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Managing climate impacts—an analysis of adaptation funding in German cities and districts

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With accelerating climate change, local governments must enhance adaptation efforts. Germany's federal adaptation funding scheme (DAS) supports municipalities in developing adaptation strategies, yet disparities in funding distribution remain. This study analyses DAS adaptation funding across 400 German cities and districts using multilevel regression models. Findings reveal that urban areas receive more funding, influenced by higher education levels, income, and political support, and prior climate mitigation funding. In contrast, the sensitivity dimension of climate vulnerability shows weak correlations with funding allocation. These results highlight an urban-rural divide in climate adaptation financing and emphasize the role of socioeconomic and political factors in shaping local climate action. By addressing gaps in adaptation policy implementation, this study contributes to the understanding of climate governance and provides insights for improving the equitable distribution of adaptation funding.

With accelerating climate change and associated hazards, like droughts, heavy rainfall, or rising sea levels, local authorities face increasing pressure to invest in adaptation measures[1–3]. Climate adaptation refers to adjustments that reduce vulnerability in ecological, social, or economic systems in response to actual or expected climate change impacts[4,5]. Local climate adaptation may, therefore, be understood as the intentional actions taken by local actors to deal with present or anticipated climate change impacts. While many local authorities are already taking steps to adjust to rising temperatures, extreme weather events, or other climate-related hazards and to build resilient societies, others are struggling to keep pace with climate change[6–10]. There are numerous barriers hampering the development and implementation of local climate adaptation strategies, including conflicting timescales and interests, lack of financial resources, fragmentation of public bureaucracies, or uncertain immediate societal costs and future benefits[11]. Moreover, recent studies have highlighted deeper causal processes and bureaucratic traditions affecting the implementation of climate adaptation measures[12,13]. As a result, international and national funding schemes seek to reduce the challenges of complex decision-making processes and incentivize local climate adaptation[14–16].

Existing research has explained the focus of international climate adaptation funding schemes on local communities[17] and highlighted the financing gap for effective local climate action[18,19]. Furthermore, scholars have examined the delivery of adaptation finance at the local level[20] or studied the Green Climate Fund as the largest international climate funding mechanism set up by the United Nations Framework Convention on Climate Change, UNFCCC[16,21]. At the same time, knowledge about national incentives for local climate adaptation is still limited[22] argue that significant research gaps exist regarding the impact of national climate funding policies.

Germany revised its adaptation funding strategy (DAS) fundamentally in 2021 to provide an incentive for municipalities or districts to develop local adaptation programs and to employ climate adaptation managers. The DAS was inspired by the National Climate Initiative ("Nationale Klimaschutzinitiative"), a successful national funding program that has allowed local-level governments to apply for federal-level funding for climate protection management since 2008. An analysis of the funding instrument for climate mitigation indicates important disparities in funding distribution across regions, with urbanized and more populated areas receiving more funding[23]. Similarly, the DAS was created to advance effective local adaptation. The underlying idea is that local adaptation management can tailor their strategies and activities to the specific needs. In two funding calls, local governments could, so far, apply for financial support for strategic development and creative implementation through novel approaches to local adaptation strategies. In the latest 2023/2024 funding call, the focus was on nature-based solutions for climate adaptation, while the first call was broader, inviting local authorities to address their climate change problems systematically. Due to the recent creation of the DAS, there exist many

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questions regarding the strategy: How are support requests distributed among local administrations? Are those cities and districts that have successfully received climate mitigation funding also more likely to receive funding for climate adaptation? What are the characteristics of local authorities receiving the highest amounts of funding?

Taking the lack of knowledge on climate adaptation finance as a starting point, this paper investigates how far and under what conditions cities and districts have participated in the DAS funding instrument (i.e., applied for and received funding) since its implementation in 2021.

With this research focus, we contribute to the climate policy literature by tackling the "black box of adaptation decision-making"[12] and the "adaptation policy paradox"[7]. The latter refers to an adaptation policy implementation gap. In other words, while the impacts of climate change are felt ever more intensely at the local level, comprehensive implementation of adaptation measures remains to be done[12,24]. The so-called black box of adaptation decision-making first refers to the lack of understanding of complex decision-making processes that lead to the aforementioned implementation deficit and successful climate adaptation. This also entails a question of justice, as those implementation deficits are unevenly distributed[25,26]. Recent research on the matter highlights that the spatial injustice[27] of climate adaptation is linked to an unequal spatial exposure to climate hazards, such as floods, heat, or droughts, leading to imbalanced impacts on health, wealth, and safety, depending on the socio-economic development status of a region. Inequality is further amplified by maladaptive practices in urban planning or land-use policies[28], or a lack of participation in respective decision-making processes, particularly regarding the inclusion of minorities or marginalized groups[29]. In addition, climate adaptation measures can also lead to a gentrification of cities, city districts, districts, or municipalities (e.g., rising prices) that might force poorer people to leave the respective areas. Hence, if high adaptation standards are unequally distributed, this might reinforce societal inequalities.

We study all 400 German cities and districts ("kreisfreie Städte" and "Landkreise") to test hypotheses concerning disparity in the likelihood and amount of adaptation funding, using data from DAS and regional statistics. We focus on cities and districts because, in the German federal system, cities and districts are the most appropriate level to analyze local-level climate policy. The German federal system is organized into three levels: the federal level ("Bundesebene"), the state level ("Landesebene"), and the local level ("Kommunalebene") The latter is further sub-divided into the level of cities and districts, on one hand, and the municipalities ("Gemeinden"), on the other. We focus on cities and districts as they are on the same level of governance, as opposed to municipalities, which are subordinated to the districts[30]. Put differently, studying the districts allows us to aggregate all local climate adaptation endeavors at the district level and compare them to the city level. Furthermore, cities and districts connect the municipal, state, and federal levels. While political decisions on climate adaptation objectives and instruments usually reside at the federal and state levels, local governments, at the district or city level, are responsible for implementing climate policies[31]. At the same time, the literature highlights that local authorities have relative autonomy in managing their specific climate change problems[32,33]. This aspect of autonomy is important as local responsibilities are categorized into mandatory and voluntary tasks. Mandatory tasks are legally required, including waste management, water supply, and urban land-use planning ("kommunale Pflichtaufgaben")[30,32]. In contrast, voluntary tasks are undertaken at the discretion of the local governments ("freiwillige Selbstverwaltungsaufgabe")[32,34,35]. Climate action often falls into the voluntary category, meaning local authorities can choose whether and how to engage in climate mitigation and adaptation beyond their obligatory duties. Hence, we consider that the extent and nature of climate adaptation activities differ significantly locally.

We expect variation in the participation of local authorities in the DAS. First, due to Germany's federal system, mitigation and adaptation policies may vary across German states ("Länder"), reflecting differences in regional priorities, capacities, and funding schemes[32,36]. Not only do climate ambitions vary across federal states, but the Länder also differ in their funding streams. For instance, Bavaria co-funds climate adaptation managers, North-Rhine-Westphalia offers grants to attain the European Climate Adaptation reward, and Baden-Württemberg and Schleswig-Holstein support local authorities through regional networks of energy and climate managers[37]. These aspects affect the capacity of local authorities to manage their voluntary climate tasks. Southern and Western cities are not only wealthier, providing them with the necessary resources to apply for co-finance and to implement mitigation measures, but they often also benefit from the aforementioned state climate funding schemes. An analysis of the distribution of climate mitigation funding has found that Southern and Western states have received more funding than Northern and Eastern states because they have larger financial budgets for climate action[23]. As German cities and districts are embedded in a multilevel governance structure and differ regionally regarding their climate action capacities, we expect the following:

H1: Cities and districts in Southern and Western states are more likely to apply for DAS funding successfully and to receive higher amounts compared to cities and districts in Eastern and Northern states.

