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Challenges and opportunities in scaling climate-resilient housing solutions in the United States

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Intensifying climate-related damages across the United States underscore the importance of climate-resilient housing, which requires coordination across diverse actors in the housing sector. Here, we assess the challenges and opportunities for reducing climate impacts on housing within U.S. coastal communities, based on 64 interviews with experts across housing-relevant public, private, and nonprofit sectors. We provide an overview of risk reduction actions being implemented as well as barriers and enablers to scaling up these responses. We find that current risk reduction actions focus on small-scale property-level adjustments or early-stage advocacy, though experts desire solutions that enable systems-wide reductions of climate–housing risks. Path dependencies, financing, and other entrenched multi-sectoral challenges currently limit resilient housing development. Experts perceive government interventions as essential in enabling resilient housing, and we find that government-led, multi-stakeholder collaborations have already catalyzed action. Understanding these cross-sectoral dynamics can inform actions and pathways to increase climate–housing resilience nationwide.

Exposure to the physical risks of climate change is increasing across the United States, compromising housing resilience. Each year, the U.S. loses, on average, one month's worth of residential construction to climate-related disasters[1], exacerbating population displacement. In 2023, 2.4 million Americans were displaced from their homes by disasters, and 16% of them reported not returning home[2]. Populations, housing, and infrastructure exposed to hazards will increase nationwide, as risks from both acute climate-related hazards (e.g., wildfires and coastal storms) and shifting baseline conditions (e.g., high-tide flooding and sea-level rise) increase over time[3–5]. Damages from extreme weather events have exacted severe costs to the economy, upwards of $2.7 trillion since 1980[6] (adjusted for 2024 CPI values), and studies are now documenting the emerging impacts of less extreme, but more frequent flooding events[5,7,8]. Integrating risk reduction measures across the housing sector is essential in transforming markets and societies to cope with future climate risks and reduce climate-related migration. However, the need for more climate-resilient housing comes at a critical moment, during which housing is undersupplied nationwide[9], affordability is low[10], and risk reduction policies for housing could increase costs or reduce land availability for new construction.

The existing climate and housing literature has primarily addressed climate mitigation concerns, through carbon emission and energy-use reduction or "green building" practices associated with resource efficiency, especially in the U.S. and other high- income nations[11–14], and not climate adaptation. Likewise, in practice, widely known industry

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standards that enhance building performance, such as Passive House standards[15] and LEED certification from the U.S. Green Building Council (USGBC)[16], are not well-suited to address the physical risks presented by climate hazards such as flooding, wildfires, or sea-level rise, though a recent LEED guidance update now integrates climate risk assessment[17]. As such, research that examines the intersection of climate adaptation and housing is a pressing need[18–20], one that low-to-middle income countries appear to be demonstrating more urgency in addressing[21–23]. Adaptation research in the U.S. should shift towards examining the climate risk–housing nexus, assessing how climate risks (both physical and transitional) impact systems that influence housing development, such as land-use, finance, design, and federal-to-local governance.

The limited climate risk and housing adaptation research has generally focused on understanding household preferences for adaptation measures[24,25]; evaluating disaster recovery policies[20]; exploring managed retreat[26–31]; improving exposure and vulnerability assessments[32–34]; and not evaluating opportunities for integrating risk reduction into housing policy. Research on these topics is beginning to gain momentum[24,35], as public and private markets are responding to the recent decline in availability and affordability of insurance in high climate risk areas[36–38]. Efforts to address these issues were featured in the 2023 National Climate Resilience Framework, highlighting federal actions to advance resilient building codes, develop in safe areas and retreat from high-risk areas, and implement the Federal Flood Risk Management Standard (FFRMS)[39]. However, even during the Biden Administration, new federal programs (e.g., the Building Resilient Infrastructure and Communities program administered by the Federal Emergency Management Agency, FEMA) and long-standing ones (e.g., Community Development Block Grant–Disaster Recovery (CDBG-DR) administered by the Department of Housing and Urban Development) could not keep pace with mounting billion-dollar disasters each year. These efforts also primarily applied to projects that use federal funding, not the largely privatized housing market, and are now either at risk of being reduced or have already been eliminated under the second Trump Administration.

In principle, multiple strategic levers exist to build climate resilience across private housing markets, at varying scales and impact potential[24]. These levers include actions that improve the quality of housing construction, regulate land use, influence housing-sector financial instruments to incorporate climate risks, and facilitate resilience through larger-scale infrastructure and management practices[40]. However, interactions among real estate developers and housing construction companies, mortgage lenders, and insurance companies, as well as federal-to-local governments, have created a complex space for advancing solutions. As such, adapting housing to become resilient to future climate hazards should consider not just increasing structural resilience, but a system-wide approach that addresses the interconnectedness of land-use, financial systems, development incentives, and multi-level governance. Understanding the interactions and dependencies across actors within the housing development ecosystem may shed light on more comprehensive policy pathways for reducing climate risks and limiting future maladaptation.

Here, we provide a multi-sectoral examination of the progress, to date, in the integration of climate risks into housing development policies and actions. We present research asking four main questions: what actions have different sectors across the climate risk–housing nexus taken to enhance the resilience of new construction within private housing markets in coastal communities within the United States? What barriers have they encountered? What factors have enabled action? And finally, what solutions do experts think should be pursued? To answer these questions, we conducted 64 semi-structured interviews with experts across multiple sectors within seven broad categories: (1) *Government*: federal, state, and local governments; (2) *Housing finance*: mortgage finance and insurance agencies; (3) *Home building*: home construction and real estate development and investment firms; (4) *Design*: urban planning, engineering, and architecture firms; (5) *Academia*: academia and think-tanks; (6) *Advocacy*: housing-focused non-governmental organizations and advocacy groups; and (7) *Climate services*: climate information providers. We applied directed content analysis to coded interview transcripts to surface key themes, interdependencies, and tensions across sectors.

Interviewing a diverse set of actors across the climate risk–housing nexus revealed the complexity of language, actions, interactions, and perspectives. Participants did not use terminology consistently, with key concepts—such as climate mitigation and adaptation or even affordability and equity—shifting in meaning depending on the speaker. We therefore present emergent themes, while acknowledging the sometimes-irreducible ambiguities across perspectives. These nuances are intertwined with the challenges of collaboration and transformative adjustments highlighted by the participants.

Furthermore, we define several key terms to clarify how we interpret expert responses within this study. First, **actors** are defined as individuals, organizations, or institutions with the agency to mobilize and effectuate change. Here, we consider actors across the wide-ranging sectors relevant to the climate risk–housing nexus. We define their effected changes as **actions**, or steps taken by actors, which can include advocacy or research efforts, property-level risk-reduction or policy changes, among others. **Policy** describes formal decisions or strategies developed by actors to guide actions toward specific goals.

We also refer to barriers, enablers, and tensions throughout the paper. We define **barriers** as factors that make it harder for actors to plan and implement actions or that restrict new policies. **Enablers**, or enabling conditions, work in the opposite way, making it easier to plan and implement actions, expanding possible policies, or creating co-benefits. We evaluate actions, policies, barriers, and enablers within each individual sector. We use the term **tensions** to refer to the misalignments and constraints that arise across sectors, for which multi-sectoral coordination is needed to advance climate-resilient housing actions. These challenges may present in a variety of ways, including conflicting priorities, institutional silos, or limits to action such as financing and technological constraints.

