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Physical climate risk creates challenges and opportunities in US municipal finance

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The US $4.2 trillion US municipal debt market finances over 70% of essential infrastructure, but escalating physical climate risks, such as flooding and wildfires, are exposing the market's emerging vulnerabilities. Rising disaster costs and insurance retreat threaten property values, and hence municipal tax bases that secure debt repayment. Despite these signals, municipal bond prices have been slow to reflect climate risk adequately. Well-resourced municipalities may use bonds for adaptation, but those facing constrained credit access may struggle to access capital. This US-focused Review identifies three challenges: (1) climate risk is underpriced in municipal bonds; (2) abrupt repricing could affect high-risk and under-resourced cities most by increasing borrowing costs and limiting capital access; (3) misalignment between adaptation planning and municipal finance weakens long-term resilience and affects creditworthiness. Together, these challenges contribute to a climate-debt doom loop that can be triggered by climate shocks. This synthesis offers actionable strategies for cities' adaptation plans and governance frameworks to disrupt this loop and strengthen municipalities' financial resilience.

Climate-related financial risks are increasingly influencing decision-making in the US public finance sector. These risks are often grouped into two categories: physical risks, which can emerge from hurricanes, floods, wildfires and sea level rise (SLR), and transition risks, which emerge from changes in policy, technology, market behavior and other shifts during the transition to a low-carbon economy[1]. Here we focus primarily on physical risks in the USA, a relatively underexplored area in urban policy and finance literature[2,3]. Acute and slow-onset climate events are increasingly exposing vulnerabilities within the public finance system, with 2023 alone experiencing 28 separate one-billion-dollar disasters[4,5].

With both federal disaster programs and private insurers pulling back from high-climate-risk (high-risk) regions, the financial burden of resilience is shifting decisively to state and local governments[6–9]. This shift reflects broader trends of long-term federal disinvestment in infrastructure, which has left municipalities with increasing responsibility, but also limited fiscal tools to respond[10]. At the same time, public infrastructure and services are increasingly financed through private markets[11]. However, these markets are not pricing physical climate risk adequately, as existing evidence suggests that the link between climate risk exposure and bond pricing is weak, inconsistent and marginal[12–14], even though scholarly evidence indicates there is a link between climate and debt[15].

Within the overall US $47.4 trillion US bond market[16], only the $4.2 trillion municipal bond market is directly available to cities, counties and other local government entities to finance operations and capital improvements. A municipal bond's federal (and sometimes state) tax-exempt status permits investors to earn interest, thereby consistently retaining their attractiveness[17–21]. Presently, municipal bonds finance over 70% of the country's public projects[17].

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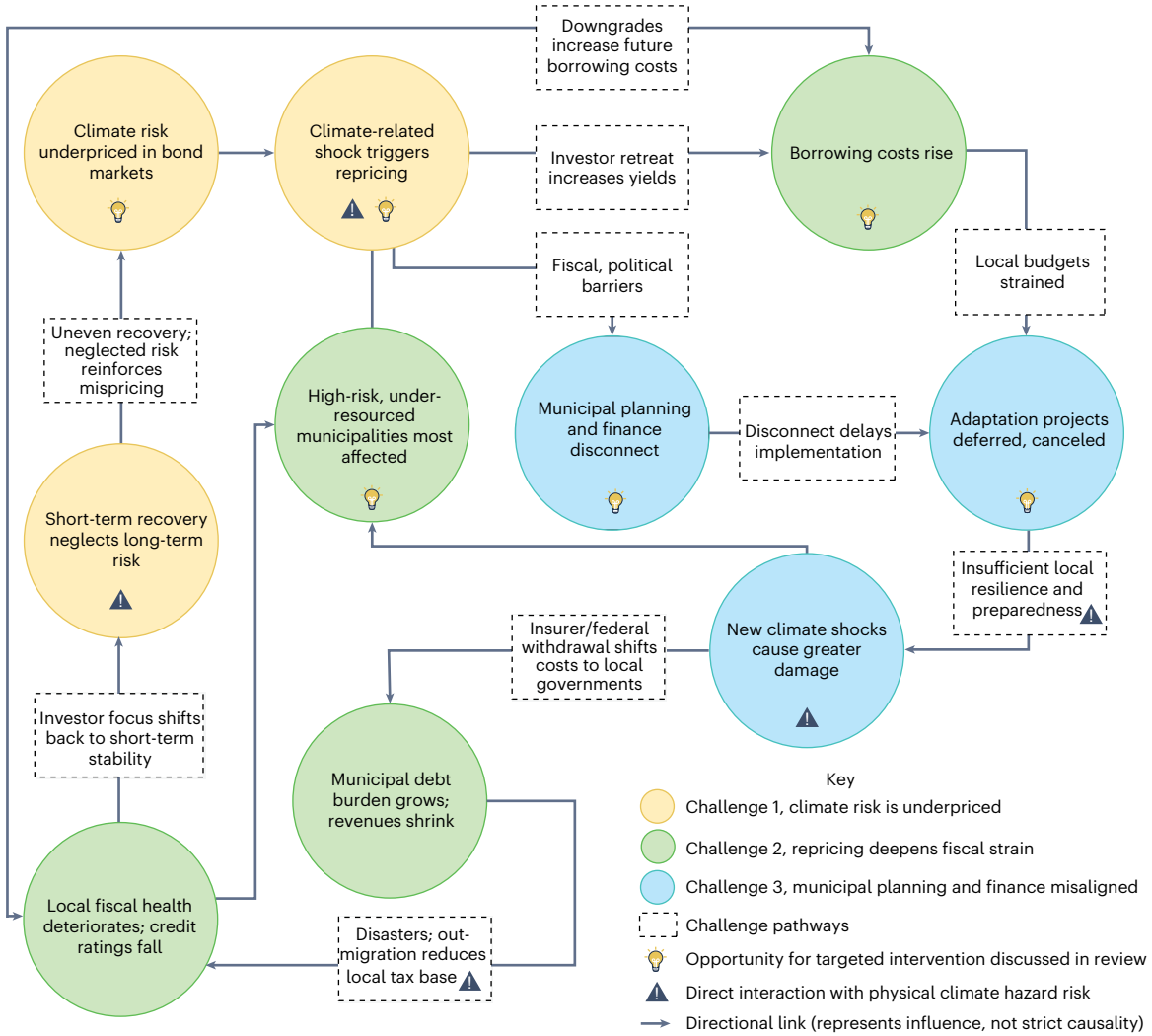