Furthermore, we assume that adaptation activity is related to a city's or district's climate risk. The IPCC defines climate risk as an interaction between climate-related hazards, vulnerability, and exposure of the affected system[4]. Germany is exposed to various climate-related hazards, such as intensifying urban heat island effects with higher temperatures within cities compared to their rural surroundings, which cause increasing heat-related health risks[38–40], and increased risks of heavy precipitation and pluvial flooding[41,42]. While these hazards reflect the physical dimension, i.e., the actual climate event, exposure (who or what is being harmed) and vulnerability (how badly) reflect the socio-economic dimension of climate risk. Literature suggests that local exposure to climate-related hazards and related risk perception determine the extent to which local actors engage in climate adaptation[24,43–45]. Hence, adaptation measures are meant to reduce the exposure of the local population, for example, by relocating communities away from floodplains or building coastal setbacks. In contrast, recent studies show that for the second component of climate risk, local-level vulnerability, the association is less clear[46,47], and the adoption of adaptation measures is not an automatic consequence, even if vulnerability is high. This is because the level of vulnerability is a function of different factors, such as the sensitivity to climate-related hazards (i.e., how badly a system is affected), and how well a system can cope with and adapt to a hazard[4,48]. A low capacity to act, e.g., due to a lack of financial or political resources, can create adaptation barriers or may result in different adaptation strategies.

Due to spatial diversity, Germany's climate-related hazards vary. For example, in Eastern Germany, low water availability and summer droughts create vulnerabilities in many sectors[49], but in particular in agriculture and forestry. On the other hand, Southwest Germany is particularly prone to high temperatures, causing health impacts for vulnerable population groups (children and the elderly). Further examples are storms and sea level rise in the coastal regions, and floods in the Alpine and Low Mountain regions. However, how vulnerable these different regions are towards these risks depends on their sensitivity; that's how strongly they react (e.g., flooding in densely populated areas, heatwaves in regions with a high share of the elderly population, or drought in an area with high levels of agricultural land). In accordance, research has shown that highly vulnerable communities (e.g., structurally weak regions with a large share of elderly people) more often rely on low-cost, short-term, or informal strategies (e.g., using household fans during heatwaves, informal water storage during droughts, or shifting farming calendars based on local knowledge), whereas less vulnerable communities (wealthier, more highly educated) might invest more long-term, transformational adaption measures (e.g., infrastructure programs such as coastal protection barriers, managed retreat, or climate-resilient urban design)[4,50–52]. Hence, we assume that vulnerable cities and districts are less likely to apply for climate adaptation funding to develop long-term adaptation strategies and hire climate adaptation managers.

H2: Cities and districts with higher climate vulnerability are less likely to receive DAS funding.

Climate policy studies have identified several factors that may explain the adaptive capacity of local authorities. For instance, studies examining the members of climate justice movements have indicated that younger people and those with higher education better understand climate impacts and, therefore, generally support adaptation action compared to people with fewer years of schooling or elderly people who my still perceive climate change as a distant issue causing costs while benefits lay in the future[53–55]. Moreover, scholars have suggested that the socio-economic and political local contexts also determine the adaptive capacities of cities and districts[9,56–58]. Accordingly, studies have argued that there is a positive relationship between left/green governments and ambitious local climate action[59–62] and that wealthier communities may have more resources to apply for climate funding. In particular, urban cores—typically characterized by high population density, strong economic activity, better infrastructure, higher levels of education, greater wealth, and more progressive political attitudes—often combine these favorable factors[63]. However, similar characteristics can also be found in cities more broadly and in peri-urban settings, such as districts with high-class residential areas of better housing and with good infrastructures in larger metropolitan areas (so-called "Speckgürtel" in German) or regional centers[23,64]. Therefore, we assume that the degree of urbanization influences the likelihood of engaging in climate change adaptation action. Accordingly, we formulate the following hypothesis:

H3: Cities and urbanized districts are more likely to receive DAS funding compared to rural cities and districts.

While many cities and districts have developed separate climate mitigation and adaptation strategies, scholars and practitioners have increasingly called for integrated approaches in order to create synergies and maximize outcomes[65–68]. They argue that knowledge and experiences from mitigation activities can be consolidated to develop comprehensive adaptation frameworks[67,69]. For instance, Araos and colleagues have found that early-stage adapters have reported extensively on mitigation initiatives and, with increasing awareness of the impacts and vulnerabilities of climate change, have taken the first steps towards adaptation[70]. Hence, we expect the following:

H4: Cities and districts that have already received federal funding for climate change mitigation are more likely to receive DAS funding.

Methodologically, we combine some descriptive analyses with regression to identify factors that drive Germany's cities and districts to (not) participate in the DAS funding program. Our results show that the patterns are very similar to what Zeigermann et al.[23] have already found out for mitigation: It is the cities and urbanized districts that tend to participate more often in the funding program, i.e., successfully apply for funding. We show that higher levels of education, younger people, and income among the population are partly associated with a higher likelihood of participating in the DAS funding program. Based on our analysis, we show that it is a combination of urbanity, wealth, left and green parliaments, and education that explain greater participation in the DAS funding program, and show that the funding instrument lacks important incentive structures to engage rural areas more effectively.

Results

Distribution of adaptation funding across Germany

Figures 1 and 2 show the distribution of adaptation funding across Germany. Figure 1 compares the total sum of funding under the DAS funding program across the 16 Länder in Germany and the mitigation funding received under the NKI in the year 2021. Not all the states ("Länder"), districts, or cities participate yet in the DAS funding program and receive

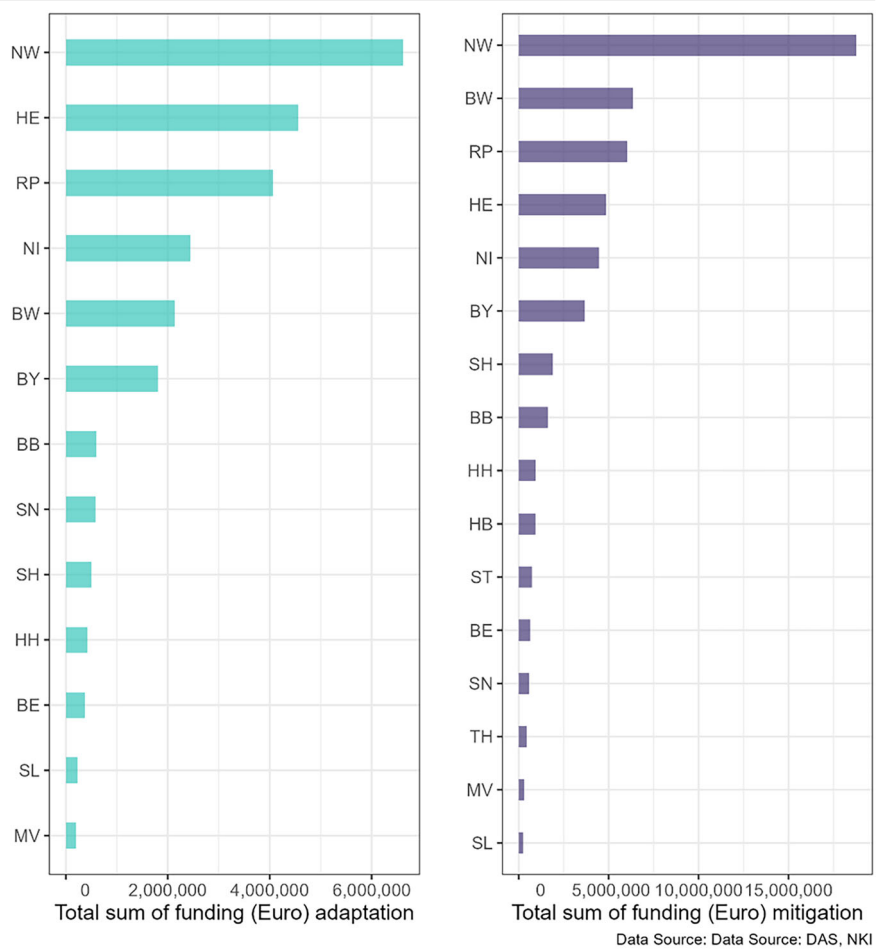


Fig. 1 | Total sum of funding across Länder. Comparing adaptation funding (status 2023/24) and mitigation (status 2021).