Results and discussion

Affordability and climate resilience are top priorities

Participants across all sectors deemed affordability ($n = 31$) and climate resilience ($n = 27$) as the top two challenges facing U.S. housing markets (Table 1, Supplemental Fig. 1). Participants highlighted other challenges, including insurance, housing supply, costs to build, regulations, labor, and infrastructure (Table 1), and noted that most of these challenges are interlinked. For example, disaster-related damages reduce the existing housing stock, worsening supply challenges. Affordability concerns also stem from limited housing supply, which is influenced by labor, construction, regulatory, and insurance costs, which are also affected by climate risks. These interconnected challenges underscore the complexity of addressing housing market issues across all sectors. One participant stated:

> *"We can't solve housing affordability and supply without also thinking about the climate impacts, including protecting and preserving existing homes, but also shifting where we're building most of our new housing." – Academia Participant*

Current risk reduction actions are inadequate, and experts desire system-wide change

Participants primarily reported taking small-scale actions to advance climate-housing resilience goals *to date*, while noting their

Table 1 | Pressing challenges in U.S. housing markets

Thematic codes	Illustrative quotes	Number of interviewees
Affordability	"Affordability and availability, which I lumped together. Housing is expensive in a bunch of places because there isn't enough of it and there are too many households competing for too few homes." – *Academia Participant*	48.4%; *n* = 31
Climate Resilience	"We are a coastal city. And we can see the coastal modeling and what areas of the city are going to flood. So how do we build responsibly? How do we build new housing but also make sure that it's going to be resilient to those future climate risks?" – *Home Building Participant*	42.2%; *n* = 27
Insurance	"I think that insurance is a big one that comes to mind with climate change and the risk landscape and how that could possibly be insured and how insurance companies adjust to those changes in risk and what that means for people who need that insurance." – *Design Participant*	28.1%; *n* = 18
Housing Supply	"The general shortage of housing. We continue to be limited as a country, it seems, in our ability to produce a sufficient number of multifamily units to meet demand." – *Design Participant*	25%; *n* = 16
Costs to Build	"Construction costs have really gone up with labor costs going up, with COVID, [doing] a really big number on supply chains…But it's a combination of high construction material costs everywhere and a pretty long protracted labor shortage everywhere, as well as I think people's drive to customize. It's not affordable to build any quality green home(s) anymore. So that's a challenge that I think our sector faces overall." – *Home Building Participant*	15.6%; *n* = 10
Regulations	"A key barrier that we have to remove is local regulatory barriers that simply make it illegal to build a lot of this housing." – *Advocacy Participant*	9.4%; *n* = 6
Labor	"Labor rates and cost of living in California make it really hard to have a workforce that can build and develop housing at the scale that's needed and be compensated fairly and then have the product be something that's affordable for the people that need that housing." – *Design Participant*	6.3%; *n* = 4
Infrastructure	"One of the biggest barriers and obstacles for private sector housing right now would be infrastructure, particularly for co-op access to increased water and wastewater infrastructure." – *Government Participant*	3.1%; *n* = 2

Participants identified the most pressing housing challenges from their perspectives. Illustrative quotes are provided for each theme discussed. Observed counts (*n*) and percents are provided for the number of interviews in which each theme was recorded.

insufficiency in tackling much-needed system-wide change. We recorded 141 actions taken across the 64 interviews in seven domains of climate resilience (Fig. 1). The most common actions were within the advocacy and research domain ($n = 37$), such as educating the public or stakeholders ($n = 15$) or conducting research for increased climate risk awareness, indicating that many organizations are still in the early stages of adaptation. Participants also reported taking actions to increase property-level resilience ($n = 34$) by elevating units ($n = 12$) and increasing freeboard ($n = 7$) in response to past events. Fewer participants reported having taken actions that improve regional resilience ($n = 23$), such as resilient infrastructural improvements ($n = 7$) or deliberately developing away from high-risk areas ($n = 5$). Participants also reported fewer policy actions ($n = 13$), financial actions ($n = 11$), and reforms to insurance ($n = 7$). Notable examples of such policy and financial actions and reforms include property-level risk reduction actions such as the City of Miami Beach's Private Property Adaptation Program or reforms to insurance like the Parametric Insurance Pilot in New York City (Supplemental Table 1).

However, when asked to identify a *future* solution that would make the most difference in reducing climate risks across housing markets, most participants identified solutions that would address more system-wide challenges. A quarter of all participants named a financial solution ($n = 16$), such as risk-based pricing for insurance premiums or mortgages (Table 2). Implementing managed retreat ($n = 11$) ranked highly among community-level risk reduction solutions, while property-level solutions ($n = 12$), proposed at scale, included elevating homes, incorporating future climate risks into building code, and imposing FORTIFIED standards (*Note*: FORTIFED standards are voluntary construction guidelines, developed by the Insurance Institute for Business & Homes Safety, to reduce risks from severe weather, primarily hurricanes, hail, and winds; Table 2). Participants also suggested several reforms to existing policies, including reforms to disaster recovery processes, the National Flood Insurance Program, tax codes, and building code adoption processes. Additionally, most participants felt legal mandates or regulations are necessary for prompting action on climate risks within their sector (65.6%; $n = 42$), including the majority of private sector participants (58.3%; $n = 14$). Their justifications included the inefficacy of voluntary measures ($n = 16$), need for standardization ($n = 10$), and importance of increasing the scalability of solutions ($n = 3$; Supplemental Table 2). Speaking in favor of mandates, one participant remarked:

> *"I don't see how we can rely on the good faith participation of private actors who are selling the product. There's always going to be somebody who provides goods for cheaper, and so you'll see markets run to the lowest level of regulation. The only way to really ensure that we develop in proper patterns is to mandate that we do so through laws and regulations." – Advocacy Participant*

Another participant from the private sector remarked on the need for standardization, as it lowers the cost of production. They referenced North Carolina's legislature passing a law prohibiting new building code updates until 2031[41], due to the influence of the home-building industry.

> *"[The prohibition] was in the code, and if it had been updated to be aligned with other codes, [my company] might have changed that. But they said, 'I'm sorry, we sell our product to everyone but North Carolina'. It's an unintended consequence of refusing to update codes." – Home Building Participant*

Participants who were unsure about the need for laws/mandates ($n = 12$) cited needing a balance between laws and incentives ($n = 3$) and that laws could have unintended consequences ($n = 3$; Supplemental Table 2). One participant from the private sector stated:

> *"[Mandates] also cause a lot of professionals to leave the investment. And there is a real risk that at a time when financing costs have gone up, unfunded mandates will cause people to stop providing responsible homeownership rental options." – Home Building Participant*

Only 7.8% ($n = 5$) of participants felt that laws and legal mandates were not necessary, citing a need to address the current misaligned incentives first ($n = 3$).