Fig. 1 | The climate-debt doom loop for municipalities. This Review centers on US municipal finance and finds three interrelated challenges. Underpriced climate risk[1,12–14] (in yellow), abrupt market repricing[22] (in green) and misalignments in municipal planning[15] (in blue) reinforce fiscal vulnerability. Lightbulb icons indicate potential intervention points discussed in the Review, and red hazard icons indicate direct interactions with climate hazards that can accelerate the loop.

The municipal climate-debt doom loop

This Review critically examines how physical climate risk interacts with the US municipal bond market, with a specific focus on (under)pricing and structural vulnerabilities. As the US market features tax-exempt bonds, a highly fragmented issuer base, and distinct federal and state institutions[18,21], the findings are typically not directly generalizable to other countries.

In this Review, 'pricing' refers to present-day borrowing terms across issuers, whether through yields or underwriting fees[1,12,13,15]. Conversely, 'abrupt repricing' occurs when investors suddenly incorporate previously neglected risk, perhaps due to new data, rules or sudden shocks[22]. Together, these dynamics operate within a 'climate-debt doom loop' that is well documented in different contexts[14]. Figure 1 illustrates the climate-debt doom loop for municipalities, whereby growing physical losses affect municipal fiscal health, which limits adaptation efforts, thereby raising future climate exposure risks and subsequently increasing borrowing costs. This synthesis identifies three reinforcing challenges that drive this vicious cycle:

- First, the municipal bond market continues to undervalue climate risk. This underpricing may be due to limited and inconsistent disclosure, short time periods for credit evaluations, and neglected risk and inattention from investors[1,2,12–14].
- Second, if investors do indeed start accounting for climate risk more fully, high-risk communities that previously benefitted from lower borrowing costs could face a sudden increase in interest rates. This abrupt repricing could also limit affordable capital access for fiscally constrained municipalities. For doubly vulnerable cities (those that are both under-resourced and exposed to high climate risk), the repricing would leave them particularly exposed to financial shocks during market adjustments[13,22–27].
- Third, local climate adaptation planning can be disconnected from municipal finance due to factors such as limited fiscal capacity, political constraints and short-term revenue-based pressures. This can make it challenging to finance equitable, long-term resilience projects. This misalignment, over time, can inadvertently reduce municipal creditworthiness[6,15,28–33].

Climate risk is underpriced

Insurer retreat may increase debt reliance

There are two distinct (but related) trends of note: (1) disaster costs are rising, and (2) a growing share of these costs are now considered uninsurable by private insurers. Historically, local governments have relied on a combination of federal protections and private property

and casualty insurance to withstand disaster-related financial losses[7] (see The Stafford Act in ref. 34). However, this dual safety net is weakening. For example, the Federal Emergency Management Agency (FEMA) and its National Flood Insurance Program face growing resource limitations, operational issues and budgetary cuts[8,9,35]. Due to increased vulnerability and growing reinsurance costs, major insurers such as State Farm and AIG have discontinued coverage in high-risk regions such as Florida, Louisiana and California[9,36]. As a result, residents and businesses who are priced out or excluded from private coverage are turning to state-backed plans instead, which were initially designed as last-resort solutions[36]. Public debt markets provide opportunities for states and municipalities to continue financing costs associated with disaster response, infrastructure development and climate adaptation.

Although alternate tools such as pay-as-you-go, public–private partnerships[18], state infrastructure banks[37] or philanthropic grants[38] are available to local governments, they can be fragmented, not always scalable, or are unevenly distributed. Within debt markets, green bonds, resilience bonds and catastrophe bonds are viable options[39]. Green bonds have been critiqued for increasing the climate and financial risks for marginalized communities, yet this is an issue common to many debt tools. Their design and structure determine whether and how they amplify debt burdens, or help to promote resilience[3,40].

Among these financing options for local governments, municipal bonds remain the most institutionalized and widely used mechanism. Bond defaults due to natural disasters have been rare, with only 12 reported in the past 15 years[41]. Notable examples include the Paradise Redevelopment Agency's default post 2018's Camp Fire, as well as Clyde, TX's default in 2023 (ref.42). The municipal finance sector involves a broad range of actors. Figure 2 illustrates this network, along with the responsibilities and constraints associated with each actor.

Weak climate pricing in municipal bonds

As municipalities increasingly consider debt markets to finance infrastructure and services, the pricing mechanisms of municipal bonds become crucial[43]. Incomplete or inconsistent pricing can limit municipal access to capital in vulnerable areas, which can reduce public service capacity, complete infrastructure projects and invest in climate adaptation[2]. Although bond pricing should, in theory, reflect a municipality's exposure to long-term climate risks, several recent studies show that this connection remains either weak or inconsistent. Studies find that US counties that are experiencing SLR exposure are paying slightly higher underwriting costs and bond yields (that is, interest)[13]. However, this is noted only for long-term bonds, and even then, only marginally so. This may suggest that the market discounts future risk unless it perceives it as 'immediate'[14].