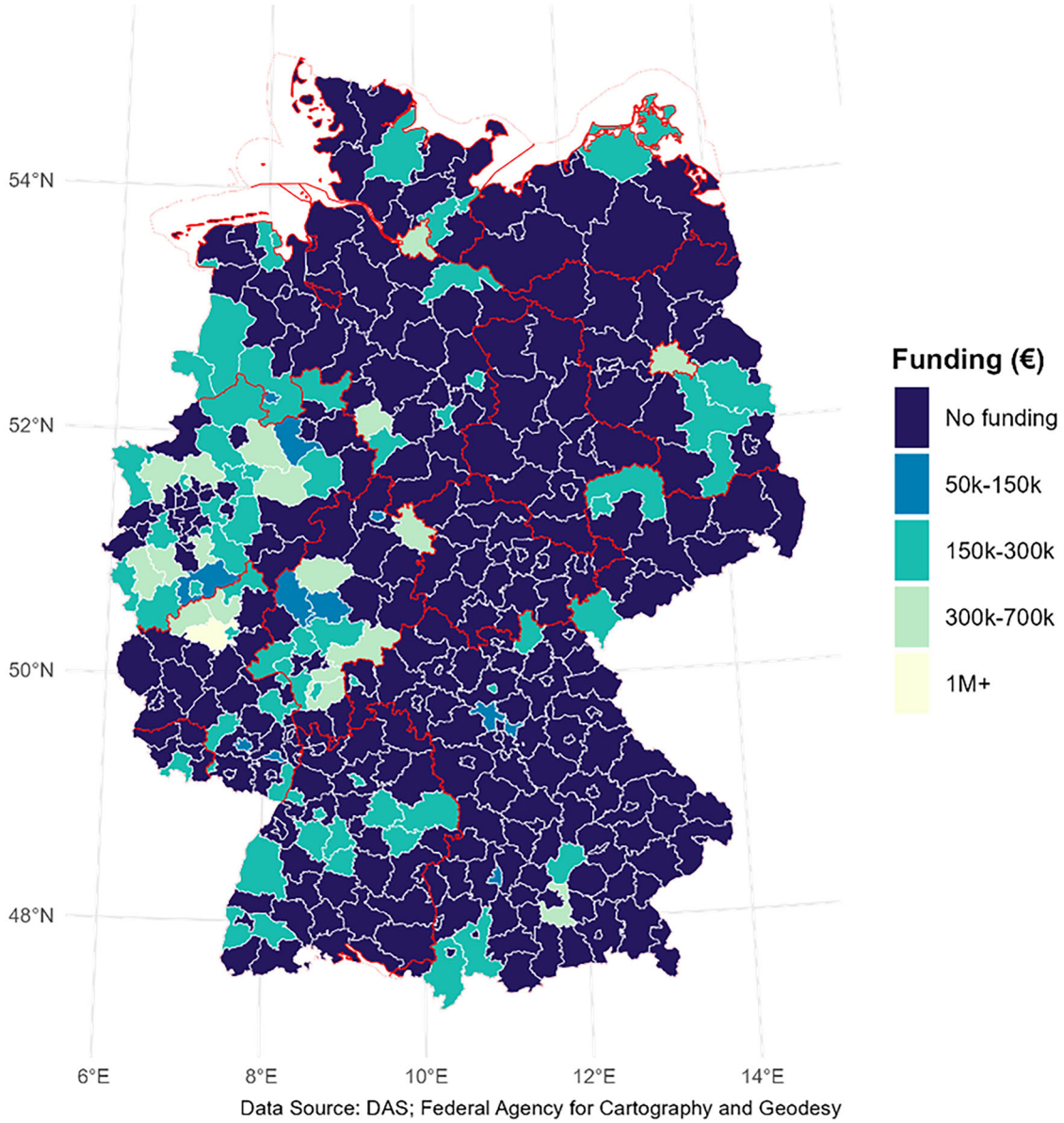


Fig. 2 | Map of adaptation funding across Germany. Adaptation funding distribution across Germany's cities and districts in 2024.

climate adaptation funding (see also Fig. 2). The main receiver Länder are North-Rhine-Westphalia (NW), Hessen (HE), Rhineland-Palatinate (RP), Lower Saxony (NI), Baden-Württemberg (BW), and Bavaria (BY). Also, the Western and Southern Länder receive more funds than the Eastern and Northern parts of Germany. Overall, the patterns look similar to the distribution of climate mitigation funding under the NKI funding program[23], but the funds for adaptation are much smaller. Clearly, this is also because the adaptation funding program has only recently been installed, while the mitigation program started in 2008 and is thus more well-known, and many municipalities already have experience with the program.

Figure 2 shows that most of the German cities and districts do not receive any adaptation funding, and most of those that receive funding are located in Western Germany, i.e., in North-Rhine-Westphalia and Rhineland-Palatinate. North-Rhine-Westphalia particularly stands out. Not only are cities and districts successful in receiving national funding, but they can also apply for funding of the "Klimaanpassung.Kommunen.NRW" program (initiated by the government of North-Rhine-Westphalia together with the European Regional Development Fund (ERDF) supporting climate adaptation projects with a total of 37 million euros, 2021–2027) and for the European Climate Adaptation reward. Two other—smaller—centers of successful climate adaptation funding can be found in the districts surrounding Frankfurt (Main) and Darmstadt in the West-German state Hesse, as well as in the districts near Koblenz in the state Rhineland-Palatinate. While the latter rural area is known for heavy precipitation and flooding risks, especially after the catastrophic flooding in 2021 in the Ahr Valley that may explain the high engagement adaptation funding[42], the districts in Hesse are examples of residential areas with a good infrastructure and an active commuting activity to the financial hub Frankfurt, that was also ranked among the top-ten German cities due to its climate mitigation and adaptation[2]. In these highly urbanized districts, learning, knowledge diffusion, and available capacities for applying for adaptation funding might explain the successful funding rather than local risks[71]. In all other German federal states, there are only very few isolated districts and cities that have already applied successfully for adaptation funding under the DAS program. The map does not reveal a North-South divide.

Distribution of funding types

Figure 3 shows the distribution of funding types across cities and districts. Almost half of them ($n = 175$) do not have climate funding. This is followed by 129 districts and cities that receive climate mitigation funding. Sixty-two