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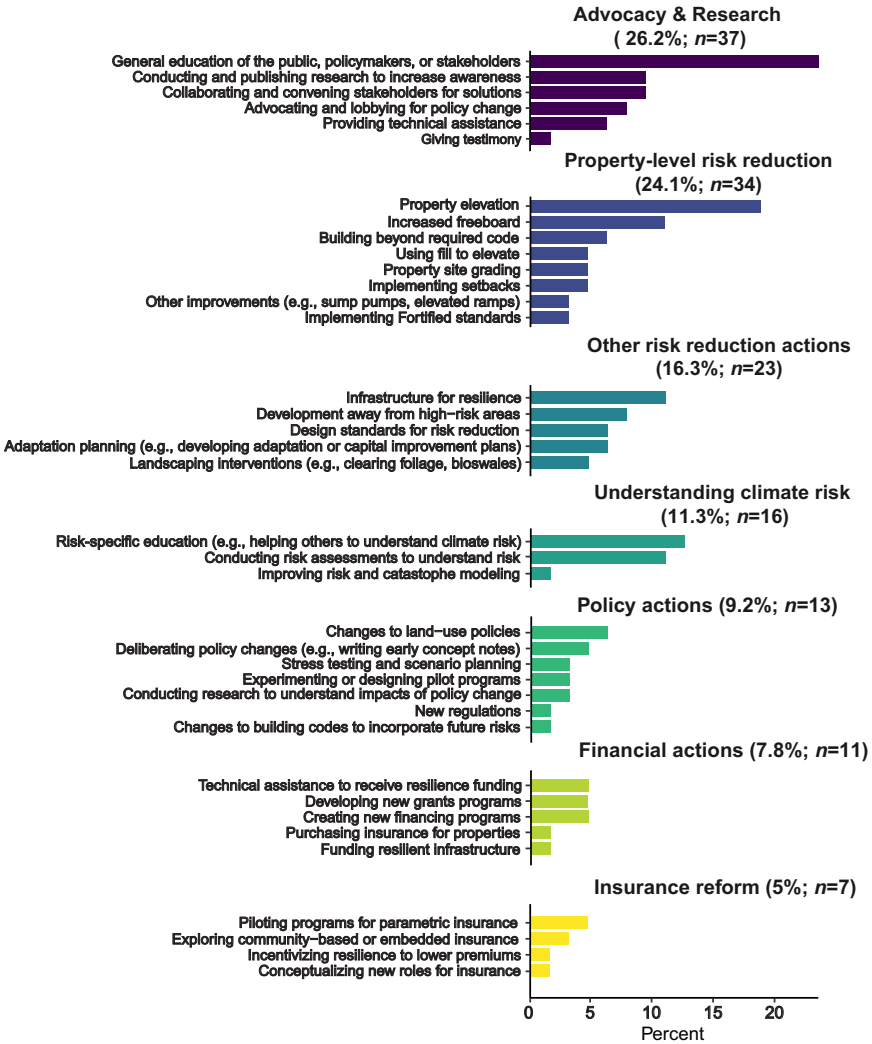

Fig. 1 | Actions taken by participants to integrate climate resilience within their work. Bar plots detailing categories of actions taken by participants to integrate climate resilience within their work are shown above. We recorded 141 actions across all interviews and categorized them into 7 themes. The overarching theme is provided first, and then subthemes that emerged within each category of action are shown. Observed counts (*n*) and percents are provided for each theme, and subthemes are shown as a percent of the actions recorded within each theme.

Barriers to action include both soft and potential hard limits to climate-resilient housing development

Participants identified barriers in policies, information, and markets as the top three obstacles to building climate-resilient housing (Supplemental Table 3). For policies, participants stated path dependencies ($n = 30$), such as implementation challenges ($n = 11$) or lack of prior examples ($n = 5$), as limiting possible solutions. For example, lack of prior examples ($n = 5$) to guide new solutions was identified as a barrier in the State of Louisiana's PRIME program (which creates resilient mixed-use rental housing with HUD support), but was eventually overcome (Supplemental Tables 1, 4). In this example, the participant stated:

> *"First and foremost was the fact that no standards existed for multifamily construction to reflect the Fortified protection. That's probably the biggest one. Costs go up whenever you [do not have standards in place]." – Government Participant*

Data or information issues ($n = 29$) such as lack of quality data for decision-making ($n = 7$) and scientific uncertainty ($n = 6$; Supplemental Table 3) ranked highly among barriers to action. With regards to scientific uncertainty, one participant remarked:

> *"The reason that we haven't gained confidence in a variety of climate risk analysis tools is that none of them have consistent results… they [Morgan Stanley] were able to do an evaluation of a bunch of different climate risk tools. All of them have different outputs…we're still trying to figure out how to interpret it." – Home Building Participant*

Financial issues ($n = 28$), such as increasing costs to builders and developers ($n = 13$) and resulting lack of affordability to future residents, were also identified as prominent barriers (Supplemental Table 3). As one home builder remarked,

> *"There's always the discussion around those of us who are putting together the design versus those who are purchasing the design and meeting national criteria to quantify or reduce costs… costs became significantly higher, and the market just wasn't able to bear the increase in costs. Sometimes costs were going up 30 to*

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Table 2 | Policy solutions for climate-resilient housing identified by participants[a]

		Potential Actors									
	n	FG	SG	LG	MF	IN	RC	CS	AT	AN	DN
Financial solutions	**16**										
Incentivize risk reduction (e.g., Fortified standards, retrofits, reduced borrowing costs)	5	X	X	X	X	X	X			X	
Restrict mortgage/insurance in high-risk areas	4	X			X	X					
Financing/incentives for affordable housing	3	X	X	X						X	
Risk-based insurance premiums	3	X	X	X		X				X	
Housing assistance for renters	1	X	X	X						X	
Land-use and community risk reduction	**13**										
Managed retreat (e.g., buyouts and rezoning)	11	X	X	X	X	X	X	X	X	X	
Stormwater management/infrastructure	2	X	X	X							X
Property-level risk reduction	**12**										
Elevate homes in floodplains	3	X	X	X	X	X	X			X	X
Increase use of FORTIFIED standards	3	X	X	X		X	X			X	X
Building code that considers future risk	4		X	X		X	X	X	X	X	X
Require high hazard wave action construction	1		X	X			X			X	X
New construction standards for wildfire	1					X	X			X	X
Reforms	**11**										
Reform NFIP	3	X						X	X		
Reform permitting process to for resilience	1			X			X				
Reform building code adoption processes	1		X	X			X			X	
Require resilience with public money	1	X	X	X							
Permanently authorize CDBG-DR	2	X									
Reform disaster recovery assistance, e.g., reducing damage bar for buyouts to 50%	1	X	X	X							
Reform CEQA	1		X								
Use of emergency powers to suspend zoning	1			X							
Climate risk information	**10**										
Increase risk awareness (e.g., risk disclosures for residents and developers)	8	X	X	X				X	X	X	
Create better scientific models	2	X				X		X	X		
New policies/strategies	**3**										
Increase housing supply in less risky areas	1	X	X	X	X	X	X	X	X	X	X
Prefabricated, moveable homes	1	X	X	X			X			X	X
Rapid production of modular housing	1	X	X	X			X			X	X
Total	**65**	**19**	**18**	**20**	**5**	**10**	**12**	**6**	**5**	**15**	**9**

Policy solutions emerging from responses when participants were asked to provide one solution that would make the most difference in reducing climate risks across housing markets are shown below. Potential sectors that could be involved in enacting and implementing the solution are also shown below and summed. Solutions are grouped by theme and subtheme, and observed counts (*n*). Actor categories are defined as federal (FG), state (SG), and local (LG) governments; mortgage finance (MF) and insurance (IN) agencies; real estate development and home construction (RC); climate risk information providers (CS); academia and think-tanks (AT); housing-related NGOs and advocacy groups (AN); and urban planning, engineering, and architecture firms (DN).
[a]Bold text is used to denote subheaders and final counts.

