	0.149	0.440	0.415	0.408	0.474	1.000		
(14) Public education and leisure	**0.671**	0.475	***0.667***	0.504	0.462	0.500	0.227	0.354	0.400	0.446	0.314	0.390	0.363	1.000	
(15) Disaster management	**0.357**	0.033	***0.597***	0.094	0.127	0.095	−0.053	0.129	0.268	0.413	0.280	0.370	0.305	0.252	1.000

Note: See Table 2 in the main text for the construction of the variables. Correlations with composite CAPI score in bold. Correlations with dimensional scores in bold-italic.

TABLE A2 Summary statistics of regressors.

	N	Mean	SD	Min	Max
Population size (log)	211	9.22	0.98	6.88	13.55
Population growth	211	0.52	5.74	−12.92	27.43
Tax revenue p.c. (log)	211	6.33	0.57	5.23	9.24
Public debt p.c.	211	1.27	0.90	0.06	6.13
Industrial employment	211	31.07	16.46	0.00	92.74
Green seats	211	6.91	6.69	0.00	29.73

TABLE A3 Regression models predicting adaptation policy output in 200 Hessian municipalities with fewer than 50,000 inhabitants.

	CAPI				Institutionalization				Measures			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Development												
Population size (log)	0.50***			0.50***	0.87***			0.86***	0.36***			0.37***
	(0.07)			(0.07)	(0.15)			(0.17)	(0.06)			(0.07)
Population growth	−0.01			−0.00	0.01			0.02	−0.01			−0.01
	(0.01)			(0.01)	(0.02)			(0.02)	(0.01)			(0.01)
Fiscal capacity												
Tax revenue p.c. (log)		0.28***		0.02		0.53***		0.11		0.17***		−0.01
		(0.09)		(0.08)		(0.18)		(0.21)		(0.06)		(0.08)
Public debt p.c.		−0.01		0.02		0.06		0.14		−0.04		−0.03
		(0.05)		(0.05)		(0.09)		(0.13)		(0.05)		(0.05)
Interests												
Industrial employment			−0.00	0.01**			−0.00	0.01**			−0.00	0.00
			(0.00)	(0.00)			(0.01)	(0.01)			(0.00)	(0.00)
Green seats			0.03***	0.01			0.05***	0.02			0.02***	0.01
			(0.01)	(0.01)			(0.01)	(0.02)			(0.01)	(0.01)
N	200	200	200	200	200	200	200	200	200	200	200	200
Log likelihood	−307.57	−327.97	−327.14	−305.91	−290.22	−326.10	−326.71	−284.36	−366.88	−381.73	−380.62	−365.86
AIC	621.14	661.94	660.29	625.82	586.43	658.21	659.43	582.72	739.76	769.46	767.24	745.73

Note: Unstandardized coefficients. Robust standard errors in parentheses.

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

TABLE A4 Survey questions.

Question	Response options
Does your municipality already have strategies, concepts, political decisions, or similar preparatory work for adaptation to climate change, or are such approaches in process or planned? (Please select the applicable answer for each option) • Administrative stock-take of the need for action • Political decision to produce a climate analysis, a concept, or a strategy • Municipal climate adaptation strategy • Municipal climate action strategy with adaptation • Intermunicipal climate action concept/strategy with neighboring municipalities • Climate adaptation concept at the county level • Climate adaptation as an explicit part of another concept (e.g., urban development, urban planning, etc.) • Program of measures or guidelines/recommendations for climate change adaptation • Political decision for the implementation of strategies, concepts, or other guiding documents • Other municipal documents:	Available (since the year...)/Under preparation/Planned/No
Which sectors are covered by your municipality's central adaptation concept? (Please select all applicable answers) • Human health • Planning • Construction • Transport, mobility, and communication • Water management, flood control • Soil • Biological diversity, nature, and environmental protection • Agriculture • Forestry • Energy economy • Finance • Disaster management • Industry • Tourism • Education	1/0
Which steps of a climate adaptation process are covered by your municipality's central adaptation concept? (Please select all applicable answers) • Preliminary studies of climate change (impacts) • Impact studies, risk analyses • (Public) participation of citizens, businesses, civil society groups, and others • Adaptation measures in land-use planning or urban development • Mainstreaming in administrative processes • Adaptation measures to extreme precipitation • Adaptation measures to extreme heat • Adaptation measures in green and open spaces • Educational measures • Monitoring of adaptation measures • Evaluation of adaptation measures	1/0