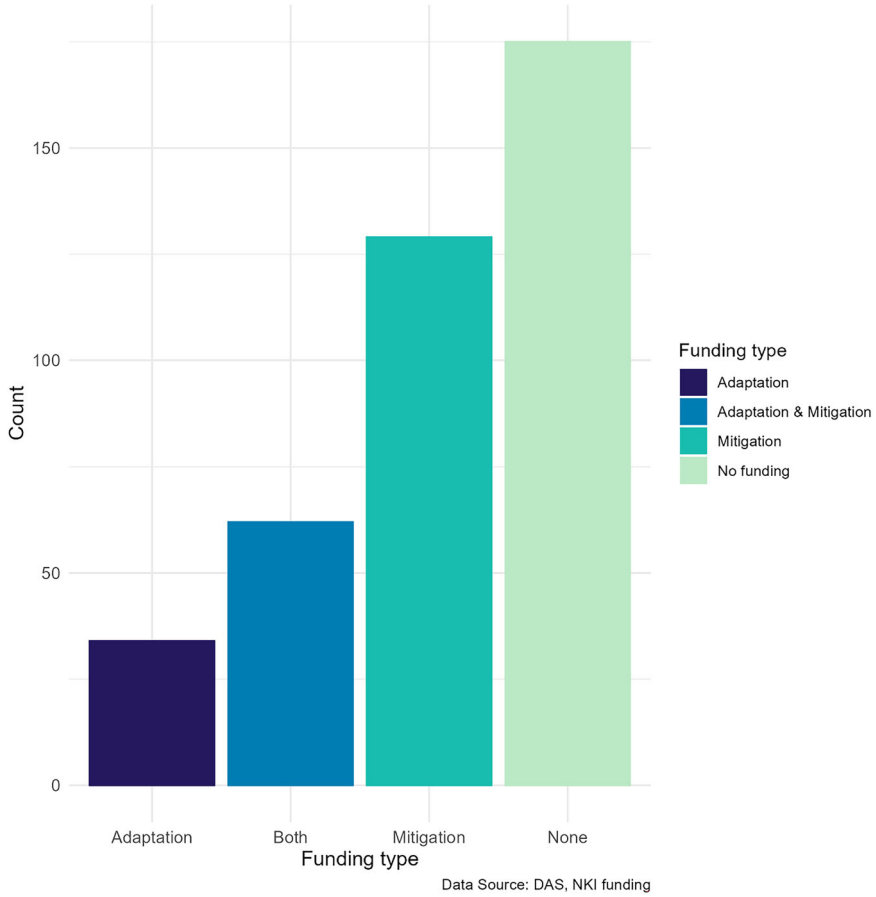


Fig. 3 | Distribution of funding types. Adaptation (status 2023/24) and mitigation (status 2021).

districts and cities receive mitigation and adaptation funding, and 34 districts and cities receive only adaptation funding. In total, 96 districts and cities, i.e., one-quarter of Germany's cities and districts, receive adaptation funding. The dominance of mitigation funding across Germany can be partly explained by the fact that the NKI program has existed much longer (since 2008). At the same time, it is telling that in this long period of more than 15 years, only half of the districts and cities have applied for mitigation funding. It seems unlikely that the picture will be different for adaptation in the future, given the similarities across the two funding schemes.

Figures 4 and 5 reveal that highly urbanized (predominantly urban) districts and cities have applied most successfully for funding under the DAS funding program, followed by intermediate districts with mixed structures of rural areas, peri-urban areas, and small cities. These patterns are similar to mitigation funding applications and point to a severe gap between rural and urban areas.

Explaining variation in the distribution of adaptation funding

The regression models presented in Table 1 confirm and extend the results of the descriptive analysis presented above. As described in greater detail in the section "Methods," we have run several regression models to test for different setups and variable combinations. All models are multilevel, logistic regression models, where we control for the observed variance (see Fig. 1) across the 16 Länder using fixed effects. The dependent variable reflects whether a city or district received funding under the DAS funding program (1) or not (0); see Table 2. See the section "Methods" for a detailed operationalization of the variables and a discussion of their collinearity.

Table 1 reveals that the variance across the Länder is strong (*see H1: Var: state (Intercept)*). This supports the results discussed related to Figs. 1 and 2, but only partly supports H1: Adaptation funding under the DAS funding program is clustered mostly in the Western federal states and not so much in the Southern States, where only a small number of cities and districts have applied for funding (but high amounts). Hence, we only partly confirm H1. The variance statistic decreases from *Model-H2* to the *Final model*, i.e., when we test for various factors. This implies that parts of the variance across the federal states can be explained by these factors as well.

Model-H2a only includes the selected indicators for the sensitivity dimension of vulnerability (*Share agricultural land*, *Share forest area*, and *Share elderly people*), but the parameter estimates are small and not significant. Although the effects for Share of agricultural land and forest area turn significant in the Final Model, the parameter estimates remain comparatively small. Nevertheless, the model implies, holding everything else equal, that a one unit increase in forest area increases the likelihood of adaptation funding by 5%, and a one unit increase in agricultural land leads to an increase of 4%. There is no significant effect related to the *Share of elderly people* in the population of a city or district. Model-H2b, on the other hand, shows strong, positive, and significant effects for the selected indicators for the capacity dimension of vulnerability, GDP, PC, logged, and *Higher education levels*. This implies that wealthier cities and districts with a highly educated population are more likely to apply for and receive climate adaptation funding through the DAS scheme. Interestingly, the parameter estimate for *GDP, PC*, and *logged* also only turns significant in the Final Model. We will discuss the implications of this result further below. In sum, these findings allow the conclusion that cities and districts that are less vulnerable, due to a greater adaptive capacity, are more likely to receive climate funding under the DAS scheme, whereas their effect on the sensitivity parameter is not unambiguous. Hence, we can partly confirm our hypothesis H2, given the selected indicators.

Model-H3 shows that cities and urban districts (see peri-urban and urban) significantly more often apply for and receive climate adaptation funding under the DAS funding program. The effect is strong and remains strong in the Final Model. In fact, the odds of applying for and receiving adaptation funding are 3.8 times higher in cities and predominantly urban

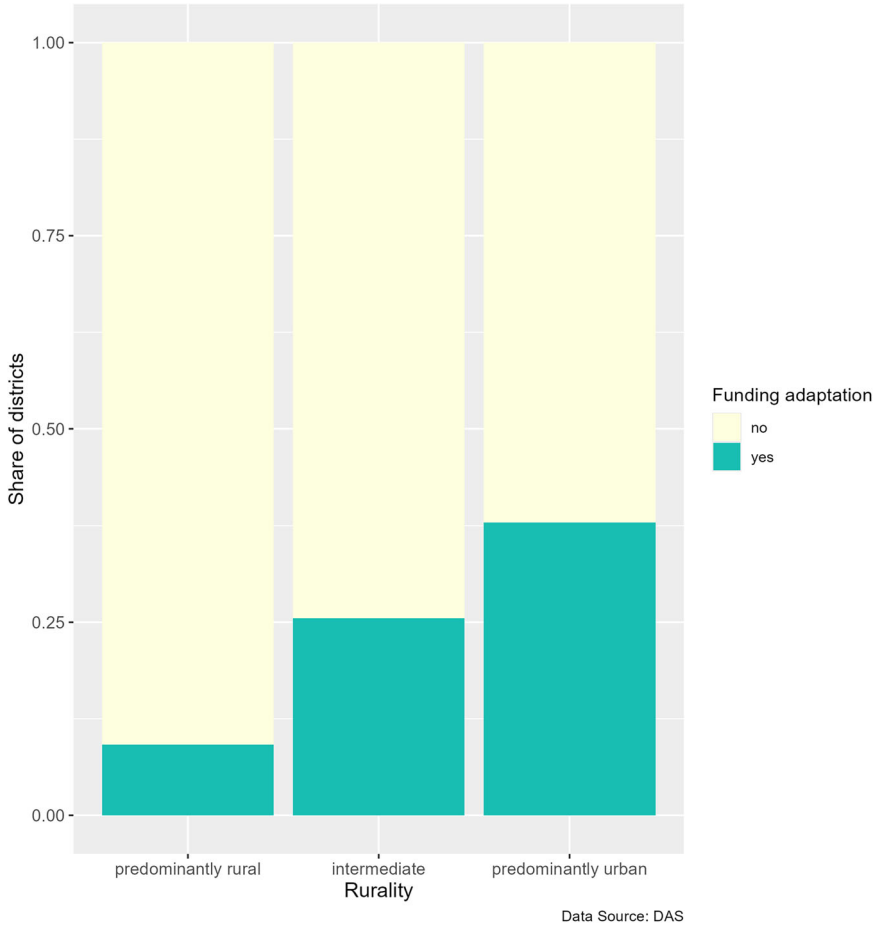


Fig. 4 | Distribution of adaptation funding (status 2023/24). The figure displays the share of adaptation funding across the different district types (rural, intermediate, urban).

districts and 2.5 times higher in peri-urban districts than in rural districts. Hence, we can confirm our hypothesis H3 that greater *Urbanity* increases the likelihood of receiving adaptation funding from the DAS funding scheme.

In Model-H4, we tested for *Mitigation funding*, i.e., participation in the NKI funding program. The model reveals a positive relationship: Districts and cities that have already applied for NKI funding in the past are 51% more likely to also apply for adaptation funding. This is also highlighted by the results presented in Fig. 2: almost two-thirds of the current districts and cities that receive adaptation funding have recently received mitigation funding (status 2021). However, when simultaneously testing for other factors, the parameter estimate is no longer significant.