There is evidence of a modest effect in pricing beginning around 2013, which was roughly when scientific projections of SLR showed an upward trend[12]. Even then, the effect is relatively small: for example, a 10% increase in SLR exposure corresponds to only a 5.3 basis point rise in credit spreads, with most of the premium concentrated in longer-dated bonds[12]. In other words, even in places facing SLR risk, investors have been charging around five basis points, or 0.05%, for every 10% increase in exposure, akin to paying US $0.50 more every year on every $1,000 of borrowing. Furthermore, this mostly only applies to longer-term bonds, with short-term bonds priced at the same level with no meaningful adjustment. Notably, many of these studies isolated SLR as the only hazard, so other threats, such as wildfires or floods, are not captured[12,13]. This may help to explain why short-term bonds appear unaffected. Even so, the long-term bonds are still not showing meaningful acknowledgment of climate risk.

The gap between climate risk and bond pricing has been noted across the published literature[2,14,15]. Even institutional investors have noted that climate risks are material, yet underpriced[44]. Financial economists have been developing increasingly sophisticated models to better integrate physical risk into sovereign and sub-sovereign debt analysis[45], but the pricing signals in municipal finance in the USA remain limited. This is not to say that sovereign-level models cannot be downscaled to the local level. In fact, the municipal bond system is made up of over 50,000 individual issuers who operate like a network of small borrowers with fiscal autonomy, similar to that of small countries[21]. Sovereign models can overlay climate scenarios on debt sustainability analyses, which can help highlight how climate damages, even with adaptation, can worsen long-term debt trajectories depending on shared socioeconomic and representative concentration pathways[46].

Neglected risk and investor inattention

Unlike the property and casualty insurance sector, where climate risk is considered in decisions such as withdrawal, investors tend to discount slower moving or uncertain risks associated with municipal bonds[44,47]. Scholars describe this as a type of 'neglected risk', where relatively infrequent but high-impact events are ignored until they materialize[47]. Others similarly argue that investors are not paying enough attention to pricing long-term physical climate risks[15,47].

Furthermore, investors may only begin pricing in climate risks beyond specific future milestones. A 2020 study tested whether investors associate climate risk with specific distant dates—this could mean 'net-zero by 2050' policy targets, scientific projections, or public narratives in the media[13]. In short-term decision-making, on the other hand, a recent disaster or significant trigger can act as a clear, immediate signal. Without this catalyst, future climate projections can often feel too abstract to factor into pricing decisions[48]. Weather and climate models can only offer predictions (often with inherent statistical uncertainty), which can leave a gap in financial assessments[49]. Together, this signals that, without clear, short-term indicators or strong datasets to support them, long-term climate risks are often overlooked or undervalued in how bonds are priced. In the absence of these indicators, the inattentiveness to climate risk is likely to continue[15,47].

Climate disclosures lack standardization

Across the board, municipal issuers do not report their climate risks in a clear or standardized way, often exercising substantial discretion for long-term, regional threats[50]. Disclosure standards vary by state and sector, with few regulatory mandates[17]. A 2023 study found that most statements rarely disclose relevant climate risks to investors[51]. Frameworks such as the Task Force on Climate-related Financial Disclosures are common in corporate finance globally[52], but are largely absent in the municipal bond market. Therefore, without consistent disclosure, even investors who want to price climate risk adequately may struggle to access reliable data[50]. Threats such as flood risk or extreme heat are often not disclosed, despite their direct link to long-term creditworthiness[50]. For example, in Miami, despite well-known exposure to SLR, the city's climate vulnerabilities were not present in financial documents[19]. Whether this is a lack of transparency or once again a case of neglected risk, it nonetheless makes it difficult to meaningfully compare risks across municipalities[53].

Disclosures from large, risky or unrated issuers affect investor decisions more than those from smaller or low-risk municipalities[50]. However, most disclosures go unnoticed by the market, especially when they are routine or delayed[50]. For example, the City of Orting, WA disclosed the long-term risk from Mount Rainier's volcanic lahars in its 2010 bond offering documentation[50]. However, neighboring jurisdictions did not disclose this information, despite the shared risk, and benefited from comparable or even more lucrative pricing[50]. Notably, Orting's bonds still sold at a premium (105% of the par value), suggesting that this transparency did not negatively affect investor behavior. This can raise questions about whether, and how, markets interpret these disclosures[50]. For instance, when filings do provide information pertaining to credit (bankruptcy notices, for example) or time-sensitive insights, both investors and credit rating agencies respond[50]. Together, these patterns indicate that, although some disclosures influence