50%. And buyers' jobs aren't changing that quickly." – Home Building Participant

The barriers to current action discussed above represent soft limits that, in some cases, have been overcome, but also are symptomatic of broader, cross-sectoral tensions where a failure to address these tensions would both limit the effectiveness of single-sector actions and potentially pose a hard limit to climate-resilient development. These *tensions* include *building code adoption, insurance mechanisms, climate risk information, and equity-related issues* (Table 3) and require multi-sectoral examination and collaboration. First, some participants ($n = 9$) stated that *building codes* are inadequate for meeting climate resilience needs because they consider historic rather than future risk, and because model code adoption processes are influenced by political forces towards keeping housing construction costs low ($n = 4$). As the aftermath of Hurricane Helene revealed in North Carolina, policy decisions about building codes can compound existing vulnerabilities[41]. Meanwhile, maintaining housing affordability and integrating resilient designs are currently at odds with increased costs from labor, financing, materials, and regulations ($n = 5$). Professional liability may soon be a significant driver of change in the future, as architects and engineers can be held liable for design failure if they do not incorporate risk reduction designs, regardless of whether they follow current building codes, which are generally understood to be insufficient[42].

Threading the balance between building affordably and resilience will likely remain a challenge for years to come. Amid already challenging market and regulatory conditions in many coastal and urban areas of the U.S., new construction faces additional strain from inflation, tariffs, high-interest debt financing, and continued labor shortages. However, California is leading the way by enacting reforms to CEQA, or the California Environmental Quality Act, an environmental protection law that has been misused to block or delay construction projects, which add time and legal costs to development. The new

Table 3 | Tensions in scaling climate resilient solutions

Themes	Subtheme 1	Subtheme 2	Subtheme 3
Building codes	Building codes are inadequate for climate resilience (14.1%; *n* = 9)	Resilient standards decrease housing affordability (7.8%; *n* = 5)	Code adoption processes can be influenced (6.3%; *n* = 4)
	"The original motivation is that if you build to code, it's really good for preserving life and safety within the building process. But it doesn't do much for resilience. There's not a lot of requirements… There's a gap between building code, and I'd say business-as-usual building practices and what building to resilience performance objectives would necessitate." – *Design Participant*	"I can go on and on about what kind of resiliency and adaptation that we're doing for climate change. But get this—for each single-family home, we're spending roughly $350,000 per home on just what I just mentioned there." – *Home Building Participant*	"But when it actually comes to how the decision is made, it's 'who's in the room', and it's a negotiation. Which is part of the problem of having this nonprofit comprised of different interest groups be the one that sets the model code, and then states and cities choosing or not choosing to adopt it… And the opposition is largely coming from red states where they're reticent to impose a more stringent code, because that then adds cost." – *Design Participant*
Role of insurance	Insurance can drive behavior change (9.4%; *n* = 6)	Insurance premiums currently do not reflect risk reduction (7.8%; *n* = 5)	Insurance inability to incentivize property-level risk reduction (6.3%; *n* = 4)
	"And now that lenders and insurance people are asking, 'what's your resiliency strategy,' our clients are grateful they had something to say about it. They're like, 'oh well, we have everything elevated, we have our conduit, we have a cistern.' They can list… and that never was the case before from the lender [and] from insurance. It is becoming the norm… whether you're ready or not, insurance and lending are going to run with this. And if we're not doing something as a community, we're going to get redlined, because they're going to say, 'too much risk and too much repetitive loss'…and they're not going to invest." – *Design Participant*	"From the wind perspective, we are now building houses to Fortified standards. We have not, however, seen a recognition of the value of that in reduced insurance rates… And one thing that I think I heard was they look at their risk on a regional scale instead of a house by house by house [basis]. And so, until we get the increased percentage more than the nominal percentage of the housing stock built to these new standards, we don't appreciably affect their potential costs in a disaster." – *Government Participant*	"Everything in there [The White House National Resilience Framework] is a system-level answer to a system-level risk, until you get to the insurance sector, and then we're supposed to incentivize individuals to somehow drive system-level change. They think insurers can, one-home-at-a-time incentivize the type of behavior that could be required to significantly reduce climate exposure. I just don't think they know how the insurance mechanism works…What the hell are sandbags in your garage going to do about 10 feet [*of sea-level rise*]? You need a barrier, you need to somehow lift your home, you need to do something dramatic…that's really difficult to incentivize in a 12-month policy." – *Housing Finance Participant*
Climate risk data	Information asymmetry (15.6%; *n* = 10)	Uncertainty challenges within decision-making (18.8%; *n* = 12)	Uncertainty implications for decision-making (6.3%; *n* = 4)
	"The data that is available is privatized data. A lot of times, it costs money to get access to it. It is not operated through the federal government; although the government does have flood risk data, it's incredibly outdated. So, I think that's a major challenge… the data accessibility, having it not run by third-party entities, having it be run by maybe a government entity and [made] publicly available." – *Advocacy Participant*	"But say, there is another source of information. If it's First Street Foundation…and they say that the BFE is here, but FEMA is here, and we decided that First Street is a better estimate than we would go with three feet above the First Street flood level. That's operationally how it works. The challenge is HUD's capacity to really say that First Street is better than NFIP. We know there are obvious limitations to NFIP, but that doesn't mean we know what is or isn't better." – *Government Participant*	(*On climate risk-based mortgage pricing*) "Something like that's got to be taken extremely seriously and carefully…there's got to be such care taken because the data that would be needed to accurately price has got to be absolutely reliable and good. And I don't think that we're there yet on having that kind of data. The potential to adversely impact people by restricting their access to financing, and to adversely impact property values, which is where so many people have their wealth. Just the implications of it could be really significant." – *Housing Finance Participant*
Realigning current market distortions	Risk disclosure as a solution (9.4%; *n* = 6)	Climate risk-based mortgage pricing as a solution (4.7%; *n* = 3)	Equity and social considerations (14.1%; *n* = 9)
	"There are risks, and you want people to have access to the information that helps everybody make a smart and informed decision. People weigh priorities differently and so long as they have access to information and can be well informed to make smart personal decisions, [that] is part of our responsibility as well." – *Advocacy Participant*	"I would ask the FHFA to ensure that climate risk is considered in underwriting of mortgages.… Because they oversee 90% of the mortgages across the country. And it perfectly addresses the issue of pairing policy with capital. And gives it the 'stick' it needs and [the] incentive it needs." – *Government Participant*	"If you find out the home was flooded 4 times in the last 10 years, that might affect your decision. That can affect pretty dramatic changes. But over a medium-term rather than an immediate short-term, and hopefully avoid those rapid devaluations. Some homes will drop in price, but if they drop in price over a longer period, it gives the homeowner and everybody else more chance to say, 'maybe I'm going to sell this house now or something'. It's just trying to figure out ways to cushion the blow." – *Housing Finance Participant*

Themes emerging from interviews that highlight cross-sectoral tensions in scaling climate resilient solutions are shown above, along with associated subthemes. Illustrative quotes are provided for each subtheme. Observed counts (*n*) and percents are provided for the number of interviews in which each subtheme was recorded.

reforms include exemptions for certain high-density projects from CEQA review, if they are not located on environmentally sensitive or hazardous sites, and reforms that would streamline rezoning in cities for more housing[43]. These reforms intend to reduce costs associated with permitting and reviews and are a prime example of how state governments can use their power to reform a single stage of the housing development process in ways that generate broader, system-wide cost savings in construction, and perhaps resilience, especially where these efforts decrease sprawl.