Next, we tested additional demographic and political factors (Control Model): *Population density, Youth Share*, and the *Share of green and left seats* that might affect climate adaptation funding[23], but the model shows no significant effects, except for *Population density*. The parameter estimate is positive and significant. This indicates that in cities and districts with higher population density, the likelihood of receiving climate adaptation funding from the DAS scheme is higher, which is further proof of the effect of Urbanity on climate adaptation funding.

However, population density has serious multicollinearity issues with several of the other variables (for more details, see the section "Methods"). Hence, in the Final Model, we combine all factors but remove *Population density*. In fact, both other control variables, *Youth Share*, and the *Share of green and left seats*, increase in magnitude and turn significant in the Final Model. As a result, we can say that in cities and districts with a younger, greener, and/ or left-wing electorate, the odds of receiving climate adaptation funding through the DAS scheme are much higher.

Overall, the different model specifications do not change any signs of the parameter estimates, which points to a robust model. However, we observe a change in significance levels for some variables. This is an indication of confounding effects; hence, some of the variables mask the true effects until they are controlled. We assume that this is the case for *GDP, PC, logged, the Share of green and left seats, and Higher education*, which turn only then significant when tested in combination with the *Urbanity* variables (see Final Model).

This allows the following conclusions: Firstly, higher levels of education (*Higher education*) among the population are very clearly and strongly associated with a higher likelihood of participating in the DAS funding program, so a higher *Share of left and green seats* in the city and district parliaments. We further see a positive relationship between the income level (*GDP pc, logged*) and adaptation funding. But as the factors only become significant when controlled for in combination with *Urbanity*, this result implies that it is usually cities or urbanized districts that are wealthy, left, and/or green, and highly educated, that tend to apply for and receive adaptation funding under the DAS funding program.

Discussion

The assessment of the German adaptation funding strategy (DAS funding program) conducted in this study provides new insights into the impact of national climate funding policies. By examining the distribution of climate adaptation funding across cities and districts, we can analyze different factors explaining the success of national climate adaptation finance schemes. Table 2 summarizes our hypotheses and results from the Final Model presented in Table 1 and the descriptive analysis. From these insights, it is possible to derive some general conclusions about the adaptation policy implementation gap that may also help improve the 2021 German adaptation strategy.

In Germany's federal system, climate policy is a matter of national decision-making, embedded in European and international climate

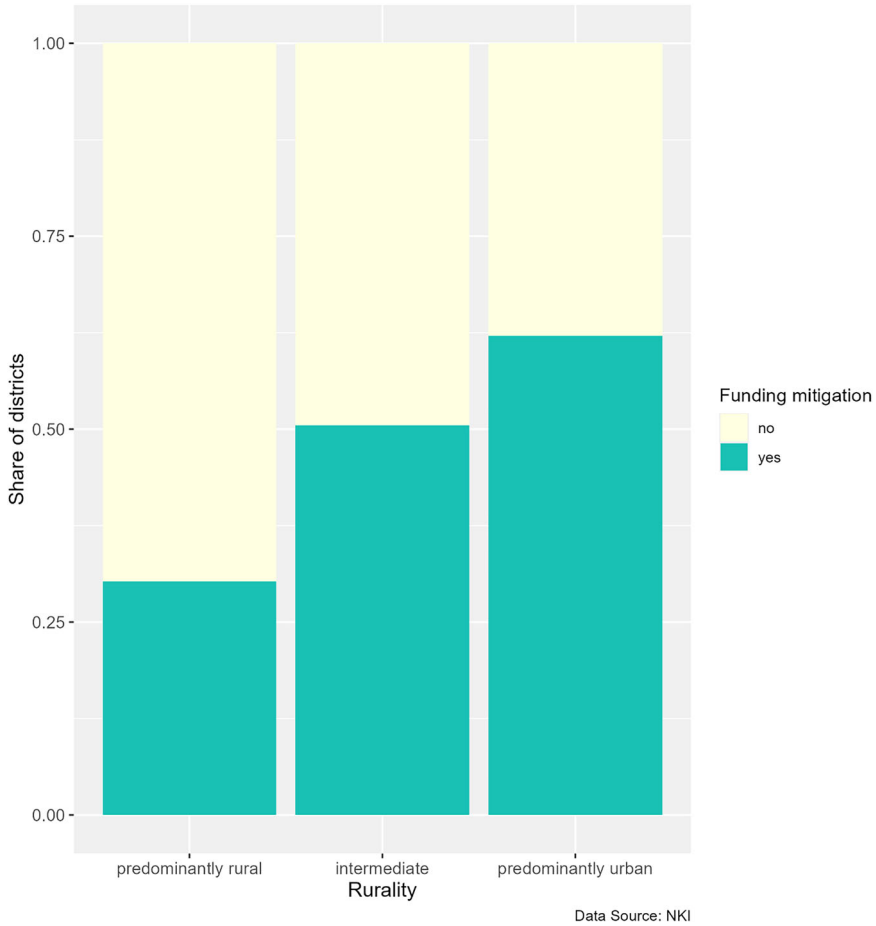


Fig. 5 | Distribution of mitigation funding (status 2021). The figure displays the share of adaptation funding across the different district types (rural, intermediate, urban).

obligations. Nonetheless, climate action varies across Länder, reflecting differences in regional priorities, capacities, and funding schemes[32,36]. Although it is very early to derive general patterns characterizing the distribution of adaptation finance across Germany, this study suggests that cities and districts in East Germany apply less often and thus receive less climate adaptation funding. Further, we identified substantial differences between North-Rhine-Westphalia, Hesse, and Rhineland-Palatinate, which participate most often in the DAS funding scheme, and all the other federal states. These findings align with previous studies examining the distribution of mitigation finance[23]. Yet, our hypothesis (H1) is only partly confirmed as we could not find a clear North-South divide across the federal states.

The hypothesis involving vulnerability as a factor explaining climate adaptation action (H2) can only be partially confirmed. In other words, testing selected indicators for climate sensitivity (i.e., the share of agricultural land, forest area, and elderly people) does not predict a higher or lower likelihood of applying and receiving climate adaptation funding. In contrast, cities and districts that are wealthier and better educated, factors that reduce vulnerability, tend to be more likely to apply for climate adaptation funding. On the one hand, this result seems to support studies contesting the link between local-level vulnerability and climate change adaptation[46,47]. On the other hand, our initial findings should not be overestimated. Our study highlights limited data availability regarding local-level vulnerability, as there is, to date, and to the best of our knowledge, no adequate dataset available that systematically conceptualizes and investigates the vulnerability of all cities or districts in Germany, systematically. Further research on local climate action should address this research gap.

Our analysis finds evidence for a rural-urban divide in local climate adaptation (H3). We show that cities and predominantly urban districts have received climate adaptation funding more often. But being a city or a highly urbanized district is not a sufficient explanation. Our results highlight that socio-economic factors, such as wealth and education, as well as political factors such as the composition of local parliaments, also seem to influence the distribution of climate adaptation funding. In fact, it is usually the wealthier, more educated cities, and with left-wing and/ or green members of parliament, who show higher rates of climate adaptation funding. Further research should investigate how these factors are interrelated and disentangle the underlying causal mechanisms. This is in particular interesting and relevant given the rapidly changing political landscape with increasing support for extreme right-wing and populist parties in many Western countries.