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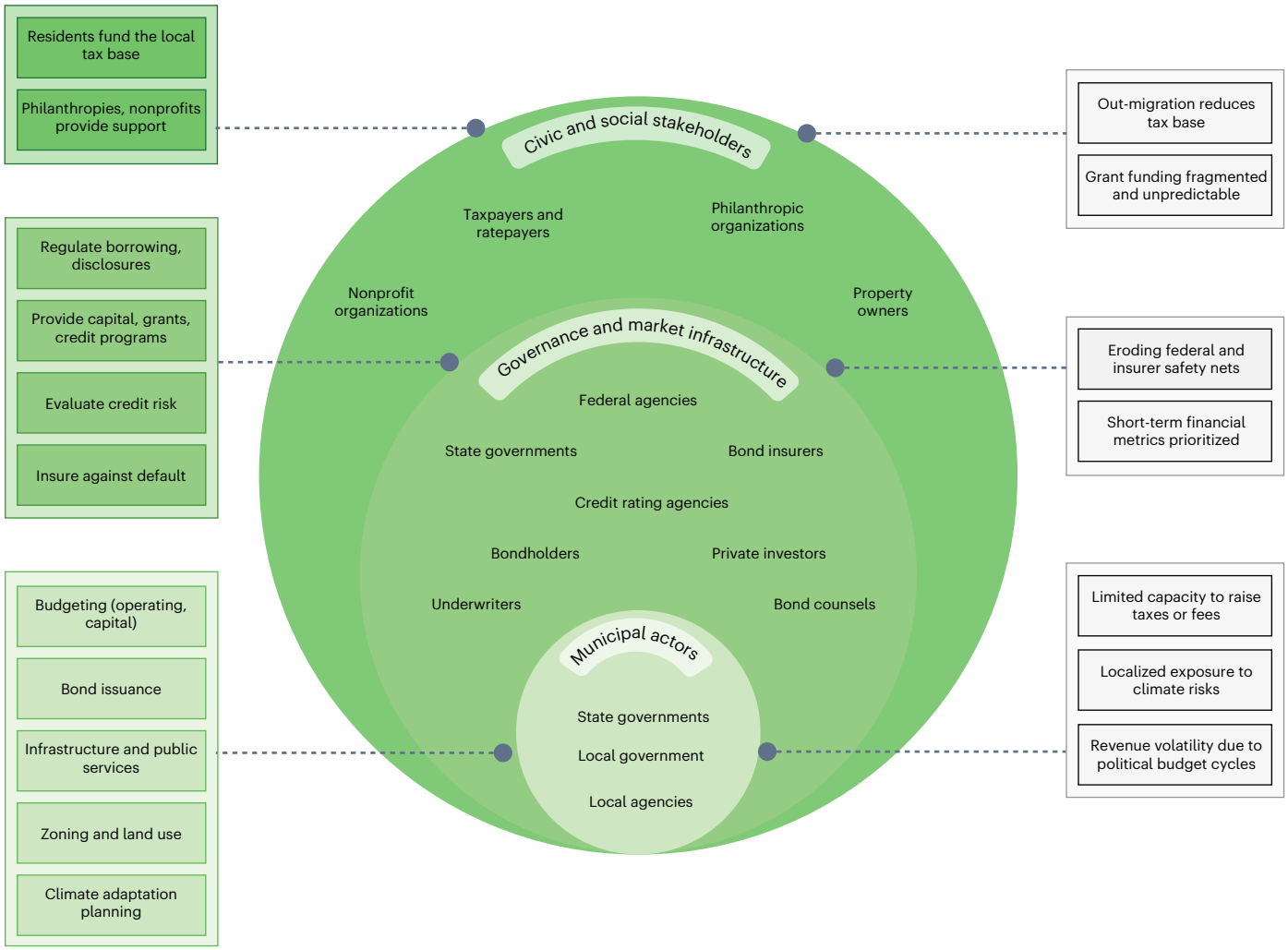

Fig. 2 | Key actors shaping municipal climate finance. This network of actors highlights distinct responsibilities (left, green boxes) and constraints (right, gray boxes). Overlapping roles, such as state governments appearing in both governance and municipal roles, reflect the multilayered nature of climate finance. Together, these interconnections shape which actors hold power, and which communities may face greater financial-climate risks[2,6,15].

market behavior, longer-term physical risks may be discounted or largely ignored by investors[50].

Institutional and structural disincentives

Credit rating agencies such as Moody's, S&P and Fitch acknowledge climate exposure using forward-looking tools, but do so inconsistently[45]. Ratings tend to emphasize short-term financial metrics, such as liquidity or reserve levels, rather than forward-looking climate vulnerabilities[54]. The issuer-pays model, where municipalities pay agencies to rate their bonds, introduces a potential conflict of interest, as agencies earn up to 90% through bond issuer fees alone[55]. Bond buyers also pay for ratings, but agencies rely more on the issuers for revenue, creating pressure to align with their interests more. Overall, credit rating agencies represent one of the most powerful levers for integrating climate risk into the market, but there is still a lack of transparency and systematic shifts thus far.

This may create a disincentive to downgrade municipalities unless there is clear financial distress[56]. Agencies have increased their market share and fees after recalibrating ratings upward, without any change in evaluations, with a one-unit increase in ratings linked to a US $1,420 increase in fees[56]. Municipalities are incentivized to obtain better ratings, and agencies are rewarded for granting them[56]. For the agencies that do incorporate climate resilience factors into their evaluations, the criteria remain vague[57], leaving many cities unclear about which investments may improve ratings, and may potentially turn municipal planning into a box-checking exercise (see the Miami Forever Bond in ref. 19). Moreover, there is a mismatch between the timelines of long-term climate impacts and short-term credit evaluation (typically three to five years)[57], which can make it difficult to price future hazards, which are often multi-decadal.

Uncertainty in climate risk models

Climate modeling generally involves substantial inherent uncertainties about physical climate systems; these are due to model assumptions, emissions scenario selections and internal climate variability. General circulation models, Earth system models, catastrophe loss models and property valuation models all have uncertainties—some scientific, others economic[58]. A core challenge is converting climate risk into financial terms[14], especially if it is not done in a manner that is consistent, comparable and relevant for public finance actors. Without there being a standard approach to climate-adjusted valuations or risk-based metrics, any efforts to price or account for climate risk can be fragmented or even misleading. Questions may arise on whether standardization should be designed to improve compatibility between municipalities, or be based on local context, needs and data capacities[6].