Second, *insurance* is thought to drive behavioral change and climate resilience (*n* = 6), but property-level risk-reduction is not currently incentivized by insurance companies through premium

reductions ($n = 5$), and current insurance mechanisms appear limited in incentivizing these types of premium reductions ($n = 4$). As one participant remarked:

> *"There are two things we do that I think…are disingenuous. One is standing up and calling for communities to take action, which we won't recognize in our pricing. The second thing we do is we all do our own studies that show $1 invested in risk reduction will save you $4, $6, $8… do we actually reflect that in our pricing? No, we never do. But it is an issue right now that we don't reflect as well as we could or should when it's a local system-level, ecosystem-type of risk reduction. – Housing Finance Participant*

The challenge referred to by interviewees reflects specific limitations in the insurance industry's current ability to price adaptation. However, the State of Alabama's adoption of FORTIFED standards demonstrates the ability and willingness of state government, a non-profit, the insurance industry, and property owners to work together to reduce disaster-related losses and insurance costs. The Insurance Institute for Business & Home Safety (IBHS), a non-profit organization funded by the insurance industry to design and test construction standards that lead to risk reduction from various hazards, introduced the FORTIFED designations in 2010. The State of Alabama created the Strengthen Alabama Homes grant program, which subsidizes the cost of installing FORTFIED roofs, combined with insurance discounts for wind coverage. An analysis of FORTFIED standards after Hurricane Sally (2020) shows that homes with varying FORTIFED designations performed better than conventional construction and reduced loss frequency by 55% to 74% and loss severity by 14% to 40%, and estimated that, if all affected homes had been retrofitted to a FORTIFIED roof, policyholders would have saved $32.6 M, or 61%, of all deductibles paid[44]. This model could be replicated for other hazards, such as flooding and wildfire, but will require willing state governments and their departments of insurance to work with insurers to incentive adoption, and time to study the impacts and quantify the benefits. Indeed, the California Department of Insurance in 2022 moved to require premium discounts for fire-proofing homes, but thus far the program had produced little savings for policyholders[45].

Third, *climate risk information* is not distributed equally ($n = 10$), as institutions that can purchase data have greater access to more sources. However, inherent scientific uncertainties pose a challenge in decision-making ($n = 12$) and model limitations may have implications for maladaptation ($n = 4$)[46]. The growing competition between private firms that provide downscaled future climate-risk information based on proprietary climate models[47] raises questions, as some researchers contend limitations in current climate science cannot support this form of risk assessment[48,49]. A recent study compared results from the national flood risk data provider, First Street, and a localized flood model and observed <25% agreement in areas deemed at risk[50]. This finding highlights a major source of decision paralysis for housing finance agencies, speaking directly to the last tension identified.

Finally, with respect to *equity-related issues*, solutions that aim to correct current market distortions, such as increasing risk disclosure ($n = 6$) and climate risk-based mortgage pricing ($n = 3$), were favored among participants but also will cause a loss of value for current owners and may not align with societal wealth generation goals ($n = 9$). Failing to adequately consider the risks posed by data that are not credible could result in the improper devaluation of properties, which will be especially consequential for homeowners who are "asset rich, cash poor," and for whom owning a home is the main source of generational wealth.

Addressing the challenge of information asymmetry and the broader question of who ultimately internalizes and bears climate risk underscores a fundamental tension in climate adaptation: making climate risks transparent produces loss for *some* despite the intention of reducing losses *overall*. For example, Gourevitch et al. [51], estimate that residential properties in the U.S. at risk from flooding are overvalued upwards of $200B[51]. Correcting climate-related market distortions will lessen future damages and benefit future owners, but present severe transitional risks to both property owners and the public through property value loss, municipal credit downgrades, and reduced tax bases. As one Advocacy participant stated, *"Everyone is looking to eliminate financial losses rather than absorb financial losses,"* attesting to a potential hard limit in realigning incentives for more resilient development.

Government leadership and collaborations are key in enabling action

Building on the need for cross-sectoral collaboration to address complex tensions, participants identified governments as pivotal actors in climate-resilient housing solutions. Most participants, including those in the private sector, felt government across all levels is responsible for driving resilience because of their outsized regulatory, financing, and information services roles (Supplemental Table 5). Almost half of participants asserted the federal government ($n = 30$) has the most responsibility in enacting risk reduction solutions and can have more impact because of its ability to marshal funding resources and absorb risk, while others stated the Government-Sponsored Enterprises (GSEs) like Fannie Mae and Freddie Mac ($n = 9$) have the most climate risk exposure and therefore should be compelled to act (Supplemental Table 5). Participants also felt local governments ($n = 24$) can exercise their land-use and zoning authority, as well as infrastructure management roles to stimulate risk reduction for housing, but noted the political realities of exercising this power. Others pointed to state governments ($n = 21$; Supplemental Table 5) as having power in regulating insurance and building codes.

Our analysis of sector involvement in the solutions that interviewees proposed (Table 2) and of multi-sectoral interactions that produce climate-housing resilience (Fig. 2) also suggests that governments appear best-positioned to stimulate climate resilience, although the system-wide changes needed to scale resilience have not yet materialized. Local government involvement was ranked highest among the proposed solutions ($n = 20$), followed by the federal government ($n = 19$), state government ($n = 18$), non-profit organizations and advocacy groups ($n = 12$), and the insurance industry ($n = 10$; Table 2). One private sector participant, who stated that government intervention is necessary, noted the challenges governments face.

> *"The private sector has not taken that risk on. We don't have the right incentives. And therefore, people continue to build in exposed areas. The ultimate damage is going to be much higher than it would be if we had the right incentives. But the government has a hard time putting the right incentives in place, because it raises equity issues and to address the equity issues at the same time as you're trying to address the risk issues…that's what makes it hard. There's no easy fix." – Housing Finance Participant*

A homebuilder who acknowledged that government regulations have a place in promoting resiliency, despite other regulations that make home building unaffordable, stated.