This uneven distribution of funding reflects broader spatial disparities between densely populated and affluent urban centers with higher capacities for climate action and sparsely populated rural areas, mainly in Eastern Germany (see also H1). This can be explained by the high problem pressure in densely populated cities that rely on an urban infrastructure[66,72] and that suffer from temperature-related health problems[38–40]. In addition, with higher shares of highly educated people in cities compared to rural districts, there seems to be greater awareness of the need to adapt to climate change. Moreover, urban cores and high-class residential areas in peri-urban districts seem to attract more affluent people and businesses, leaving rural regions to deal with more socio-demographically vulnerable groups with fewer resources to apply for climate adaptation funding and with pressing socio-economic challenges to deal with. These structural disadvantages reinforce the vulnerability of rural regions and perpetuate existing socio-spatial inequalities. As similar patterns can be observed in regard to climate mitigation funding[23], our results suggest that smaller cities and rural districts are systematically disadvantaged in accessing national climate finance. Future research should explore the integration of justice into climate policy and examine (funding) mechanisms supporting climate action in smaller cities and rural districts. Not only have they often been overlooked in the

Table 1 | Regression results

DV: Adaptation funding (dummy)	H1 Spatiality	H2a Sensitivity	H2b Capacity	H3 Rurality	H4 Mitigation	Control	Final	Weighted
(Intercept)	−1.26***	0.73	−14.00*	−2.20***	−1.53***	−4.85*	−22.98**	−22.03**
	(0.29)	(1.01)	(6.13)	(0.41)	(0.30)	(2.32)	(7.19)	(7.20)
H2 Vulnerability								
(a) Sensitivity indicators								
Share agricultural land		0.00	0.02*				0.04*	0.04*
		(0.01)	(0.01)				(0.01)	(0.01)
Share forest area		0.02	0.03**				0.05***	0.05***
		(0.01)	(0.01)				(0.01)	(0.01)
Share elderly people		−0.06*	−0.04				−0.03	−0.03
		(0.03)	(0.03)				(0.03)	(0.03)
(b) Capacity indicators								
GDP, pc, logged			1.01				1.35*	1.35*
			(0.52)				(0.53)	(0.53)
Higher education			4.73*				3.78*	3.78*
			(1.90)				(1.90)	(1.90)
H3 Urbanity								
Peri-urban				1.13**			0.95*	0.95*
				(0.39)			(0.41)	(0.41)
Predominantly urban				1.28**			1.35**	1.35**
				(0.43)			(0.51)	(0.51)
H4 Mitigation funding					0.52*		0.43	0.43
					(0.26)		(0.28)	(0.28)
Controls								
Youth share						0.07	0.08	0.08
						(0.06)	(0.07)	(0.07)
Share of green and left seats						0.42	4.57*	4.57*
						(1.83)	(1.93)	(1.93)
Population density						0.26*		
						(0.13)		
AIC	417.12	415.85	406.80	409.13	415.12	418.64	399.43	399.43
BIC	425.10	435.81	434.74	425.09	427.09	438.60	447.33	447.33
Log Likelihood	−206.56	−202.93	−196.40	−200.56	−204.56	−204.32	−187.72	−187.72
Num. obs.	400	400	400	400	400	400	400	400
Num. groups: state	16	16	16	16	16	16	16	16
H1: Var: state (Intercept)	0.79	0.59	0.60	0.59	0.61	0.49	0.16	0.16

p values: 0.001 "***" 0.01 "**" 0.05 "*" 0.1 ".".

literature, but we show that they have benefited less from national climate finance despite their potential for mitigation and adaptation.

Our findings also underscore a link between climate mitigation and climate adaptation (H4). They suggest that cities and districts that have already benefited from climate mitigation funding are often also those cities and districts that have benefited from the new finance scheme set up by Germany's climate adaptation strategy. As expected in H4, we have found a positive relationship between cities and districts that have successfully applied for mitigation funding and those pioneers receiving funding from the novel adaptation scheme. One explanation could be that these local authorities benefit from their experience with funding applications. Furthermore, having climate mitigation management in place, they have (more) financial resources and climate-related expertise that they can use to engage with adaptation issues.

As suggested by other authors[68], consolidating knowledge and institutional capacities around climate mitigation and adaptation can create positive synergies, and "mitigation planning seems to be a good place to start [adaptation action]"[73]. In line with this, we initially expected a strong empirical link between prior mitigation and current adaptation funding (H4). However, this link weakens substantially when we control for socio-economic and demographic factors, such as education, income, and urbanity. These findings align with recent critiques in the literature suggesting that access to climate finance is shaped less by programmatic integration than by institutional capacity and path-dependent funding structures[16,74]. As Sharifi[68] notes, the structure of funding mechanisms often favors well-resourced, urban municipalities with prior experience in navigating climate finance. Thus, while our analysis initially supported Hypothesis 4, the full model indicates that the observed overlap is not the result of coordinated planning but of deeper governance inequalities. We therefore cannot confirm H4 and instead interpret the correlation as an outcome of structural disparities in administrative capacity and access, raising critical questions about the design and equity of national climate finance systems.

Table 2 | Summary of hypotheses and results in the final model

Hypothesis	Determinants	Expectation	Result
H1: Multilevel governance	Federal state, the city or district belongs to	+	(+)
H2: Vulnerability	Share agricultural area	−	+
	Share forest area	−	+
	Share elderly people	−	0
	Higher education	+	+
	GDP, pc, logged	+	+
H3: Urbanity	Level of urbanity (urban, peri-urban, rural)	+	++
H4: Mitigation	Participation in mitigation funding	+	(+)
Controls	Share green and left seats		++
	Youth share		0
	Population density		++

++: strongly positive, significant association; +: weakly positive, significant association; (+): partly confirmed positive, significant association; 0: no association; − negative association.

These findings speak to the growing literature on climate leaders, followers, and laggards[2,75,76]: Accordingly, one could argue that it is surprising that mitigation leaders are more likely to receive (higher amounts) of adaptation funding. This is because mitigation pioneers have, in many cases, started to institutionalize their climate action and are engaged in developing integrated climate (mitigation and adaptation) strategies[65,66]. Hence, they do not need national climate adaptation finance, which often comes with complicated administrative requirements. They can set up their own local adaptation programs. On the other hand, one could also argue that our findings speak to recent studies examining local climate action in the United States that point to unequal access to climate finance as public spending is intertwined with debt financing[74] and that show that climate and financial processes co-determine not just one another but the transformation of contemporary urban socioecological landscapes more broadly[77].

Urban climate action has repeatedly been associated with the success of "networker cities"[73]. These cities may exchange knowledge and best practices and cooperate through their membership in initiatives, like the Local Governments for Sustainability (ICLEI), the Cities for Climate Protection Campaign (CCPC), the C40 Cities Climate Leadership Group, the 100 Resilient Cities Network (active from 2013 to 2019), or the European Union's Covenant of Mayors for Climate and Energy[8,78,79]. As districts are generally not part of these networks, we have not analyzed this aspect in our study. However, further analysis could also assess how and to what extent participation in city networks affects the participation of cities in climate adaptation funding. This seems particularly relevant because recent studies have highlighted that cities that have adopted the C40-driven equity pledge positively correlate with the integration of procedural justice in their climate action plans[80]. Another research direction could explore the function and influence of climate adaptation managers often installed in the context of the DAS. Like the whole adaptation strategy, these positions are also inspired by the German mitigation strategy. So far, initial studies have only dealt with mitigation managers[81,82], but comparing climate mitigation and climate adaptation managers and examining the role they play in local climate action would be a promising next step to better understand the impact and functioning of national climate incentives.

Finally, further research should also critically examine the design and implementation of Germany's climate adaptation funding, administered by the Federal Ministry for the Environment. This includes exploring whether current allocation logics implicitly favor actors with prior success in climate (mitigation) funding applications or resources, and how funding instruments might be reformed to build capacity in underrepresented regions. Although the program generally covers up to 80% of eligible costs, and up to 90% for financially weaker municipalities, usually in rural areas, with funding periods typically lasting up to 3 years for developing adaptation concepts or implementing innovative nature-based solutions, significant barriers remain[83]. Despite support structures aimed at reducing inequalities, cities and districts with limited financial resources or lacking the administrative capacity and expertise to prepare competitive applications may struggle to meet the program's requirements. This may, in turn, limit their ability to access funding. Furthermore, the selection process is single-stage, and applications are processed in the order of submission via the "easy-Online" portal, depending on the availability of federal budgetary resources and subject to the federal government's overarching interest[84]. This "first come, first served" mechanism may structurally advantage municipalities with greater administrative speed and awareness of deadlines, often those with more experienced staff and resources. At present, however, no publicly available data exist on the number of applications submitted or the approval and rejection rates by region. This constitutes a limitation for assessing whether certain areas, such as parts of northern or eastern Germany, are underrepresented in the allocation of funds due to low application rates rather than systemic rejection.