Green bonds and transition risks

Green bonds can also affect market signals around climate risk[59]. These bonds are tied to environmental projects and, in theory, suggest a market recognition of climate concerns. In practice, however, they often reflect investor preferences and marketing more than attempting to price long-term climate risk. Municipal and corporate green bonds often trade at a slightly lower yield than similar bonds without the green label[60]. This 'greenium' indicates that some investors are willing to earn slightly less in exchange for holding bonds that are labeled as environmentally friendly[59,60]. However, investors may be rewarding the bond's climate intent labeling more than the actual long-term climate threats[61]. Moreover, green bond access tends to favor wealthier, investment-grade cities that are able to afford costs relating to certifications and compliance[59]. Finally, transition risks such as new zoning rules, insurer withdrawals and investor sentiment shifts can affect municipal finances comparatively quickly, especially if the risks affect property values or tax bases[1,15].

Taken together, these dynamics can reinforce the climate-debt doom loop. Very broadly, insurer retreat shifts costs to municipalities, so cities rely more on debt. Borrowing terms currently reflect physical climate risk weakly or inconsistently, so adaptation may be delayed, and investor attention stays limited until a shock triggers a response, with inconsistent disclosures contributing to slow responses. If or when ratings do shift, debt service rises and overall municipal budgetary capacity is limited. Meanwhile, climate-related uncertainties further contribute to delayed action, which increases losses. Higher losses and shrinking revenues lead to weaker credit-related metrics, which leads to increased borrowing costs, essentially restarting the loop.

Repricing affects underinvested cities most

The risk of abrupt repricing

The concern regarding underpriced climate risk in municipal bonds is not only about whether current bond pricing is fair or well-calibrated, but rather that a single major event could cause investors to suddenly reevaluate the risks that had been neglected so far. Historical trends indicate, as seen in the 2007–2008 financial crisis, that markets can reprice assets in a matter of days. For example, mortgage-backed securities such as Jumbo and Alt-A loans (which were not inherently riskier) were abruptly penalized during the financial crisis[22].

There is a little precedent for climate risks abruptly disrupting financial markets. However, if investor attention does shift towards accounting more for climate risk, municipal bond yields would increase and prices would fall, with the greatest impacts on issuers that are both fiscally fragile and highly climate-exposed. Extreme heat, for example, is associated with higher municipal bond spreads, even after controlling for other risk factors[1]. This pricing effect is more pronounced for issuers that have lower credit ratings and longer-term or revenue-based debt, and this suggests that both climate exposure (at the very least, extreme heat) and fiscal resilience are influencing investor behavior. This could indicate that climate risk is starting to be priced in, but only selectively. Furthermore, it can suggest that any future shifts in investor focus and prioritization can abruptly amplify financial disparities between and within municipalities[1].

The aforementioned climate-debt doom loop could arise rapidly once repricing begins. Hypothetically, it could be triggered by a single event or series of events: a major insurer withdrawing from a market, new disclosure mandates requiring municipalities to share all climate-related liabilities, or the occurrence of catastrophic extreme weather that is not covered by FEMA disaster relief funds. The financial consequences emerging from this would probably be most severe for those municipalities that are either under-resourced or fiscally fragile; that is, those least equipped to absorb sudden cost spikes or access alternate and affordable financing. This can include socially vulnerable communities, as well as regions with existing deficits or downgraded credit ratings, or those facing both of these challenges. Furthermore, the USA has historically underfunded its infrastructure (given its US $2.6 trillion gap[62]), leaving many communities with inadequate revenue streams to support resilience investments, despite the existence of (albeit sometimes unaffordable) financing options[63].

Climate risk intensifies inequality

The municipal debt market has historically favored affluent cities, reinforcing spatial inequality[2,26,27,64]. Wealthier municipalities typically have stronger credit ratings and have easier access to capital markets for public investment, whereas disinvested cities have often faced downgrades and higher premiums, even though residents contribute equally to debt servicing[26,64].

Although often perceived or marketed as a 'growth opportunity', climate urbanism can prioritize infrastructure protection over social equity, making just planning more challenging[65]. For example, in Philadelphia, PA, green infrastructure projects can actually increase displacement pressures in low-income neighborhoods, thereby reinforcing social insecurity rather than reducing it[66]. With protective, resilient infrastructure concentrating in wealthier zones, vulnerable communities may be overlooked or priced out[66].

Furthermore, predominantly black communities pay an estimated 0.44% more in total annualized borrowing costs, a 'black tax' totaling US $110 million in 2019 alone[67]. Another study found a racial penalty of 19 basis points, totaling US $900 million annually across the municipal bond market[2]. Together, these findings point to a systemic mispricing where race contributes to raised costs. Places such as Jackson, MS, a predominantly black city, have faced decades of extractive financial arrangements that promised public benefits, but instead left it with heavy debt burdens, widening the socioeconomic gap for residents (see the Siemens performance contract in ref. 27).

Redlining's evolution to bluelining

Climate risk introduces a new layer of complication. Redlined communities, for instance, on average face higher heat exposure and environmental justice issues such as higher exposure to industrial pollution and particulate matter[68]. These regions are more likely to be 'bluelined', a modern form of disinvestment where regional banks restrict mortgage access in high-risk areas and offload riskier loans to the federal housing finance agencies[69–71]. This process is a structural withdrawal of capital from communities, as investors and financial institutions retreat from municipal markets in marginalized areas[70]. Credit ratings accordingly reflect this in their downgrades[72].

Mortgage lenders are beginning to price in long-term physical climate risks, especially for properties exposed to SLR, serving as a warning or model for the municipal market[73]. Lenders charge a higher interest rate on these types of property, even when the short-term default risk is the same[33]. This indicates that perceived climate risk alone could already influence the cost of borrowing[33]. When local temperatures spike (serving as a proxy for greater attention to climate risk), loan officers approve substantially fewer mortgages, once again particularly so in SLR-exposed counties and among smaller lenders[74].