> *"Homeowners associations can have rules about what someone can do in their yard, but they can't actually go in and inspect and enforce that. The Fire District is the one who has the legal right to do that, if they wanted to. But in this case, this Fire District doesn't have the staffing to do that. They didn't want to be the regulator, and in writing our fire policy, we called it fire guidelines. Because there is no enforcement ability to it. There's no 'stick', as it were.*

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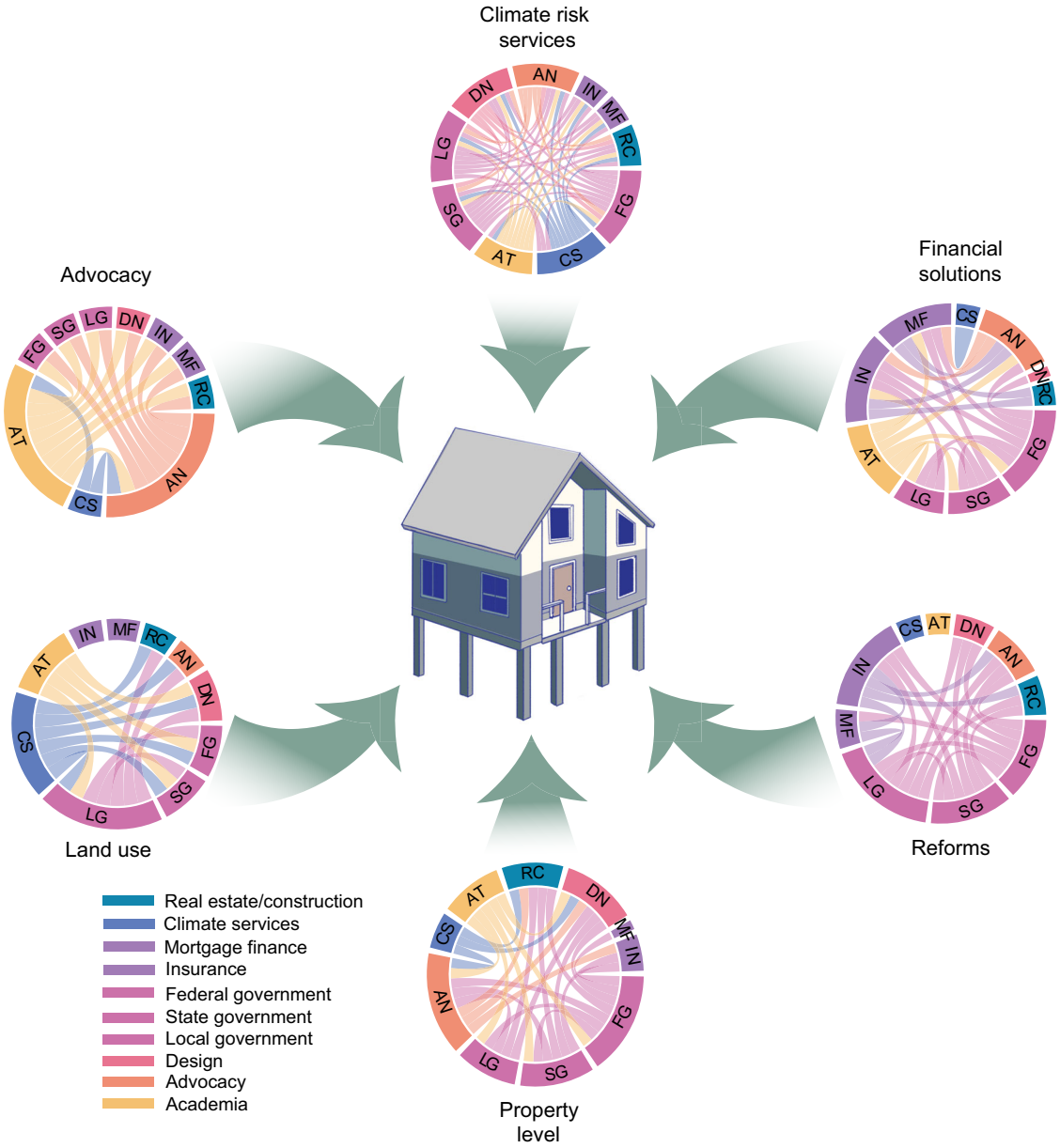

Fig. 2 | Conceptual diagram of multi-sectoral interactions within each solution type that stimulate climate-housing risk reduction. An overview of primary interactions between each sector within each solution type is depicted above. Acronyms for sector categories are defined in Table 2. A full list of interactions is included in Supplemental Note 1. Image in center created by E. Hartley | elabarts.com.

Which is funny, I keep arguing against regulation. And here's an example where regulation might be important." – Home Building Participant

We also detailed the primary interactions across sectors within each action type that foster climate-resilient housing decisions to illustrate the influence of sectors on one another (Fig. 2; see Supplemental Note 1 for a list of interactions). In each action type, apart from advocacy, all levels of government can influence the actions of other sectors by enacting reforms and new regulations, which was noted in the expert responses (Supplemental Table 5), as well as providing financing and climate services. Specifically, the federal government has an outsized role in providing financial solutions (e.g., through mortgage securitization or disaster relief funding), property-level resilience (e.g., mandating property-level risk reduction through disaster relief or proactive resilience programs), and providing climate risk information (e.g., NOAA or FEMA data products). Notably, climate services also have a large role in helping to determine land-use decision-making, while both reforms and new financial solutions can produce risk reduction actions within the mortgage finance and insurance sectors (Fig. 2). These interactions further highlight the need for careful consideration of the roles and influence each sector has in driving change and the necessity of multi-sectoral collaborations. As one participant remarked.

"My personal feeling is that the only way we're going to solve the problems and find solutions is through a joint effort. Federal government, state, local municipalities, and developers. You can't put the burden on the developers because you're going to stop development. You can't put the burden on the cities because they'll go broke. So, there's got to be some type of shared responsibility amongst everybody, and then [to] understand the impact of

whatever decisions are made, so that those impacts can be paid for by somebody." – Home Building Participant

Indeed, sociopolitical factors ($n = 21$), such as collaboration and consensus building ($n = 14$), acknowledgment of urgency or crisis ($n = 7$), and political leadership ($n = 6$), emerged as key enablers of climate resilient action (Supplemental Table 4). Collaborations and consensus building offer an opportunity for various stakeholders to consider diverse motivations, create buy-in, and resolve conflict[52], while a crisis prompts action out of either economic or social necessity. For instance, all three socio-political factors were identified as enablers in the City of Charleston's prohibition of "slab on grade" construction in floodplains (Supplemental Table 1). In detailing the circumstances that led to this action, a participant conveyed,

"Our tidal flood events started to increase in the early 2000s. So, the salience of flooding was pretty high. One of the ways to build affordable homes is to put them in the 100-year floodplain and then use fill to get to the base flood elevation. So, there was a strong push to regulate fill. That led to a push by a couple of members of the city council to ban fill everywhere. Environmental organizations came and said, 'let's ban fill'… the home builders and realtors are like 'well, we understand the problem, but banning fill is not a solution'. And the preservation groups were also part of this because they want to see Charleston develop in a smart way. So, we had a series of meetings, and we got to a point where we could agree to this ban of slab-on-grade foundations for new residential in the 100-year floodplain and for substantial redevelopment." – Government Participant

While collaborating and building consensus is not a particularly new solution for addressing challenges with multiple stakeholders[53], the role of government in driving climate risk and housing solutions should not be understated. All but one solution detailed in Supplemental Table 1 was either government-led or part of a government collaboration with private, public, and non-profit partners, underscoring the critical role governments play in creating space for innovative solutions.