A second set of limitations refers to the data and its operationalization. The paper mainly uses data from the German adaptation strategy that has existed since 2021. With only two funding calls issued under the DAS, the mechanism is still very new, and it might be too early to draw general conclusions. This makes comparing the mitigation funding program challenging: While the DAS has existed for merely 4 years, the mitigation strategy has offered funding since 2008. After 15 years of being installed, the latter is well-known. Hence, cities and districts that have responded to previous funding calls may not be listed as recipients, not because they are not engaged in climate mitigation action, but because they are using other funding or because they have already institutionalized climate mitigation (and adaptation) in their local administrations. There are no simple solutions to this imbalance, but to mitigate this problem, at least to some degree, we only included climate mitigation projects that started after 2017 and ended no later than 2024. In this way, we limit the link to the most recent climate funding programs and their immediate effect on adaptation.

A further limitation is potential multicollinearity among the tested variables. Naturally, we see links among the selected socio-economic and demographic factors that we included in this analysis and between those factors and our key concepts of interest, i.e., *Urbanity, Vulnerability*, and *Mitigation funding*. Of course, urban areas are often characterized by a younger population, often a left-leaning electorate, and higher education levels. But not always, and these factors alone do not explain the tendency to apply or not apply for adaptation funding under the DAS funding scheme. Hence, in our analysis, we tried to disentangle these factors by a stepwise approach that is also supported by some descriptive investigations. In essence, our results show that it is a combination of factors that must play together, i.e., rather wealthy, highly educated, and left-leaning urban areas tend to engage more likely in adaptation activities, while rural districts clearly fall behind.

To conclude, as cities and districts face increasing climate change impacts, national adaptation funding schemes have been set up to facilitate local strategies and the implementation of climate adaptation action. Considering that one-quarter of Germany's cities and districts have already received adaptation funding after only 4 years of the DAS financial mechanism being in place, we can posit that there is a high interest in local climate adaptation. National climate finance can thus have a positive effect on climate adaptation action. Due to high regional variation in the use of national adaptation schemes, this study focuses on the factors explaining the successful application of national climate adaptation funding. We find that differences can be primarily explained by a rural-urban divide. This suggests that there is still much unused potential for climate adaptation in rural cities and districts. The German adaptation strategy could more directly address these underrepresented rural regions where the impacts of climate change are already being felt, but which nonetheless lack the financial resources to formulate and implement climate adaptation plans. Hence, this study

enhances our knowledge of local climate adaptation decision-making and implementation.

Methods

Operationalization of variables

In the following, we briefly describe the operationalization of our variables (see Supplementary Materials (1–3) for datasets and the replication script).

We received the data for our dependent variable (*Adaptation funding dummy*) from the Federal Ministry of the Environment in 2024. This dataset covers all cities, districts, and municipalities that have received funding so far to develop a climate adaptation plan or to hire a climate adaptation manager under the DAS funding scheme. We aggregated the data to the city and district levels. Hence, our dependent variable reflects whether a city or district has received adaptation funding since establishing the new funding instrument (1) or not (0), see Fig. 6. Furthermore, we use the information on the height of the funding sums to plot Figs. 1 and 2.

For our independent variables and control variables, we draw on different datasets, such as the regional statistical offices, Eurostat, the German

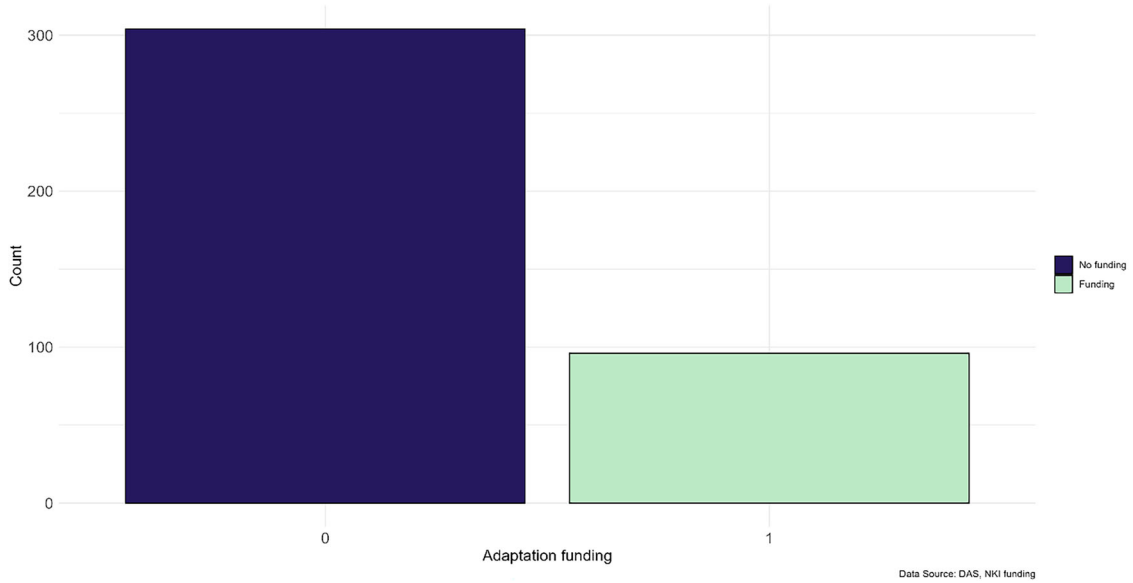


Fig. 6 | Number of districts that received adaptation funding or not.

Table 3 | Overview of variables, their role in the research design, and data sources

Variable name	Explanation	Data source	Research design
Adaptation funding dummy	Dummy variable indicating if a district or city receives funding in the context of the German adaptation strategy (1) or not (0)	Federal Ministry of the Environment, 2024	DV, Fig. 3
Adaptation funding sum (logged)	Logged amount of funding received per city or district in the context of the German adaptation strategy	Federal Ministry for the Environment, 2024	Figs. 1 and 2
Federal state	Federal state that the district or city belongs to	German Regional Statistics	H1, fixed effect in the multilevel model
Share agricultural area	Share of agricultural land	German Regional Statistics	H2
Share forest area	Share of forest land	German Regional Statistics	H2
Elderly population	Share of elderly population	German Regional Statistics	H2
Urbanity	Typology of districts into urban, peri-urban, and rural (baseline category)	Eurostats, NUTS 2021	H3, Fig. 4a, b
Mitigation funding dummy	Dummy variable indicating if a district or city receives funding from the National Climate Protection Initiative (NKI) as of 2021 (1) or not (0)	Federal Ministry for the Environment, 2024 Zeigermann et al.[23]	H4, Fig. 3
Mitigation funding sum (logged)	Logged amount of funding received per city or district from the National Climate Protection Initiative (NKI) as of 2021	Federal Ministry for the Environment, 2024 Zeigermann et al.[23]	Fig. 2
GDP per Capita	GDP per Capita, Gross domestic product divided by the population, 2019, logged	German Regional Statistics	Control
Higher education	Number of graduates with a general higher education entrance qualification, 2019	German Regional Statistics	Control
Youth share	Youth Quotient, Ratio of young people to the labor force, 2019	German Regional Statistics	Control
Share left and green seats	Share of left and green seats in city and district parliaments, this includes SPD, Left, and Green party seats.	German district assembly, own coding for cities, 2021	Control
Population density	Area in square km divided by the total population, 2020	Own calculation based on German Regional Statistics	Control
Geodata	Geodata for German cities and districts	Federal Agency for Cartography and Geodesy	Fig. 2

district assembly, and the websites of the city parliaments (see Table 3). The data for climate mitigation funding under NKI funding stems from the Federal Ministry of the Environment in 2022[23].