In some ways, bluelining can indicate a shift from neglected risk to targeted withdrawal. High-risk communities can be explicitly identified by lenders and insurers as financial 'no-go' zones[70]. Although some degree of regional withdrawal may be justified, and even necessary from a risk management perspective[75], the process by which these zones are identified matters[76,77]. If poorly managed, this retreat risks reinforcing historic patterns of disinvestment[76,77]. Because financial markets rely on historical data and performance, past disadvantages can strongly influence present (dis)investment patterns and risk assessments[78]. This is already happening in cities such as Miami, FL, where investors are buying properties at higher elevations while abandoning flood-prone areas[79]. These shifts raise housing costs and displace lower-income residents towards more vulnerable areas[79].

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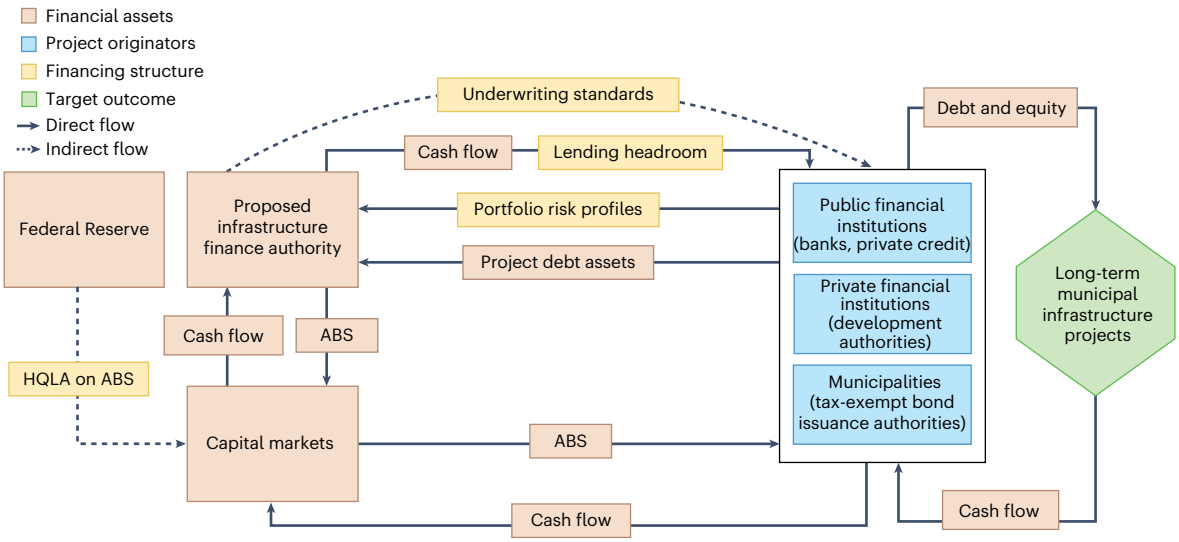

Fig. 3 | Proposed infrastructure finance authority. A proposed federal institution could help cities to finance climate-resilient infrastructure. The authority would buy and bundle local loans into asset-backed securities (ABSs). If granted a high-quality liquid asset (HQLA) status, these ABSs could lower borrowing costs, expand credit access, and help to support more stable and climate-oriented financial systems. This conceptual framework was developed by the authors based on ref. 89.

Urban governance and adaptation planning

Misaligned financial and adaptation plans

Within local adaptation plans, municipal and green bonds remain an underutilized tool[20]. Some sectors, such as water and sewer, are better at considering these debt tools for adaptation[20], but overall, there is a missed opportunity. In many cities, there is a disconnect between climate adaptation plans and municipal finance, which can affect project implementation[29].

These disconnects can be exacerbated by intergovernmental or political frictions, such as state-level budget priorities overshadowing city-level climate goals or partisan division over resilience planning[28]. For example, initiatives such as Climate Ready Boston and the Resilient Boston Harbor Plan outlined detailed risks and community priorities yet faced barriers integrating into the municipal capital budget without dedicated public funding streams[80]. By contrast, San Antonio, TX's adaptation plan explicitly links climate inaction to fiscal risk, tying resilience planning to credit ratings and borrowing costs[81].

Addressing climate risk at the local level is highly contingent on whether municipal budgets and the available financial tools can support the adaptation and resilience goals[6]. Municipal finance, including revenue generation, debt capacity and budget allocations, plays a key part in influencing how, where and for whom climate action gets implemented[6]. For example, a higher municipal expenditure per capita was found to substantially increase the likelihood of adaptation planning, indicating that financial capacity has a key role in determining whether climate projects move from planning to actual implementation[31].

Many cities lack adaptation plans altogether, not necessarily due to apathy, but often due to limited budgets and workforces, along with political barriers, public and stakeholder views, technical hindrances and process issues[82]. A 2022 study found that, of the 87 major US cities they assessed, only 48 (about 55%) had developed climate adaptation plans that accounted for variables such as rainfall intensity (notably, some of the remaining 45% did have broader, state-level guidance)[30].

Fragmented governance and fiscal incentives

Even when adaptation funding is available, access and allocation are not limited by climate risk alone, but are strongly shaped by political priorities, staff capacity and institutional barriers[32]. These challenges are compounded by fragmented coordination between the different levels of government, which can make long-term adaptation planning and implementation more difficult[32]. Within municipal finance itself, constraints can range from state oversight of debt issuance, political pressures to maintain strong credit ratings, and legal limitations on revenue generation[6].