Beyond socio-political factors, participants also stated increased climate risk awareness ($n = 9$), as well as actual mandates ($n = 5$), enabled risk reduction actions. If climate resilience were occurring at any scale, it could have occurred through affordable housing developments or post-disaster rebuilds that require risk reduction through mandates attached to recovery funding. However, the adoption of the FFRMS by both FEMA and HUD[54,55] under the Biden Administration has been eliminated under the second Trump Administration. In cases where property-level risk-reduction actions were not mandated, consumer demand drove the uptake of these solutions. One participant remarked:

"We see home prices for places that are in flood risk areas appreciate slower. We're seeing consumer action and behaviors saying 'I'm not going to prioritize these coastal homes just because they're on the water, because I see climate risk in that'… And so, consumer sentiment, I think, is a huge piece of this." – Climate Services Participant

Our study indicates that the integration of climate risk reduction policies and strategies across the housing ecosystem is still in its infancy. Property-level risk reduction is currently occurring at small scales, driven by mandates (for publicly financed or subsidized development) or consumer demand through the recognition of risks (in the case of market-rate development), but these actions face many barriers to implementation and scalability. Most experts believe that laws or mandates are necessary to prompt professionals or sectors to integrate climate risks into their work, citing voluntary measures as insufficient and a need for risk awareness and standardization of solutions. However, while mandates provide some cost savings with economies of scale, they could also exacerbate housing unaffordability and inequality. These dynamics may further bifurcate private markets, where only consumers who can afford risk reduction designs can access these measures absent mandates.

Our study makes clear the role of federal, state, and local governments in stimulating change and highlights risks of government inaction, specifically federal inaction. Our analyses of sector involvement in proposed solutions and multi-sectoral interactions, as well as participant responses, highlight key responsibilities for government action due to its outsized regulatory, financial, and information services roles. Our analysis of enabling conditions reaffirms that governments play a pivotal role in convening or participating in the collaborations that lead to multi-stakeholder consensus-driven action and policy change, highlighting a path forward for risk reduction solutions. However, progress on adapting to climate risks across the housing sector was slow prior to the second Trump Administration, and the actions of the current administration have reversed and hastened a decline in future progress. The risks of federal inaction are clear, as even private sector experts highlight the critical role of the federal government in catalyzing action, particularly on issues of climate services and financing. Further federal delays on either new policy or reforms will only widen existing gaps in information provisioning and adaptation financing, leaving looming transitional and fiscal risks at large.

Multi-sectoral collaborations offer a path forward, but some challenges may represent hard limits to adaptation. The four cross-sectoral tensions—building code adoption, insurance mechanisms, climate risk information, and equity-related issues—identified in this study represent critical areas where innovation through multi-sectoral collaborations is needed to advance climate-resilient housing solutions. For example, financial institutions do not currently have adequate tools to incentivize risk-reduction behaviors, but perhaps in collaboration with academia, non-profits, willing state and local governments, and climate services firms, necessary innovations in modeling and assessment could emerge. Developing collaborations and evaluating policy impacts at state and local levels can stress-test new approaches before advocating for federal adoption. However, addressing transitional risks associated with information asymmetry and potential wealth devaluation represents a potential hard limit to adaptation, as few stakeholders are willing to absorb the true costs of climate risk. Without multisectoral solutions that spread and offset the costs of adaptation, risks will continue to rise and someone—whether it be individuals, governments, or private markets—will bear the costs. Ultimately, addressing climate-housing resilience will require a collective effort across sectors, leveraging diverse expertise and resources to scale effective and affordable resilient housing solutions.

Study limitations

Our study has limitations. It captures the opinions of 64 professionals working on climate risk–housing issues, primarily in coastal areas, and is not generalizable nationwide or internationally. Our interview recruitment strategy was unsuccessful in reaching professionals at mortgage origination firms. Our study also focuses on risk reduction policies for the *new construction* of *residential* units to target our sample population because we could not identify a large population of professionals working on retrofitting homes for adaptation. Retrofitting the existing housing stock represents the greatest climate risk–housing challenge and should be prioritized in policies and financing mechanisms. Finally, our study does not address what should be the goal for resilient housing: the integration of decarbonization into the types of risk-reduction measures we discuss here. Though our study has limitations, these insights are critical for informing future

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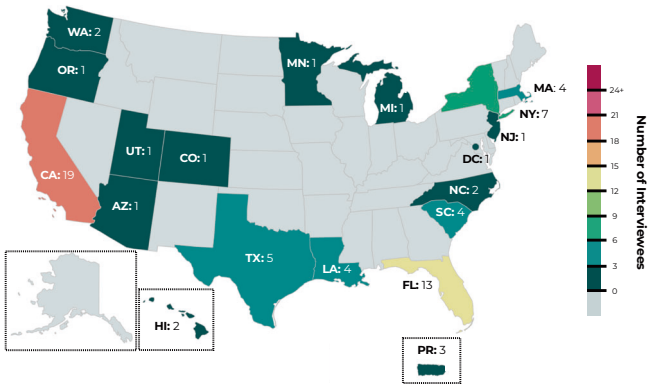
a

Participant Characteristic	Count	Percent
Sector of Employment		
Academia	7	10.9%
Advocacy	12	18.8%
Design	11	17.2%
Government	15	23.4%
Finance and Regulators	8	12.5%
Information Services	2	3%
Real Estate/ Home Construction	9	14.1%
Career Stage (n=63)		
Early	2	3.1%
Early to Mid	5	7.8%
Mid	29	45.3%
Mid to Late	10	15.6%
Late	17	26.6%
Organizational Level		
Associate	10	15.6%
Senior	36	56.3%
Principals/Executive	18	28.1%
Years in Current Position (n=62)		
1-5 years	42	67.7%
6-10 years	10	16.1%
11-20 years	3	4.8%
20 + years	7	11.3%
Housing Type		
All housing types	16	25%
Single-family (market-rate)	28	43.8%
Multi-family (market-rate)	39	60.9%
Single-family (affordable)	9	14.1%
Multi-family (affordable)	16	25%
Other	13	20.3%
Mitigation or adaptation		
Primarily mitigation	5	8.3%
Primarily adaptation	36	60%
Both	17	28.3%
Unspecified	2	3.3%

b



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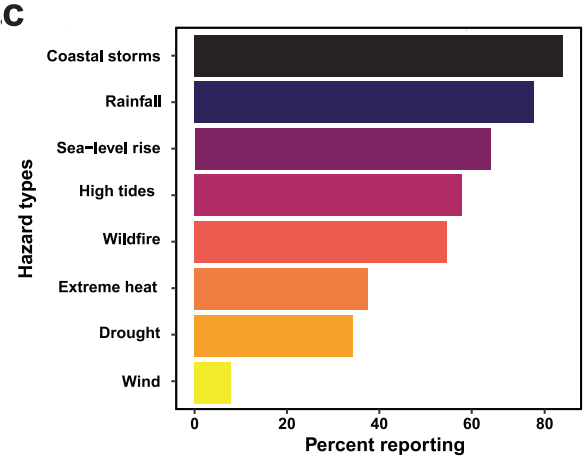

Fig. 3 | Respondent characteristics. a Selected characteristics of interviewees as a percent of the total sample ($n = 64$), along with observed counts (number of participants) for each subcategory, unless otherwise indicated. **b** A choropleth map of the United States, detailing at various scales the geographic area of focus for interviewees, created with mapchart.net, licensed under a CC BY-SA 4.0 Attribution-ShareAlike 4.0 International license. **c** A bar plot detailing the hazard types that interviewees reported they are responding to in their work is shown.

research, policy development, and industry practices that will catalyze climate-resilient solutions across the housing sector.