(Continues)

TABLE A4 (Continued)

Question	Response options
Have new staff positions or units dealing with climate change adaptation been established in your municipal administration?	Yes/No
The effects of climate change and corresponding adaptation strategies typically touch upon multiple departments. Is there an interagency or cross-sectoral working group in your municipality coordinating adaptation measures?	Yes, since... (please add the year)/ Under preparation or planned for the year ... (please add the year)/No
Which agencies/departments are involved in this working group? • Environment • Urban development • Urban planning • Building construction • Transport • Green space • Civil engineering • Water disposal • Water supply • Health	Leading/Involved/Not involved
We will now turn to the concrete climate adaptation measures. Which measures does your municipality pursue in order to adapt to the long-term consequences of climate change?	
...in the area of open and green spaces, forestry and agriculture? (Please select all applicable answers) • Keeping fresh-air corridors open • Design and redesign of green spaces (e.g., parks) • Network green spaces and corridors • Watering public green spaces and/or agricultural areas during heat periods • Support of mixed forest and diversity of species (e.g., in forests and parks) • Climate adjusted, site-specific selection of trees and plants • Support of climate-ready water governance • Other:	Implemented/Adopted/Discussed/Not pursued
...in public spaces? (Please select all applicable answers) • Creation of drainage and retention areas • Planning of multifunctional areas as "water plazas" (e.g., play-, sports-, and parking grounds as temporary precipitation storage) • Creation of "green oases"/shading in public space • Creation of public drinking water fountains • Creation, maintenance, or raise of dams, dikes or flood protection walls • Creation or maintenance of flood retention basins, barrage dams, and polders • Ecological flood control (e.g., through renaturation of water bodies or pasture land) • Other:	Implemented/Adopted/Discussed/Not pursued
... with a view to transport infrastructure? (Please select all applicable answers) • Protection of underpasses (e.g., with drainage or seepage ditches) • Greening of streets • Greening of railway tracks • Climate-ready public transport stops (heat protection etc.) • Light surfaces for traffic areas • Shadowing of parking spaces • Other:	Implemented/Adopted/Discussed/Not pursued

TABLE A4 (Continued)

Question	Response options
... in developed or developing areas? (Please select all applicable answers) • Greening of brownfields • Setting development limits • Creation of retention areas within settlements • Surface unsealing • Coloring of traffic routes and plazas • Creation of open water surfaces and streams (e.g., fountains, water features) • Other:	Implemented/Adopted/Discussed/Not pursued
...with buildings? (Please select all applicable answers) • Greening of roofs and facades • Thermal insulation • Cooling of buildings • Shadowing of buildings • Shadowing elements on buildings • Backwater protection • Other:	Implemented/Adopted/Discussed/Not pursued
...with a view to public education and leisure opportunities? (Please select all applicable answers) • Creation of new, sustainable leisure activities (e.g., in case of reduced snowfall) • Creation of new educational offers related to sustainability/nature (e.g., a climate change tour) • Sensitization and information of citizens about climate change and adaptation in general • Sensitization and information of citizens about specific topics/hazards (e.g., handouts about heat-related behavior, information about heavy rainfall, brochure with tips for builders or farmers) • Other:	Implemented/Adopted/Discussed/Not pursued
... in the area of disaster management? (Please select all applicable answers) • Expansion of technical capacities (e.g., vehicles, equipment, etc.) • Expansion of personnel capacities • Creation of early warning systems (e.g., in collaboration with hospitals and care facilities, retirement homes, housing companies, and other social service providers) • Other:	Implemented/Adopted/Discussed/Not pursued

Note: Own translation from German by the authors. The "other" categories were not used due to the small number of answers.