Accordingly, cities that do align their adaptation plans with financial strategies (that is, integrating projects into capital budgets, issuing bonds or identifying funding streams for implementation) are often pressured to prioritize financial metrics over climate equity. For example, coastal municipalities may continue approving waterfront development to meet short-term budget goals from property taxes—despite knowing the risks associated with SLR[63]. However, this short-term strategy clashes with housing finance trends. As mentioned earlier, mortgage lenders pricing in SLR (to an extent) are raising borrowing costs in these very regions[33].

This potential mismatch between local fiscal incentives and the financial sector embedding climate risk assessments in decision-making can create further neglected risks that may surface at a later time—yet another instance of the climate-debt doom loop. As lenders and insurers factor in threats such as SLR, cities may simultaneously encourage development in those very areas to protect their tax revenues[6,33]. Essentially, riskier but short-term growth today will probably lead to reduced creditworthiness, especially if declining property values or capital flight reduce the tax base—ironically, the very things the high-risk development projects intend to avoid[6,19,33].

Climate migration, credit and debt capacity

Migration away from high-risk areas and towards perceived climate havens is intensifying, and all cities—whether gaining or losing population—need to plan ahead[83]. For example, in 2022 alone, over three million Americans were displaced by disasters, which can decrease local tax bases, economic growth and recovery capacity[83,84]. A 2022 study found that there was a statistically significant increase in out-migration both immediately (2005–2006) post hurricanes Katrina and Rita, and over a longer period (2007–2011) compared to before 2005 (ref. 85). Major disasters such as hurricanes can have long-term demographic and fiscal shifts that are complex to understand or predict immediately following an event[85].

Lower climate risk 'havens' need to prepare for sudden in-migration, which may strain housing, transportation, basic infrastructure and

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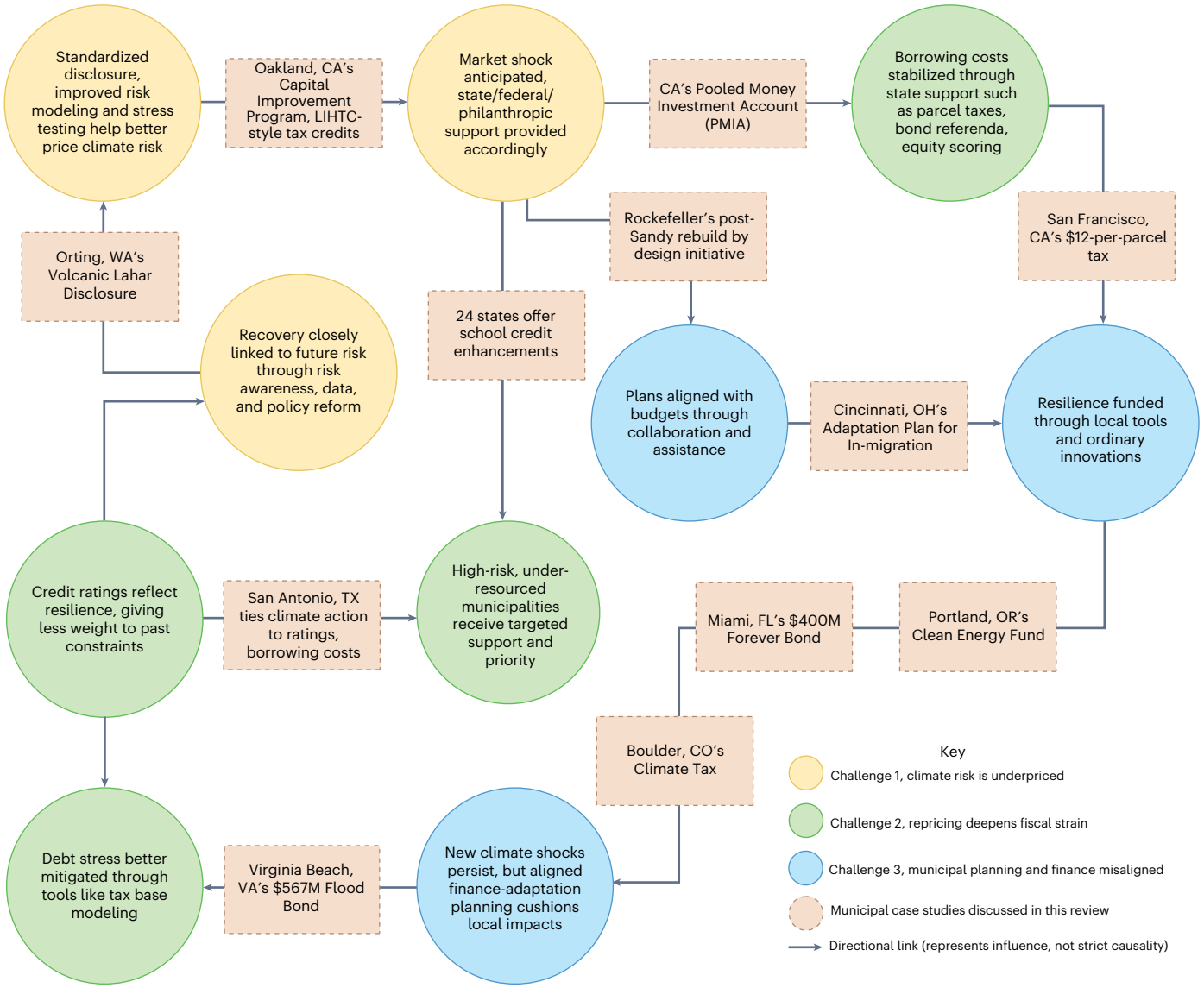

Fig. 4 | Disrupting the climate-debt doom loop. Municipal cases are mapped to the mechanisms in Fig. 1 to indicate where pressures may be relieved[6,19,50,72,80,81,90,91,93,95,97,100]. LIHTC, Low-Income Housing Tax Credit.

public services[86]. These mobility patterns can have direct implications on the municipal bond market. A reduced local tax base is one of the key determinants of a city's ability to repay its debt, which would be exacerbated by out-migration. Climate havens may face higher infrastructure costs from sudden population influxes, but not necessarily a commensurate rise in high-income taxpayers. In both cases, climate migration can disrupt municipal bond ratings and debt capacity, adding more complexity to local public finance.