Methods

We conducted a multisectoral expert elicitation using semi-structured interviews to address our research questions. We use the term "expert" as an inclusive descriptor for all interviewees, encompassing practitioners, professionals, and researchers with demonstrated experience or specialized knowledge across climate risk and housing. We organized our recruitment methods to search for experts across six sectors, listed and defined below: (1) ***government:*** federal, state, and local government officials working on climate resilience, disaster recovery, zoning, housing, or economic development issues; (2) ***housing finance***: climate risk and resilience officials at insurance and reinsurance companies, state insurance regulators offices, and public-sector housing finance agencies; (3) ***home building***: officials at home construction companies, real estate development (affordable and market-rate) and investment firms; (4) ***academia***: leading academics and researchers at think tanks on issues of housing and climate risk and adaptation; ***(5) design***: urban planning, engineering, and architecture firms; and finally (6) ***advocacy***: officials at housing-focused organizations (national and community-based) as well as industry and housing relevant non-profit organizations (no housing construction organizations). We added a seventh category (7), ***climate services***, to account for providers of climate risk information after our recruitment strategy led us to these individuals.

We applied multiple approaches to recruit experts for this study. We focused on recruiting professionals who are actively working on climate–housing solutions, primarily within coastal communities nationwide, to capture the range of potential actions or implemented solutions. Across all searches, we carefully screened potential participants, selecting for professionals working at the intersection of climate adaptation and resilience and housing. We first compiled a contact list based on attendee and speaker lists of climate resilience and housing-related conferences. We used LinkedIn to search across relevant professional networks and professional groups. We employed the following search terms for professionals within the housing sector: "climate risk, resilience, or adaptation", "environmental risk", "climate development", "ESG" (for private sector employees, primarily), and "disaster recovery or resilience". We conducted deep research on companies and organizations, stemming from these initial searches and further narrowed potential experts based on our stated criteria. We contacted authors from relevant publications, including organizational reports and academic publications, as well as experts featured in relevant media publications. Finally, we used balanced snowballing sampling, asking interviewees to recommend potential participants who agreed and disagreed with the perspectives they shared within their interviews. We made attempts to recruit officials from major

mortgage lenders but were unable to reach these individuals. We sent 108 invitations and conducted 64 interviews. We suspended recruitment once we reached sufficient saturation within each of the six initial categories.

Interviews were conducted with approval from the Institutional Review Board at Columbia University. Participants spoke on conditions of anonymity, aiding our ability to surface ideas and considerations that are not easily discussed publicly, especially for representatives of institutions who have decision-making authority across sectors. Participants were not compensated for their contribution. The interview protocol aimed to uncover considerations and tensions that occur across multiple sectors within the housing policy, development, and finance ecosystem in either developing or implementing climate risk-reduction strategies (Please see Supplemental Note 2 for the full interview protocol). The questions focused on considerations relevant to new construction, as our search efforts did not yield many professionals focused on resilience retrofitting. Specifically, we aimed to understand (1) the types of risk-reduction strategies being developed or implemented, (2) the barriers and (3) enablers in their implementation and development and (4) tensions between sectors in addressing climate risk-reduction. We also asked questions on (5) general housing challenges to understand how climate resilience aligns with or not with more pressing housing issues. Finally, we investigated (6) new or existing policy solutions that should be more seriously considered for cultivating climate risk-reduction across sectors. We began piloting the interviews in August 2023. The interviews took place online over Zoom. Interviews initially required respondents' participation for 45 to 60 minutes. However, we began offering abridged versions of the interview, 30 to 45 minutes, to attract more professionals to the study. As such, some interviewees did not answer all questions, but only as many as time allowed. Interviews concluded in February 2024. The average time spent within the interviews was 45 min.

We used Otter.ai services to assist with the interview transcriptions and applied directed content analysis to both deductive and inductive themes. We used Google Forms to design a structured questionnaire that allowed us to systematically capture both deductive and inductive themes during the coding process. The form included predefined categories aligned with the deductive themes emerging from our conceptual framework, as well as open-ended text fields to record observations and apply directed content analysis to surface inductive themes. Inductive codes were developed over three iterations of coding. NS, AG, and TC edited and coded all interviews. Quality control checks were performed by double-coding 20% of the sample, and coding discrepancies were identified within this subset. After discussing and resolving these discrepancies, NS reviewed the full dataset for these discrepancies and made changes throughout to ensure consistency in coding. We analyzed responses by code categories and interviewee sectoral affiliation.

Interviewees were given the opportunity to read a draft of the manuscript while the paper was under revision and asked whether they would like their organizational affiliation published. Only a few interviewees elected to disclose their organizational affiliation. They are as follows: the County of Kauai Planning Department, California YIMBY, the Center for Resilient Cities and Landscape at Columbia University, InnSure, Aon, and OneShoreline.

Participant demographics

Interviewees hailed primarily from Government ($n = 15$), Advocacy ($n = 12$), and Design ($n = 11$) sectors. Most respondents ($n = 42$) indicated they held their current position for 1-5 years, despite many of them (45.3%) indicating they were mid-career or held a senior position in their organization ($n = 36$; Fig. 3a). Most professionals (60.9%) indicated they worked within multifamily housing (market-rate), followed by single-family housing (market-rate). Most interviewees (60%) also indicated they worked primarily on climate adaptation. Geographically, 45.3% of interviewees work nationally (not shown), followed by California ($n = 19$), Florida ($n = 13$), and New York ($n = 7$; Fig. 3b). Respondents reported working on risks from coastal storms ($n = 52$), rainfall ($n = 48$), and sea-level rise ($n = 42$; Fig. 3c).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

Data are not publicly available due to them containing information that could compromise research participant privacy or consent. The data that support the findings of this study are available on request from the corresponding author, NAS. Please allow up to 4 weeks for a response. Interviews were conducted with approval from the Institutional Review Board at Columbia University.

Code availability

Code available at https://doi.org/10.5281/zenodo.17923693[56].

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Author contributions

N.S. conceptualized the study. N.S., L.S., K.M., A.C., and R.H. developed the methodology. N.S. conducted data collection. N.S., T.C., and A.G. conducted the analysis. N.S., L.S., K.M., and R.H. interpreted the results. N.S. and T.C. created data visualizations. N.S. drafted the original manuscript, and L.S., K.M., and R.H. assisted with the writing process. All authors reviewed and edited the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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