To test H2, we draw on two sets of indicators that proxy climate vulnerability. Firstly, to operationalize sensitivity towards climate risks, we use three indicators, i.e., the *Share agricultural land*, *Share forest area*, and *Share elderly people*[48,49]. Secondly, to measure adaptive capacity, we draw on two indicators as proxies, i.e., the income level reflected as *GDP per capita* and *Higher Education*. We expect a negative relationship with the likelihood of engaging in adaptation activities with the first set of indicators and a positive relationship with the second set.

To test H3, we operationalize *Urbanity* with a variable that classifies all cities and districts into "rural," "peri-urban," and "urban." The urban-rural typology[85] is a geographical measure issued by Eurostat that takes the most recent NUTS classification[86] of European regions and the population grid into account. Cities and regions are classified based on the share of the population living in rural grids, also called the "rural population"[87]. The urban-rural typology defines that urban regions have less than 20 percent of the rural population, peri-urban regions have between 20 and 50 percent of the rural population, and rural regions have more than 50 percent of the rural population. We expect that cities and predominantly urban districts are more likely to receive climate funding. Thus, we should see a positive and significant parameter estimate in our regression models linked to the urban and intermediate categories.

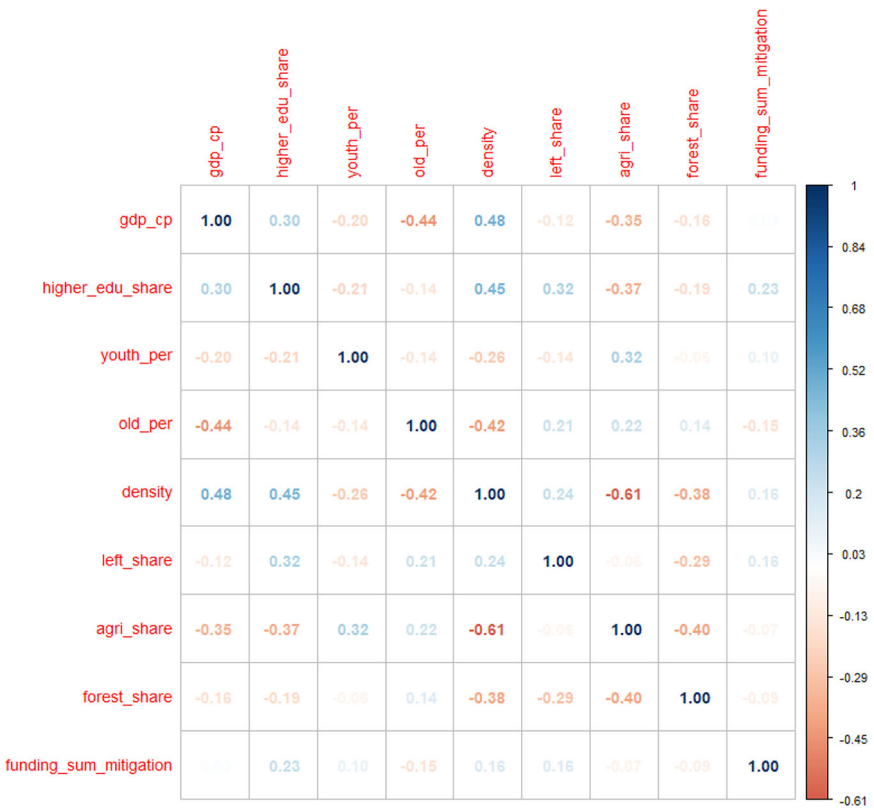
To test H4, we use data from the NKI mitigation funding program. Specifically, we create a dummy variable that indicates if a district or city has received mitigation funding during the period of 2017 (earliest start of funding period)–2024 (latest end of funding period) or not[23].

We use a set of three variables to indicate the socio-economic background in the German cities and districts in the year 2019. The first variable is wealth, which we operationalize as the Gross Domestic Product per Capita of a city or district (*GDP, pc. logged*). This variable controls whether wealthier cities and districts are more likely to participate in the DAS funding program. In our regression models, we use a logged version to avoid variables on different scales in the model. We expect a positive and significant correlation between wealth and the likelihood of getting funding. Second, we test for *Higher education* levels, which we measure as the share of graduates with a higher education entrance qualification in a district in relation to all other graduates in the year 2019. We retrieved this information from the German Regional Statistics for the year 2019. We use this variable to test the association between higher education levels in a city or district with a greater likelihood of receiving funding. We expect a positive and significant relationship between the higher education variable and adaptation funding. Finally, we include the share of the *Youth share*, i.e., the youth quotient, as a measure of how young a population is. The youth quotient, as issued by the German Regional Statistics, sets the number of people below 20 in relation to the rest of the population. The youth quotient has a simple interpretation and allows easy comparison across cities and districts. We expect a positive and significant relationship with adaptation funding in both regression types.

Table 4 | Variance Inflation Factors

Variable	GVIF	$GVIF^{(1/(2\times Df))}$	Interpretation
Forest share	2.215689	1.488519	No collinearity problems
Agricultural share	2.599269	1.612225	No collinearity problems
Elderly population	1.465031	1.210385	No collinearity problems
Young population	1.383516	1.176230	No collinearity problems
GDP, pc, logged	1.926480	1.387977	No collinearity problems
Urbanity	1.537920	1.113611	No collinearity problems
Mitigation funding	1.044732	1.022121	No collinearity problems
Share of left seats	1.352739	1.163073	No collinearity problems
Higher education	1.423158	1.192962	No collinearity problems

Fig. 7 | Correlation plot.



Furthermore, we also include the share of *left and green seats* in city and district parliaments in our models. We retrieve this information by drawing on a dataset that we received from the German district assembly[88] and our own research on the distribution of seats for city parliaments[23]. To calculate the share of left and green seats, we divide the sum of green and left seats by the total number of seats in a city and district parliament.

Further, we control for the population density of cities and districts since this is a different way of operationalizing rurality. Usually, rural areas can be characterized by a lower population density. We gathered this information from the German Regional Statistics for the year 2019. We expect that more populated and denser districts are more likely to succeed in receiving funding from the NKI.

Multilevel logistic regressions

We use several models to identify the factors that explain participation in the DAS program. All these models are multilevel logistic regressions with fixed effects for the federal states (see Table 1). We investigate whether a city's or district's socio-economic, political, and settlement characteristics are associated with a higher or lower likelihood of receiving funding. For that purpose, we draw on the full dataset ($n = 400$). Further, we assume that the effects might differ across the German states. At least our data shows that some variations can be observed regarding the received funding sums, see Fig. 1. Hence, we apply a multilevel model with random intercepts for states to control for the different number of cities and districts that have received funding and potential differences in the height of the amount they have received. Furthermore, as shown in Fig. 6, our sample is moderately imbalanced, with only around 96 cities and districts receiving funding, as opposed to 304 cities and districts that do not yet receive adaptation funding. Given the moderate class imbalance (~1:3), weighted logistic regression was tested. Results were substantively identical to unweighted models, suggesting no need for further correction for class imbalance[89,90].

Test for multicollinearity

The above-described set of variables is necessarily interrelated. Hence, it is key to test for multicollinearity among the tested factors. To do so, we use the Variance Inflation Factor (VIF, see Table 4 and a correlation plot, Fig. 7). We see that in most variables, there are no serious multicollinearity issues. The exception is *Population density*, which is negatively correlated with the Share of agricultural land but has rather high correlation values for all other variables. Table 4 shows, however, that there are no serious multicollinearity problems in our Final Model.

Data availability

The data to replicate the analysis are available in Supplementary Materials 1 and 2. The R-code to replicate the analysis is available in Supplementary Material 3.

Code availability

The R-code to replicate the analysis is available in Supplementary Material 3.

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Competing interests

The authors declare no competing interests.

Additional information

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