Innovations to disrupt the climate-debt loop

Strengthening modeling and disclosures

Requiring municipalities to disclose hazard-specific risks in bond offering documents, as well as aligning disclosure timelines with annual budgets and bond issuances, could help to bridge the current disconnect between climate risk and municipal finance transparency. Frameworks such as the Task Force on Climate-related Financial Disclosures can help to create a standardized way for disclosure, including scenario analyses for physical risks and clear short-, medium- and long-term horizons[51,52].

One approach is to model how climate risk affects a municipality's tax base[63]. Because most local governments depend on property taxes, falling property values can erode the tax base and fiscal capacity[63]. In addition, identifying intersecting 'green swan' (sudden changes in climate risk perceptions) and 'Minsky-type' (sudden financial sector adjustments) shocks can help to strengthen climate-financial modeling. Here, climate risk stress testing frameworks can explicitly incorporate these types of sudden, nonlinear event. This can help state governments to assess system-wide vulnerabilities and prioritize support for high-risk municipalities. Municipal green bonds may also be well-suited for emergency issuance during climate-related fiscal shocks[59].

Real-time trading behavior in the aftermath of localized extreme weather events can be a forward-looking signal[14,87]. Asset pricing may reflect belief heterogeneity, where effects depend not just on physical exposure, but also on local-level perceptions of climate risk[14,88]. Finally, a national institution, backed by the federal government, could buy or guarantee loans for resilient infrastructure projects. Although such support may improve private investor participation, it is still important to acknowledge that governments themselves face a growing fiscal exposure to climate risks[45]. Public guarantees should be designed to be partial or conditional, or linked to standardized resilience metrics, to avoid concentrating risk at higher government levels, especially

given that climate adaptation responsibilities are increasingly shifting to state and local governments. Figure 3 (developed by the authors) shows a conceptual framework[89].

Innovative fiscal tools for adaptation

Cities are increasingly developing climate plans, yet many hesitate to fund them through stable or general revenue sources[6]. Municipalities can use a mix of existing tools to fund and manage adaptation, including cross-departmental collaboration, zoning and development fees, and voter-approved parcel taxes. For example, the San Francisco Bay Area approved a US $12-per-parcel annual tax to create long-term, voter-backed adaptation funding[90]. Participatory planning through initiatives such as community-driven project selection can better ensure that locally identified vulnerabilities are actually addressed. Although political opposition and limited public support can lead to climate inaction, participatory budgeting helps by engaging residents directly to co-develop ideas and solutions. Inclusive planning processes can improve transparency and strengthen project proposals, given community input and involvement. Virginia Beach's US $567 million flood bond was designed with public input to reduce long-term losses from floods[91]. However, participatory tools have limitations, especially in highly polarized communities[92].

Cities are also embedding climate and justice goals into everyday financial tools, and these 'ordinary innovations' can include budget allocation frameworks that score proposals based on equity and climate goals, participatory budgeting processes, and climate-specific revenue funds[6]. Boulder, CO's Climate Tax and Portland, OR's Clean Energy Fund are examples of how standard fiscal tools can be repurposed and adapted to support just climate adaptation[6]. Lower-risk cities should integrate migration into adaptation plans by aligning land use, zoning and infrastructure investments with affordable, high-density housing[84]. Cincinnati, OH's climate adaptation plan is among the first US cities to plan for in-migration, where it prioritizes affordable housing and public transit to accommodate climate-displaced populations[93].

Beyond debt financing for climate adaptation

Notably, strengthening local adaptation typically requires capital up front. At a national level, for example, studies find that adaptation projects require governments to cover roughly one-third of the costs just to break even[47]. Given that municipalities have narrower tax bases, face stringent budget-balancing rules, and risk experiencing rating downgrades, this one-third indication can be useful to gauge the debt to non-debt reliance[6,18,55]. Therefore, a debt-only approach to adaptation can inadvertently worsen short-term fiscal health, lead to costs falling onto taxpayers and ratepayers[3,20,40], and accelerate the climate-debt doom loop, even if the benefits materialize at a later time[15,63]. It is important for municipalities to consider a blend of funding rather than rely on debt alone, which may include removing or easing revenue-raising restrictions, giving cities stronger legal and institutional support, and making sure that climate adaptation costs are not unfairly shifted onto municipalities least able to afford them[3,6,20,40].

Tools such as state credit enhancement programs[72] can help to reduce borrowing costs and counter historical biases in how creditworthiness is assessed. They do not require upfront state spending and can be a cost-effective way to promote more equitable investment in underserved communities[72]. To ensure fairer credit assessment, evaluations should not penalize municipalities that inherited fiscal constraints or face high social vulnerability; instead, frameworks should reward proactive resilience investments and equitable adaptation strategies.

State policymakers could also consider resilience-based subsidies or tax credits, modeled after programs like the Low-Income Housing Tax Credit[94]. They can also consider adopting Oakland, CA's Capital Improvement Program's resilience scoring[95], where projects from lower-capacity regions that propose equity, health and safety, environmental or economically attractive projects are prioritized. Establishing technical assistance hubs, designed to help to integrate climate risk assessments and adaptation projects, could help local governments to improve their planning capacity[96]. Furthermore, contingency funds such as California's pooled money investment account[97] and multi-city insurance programs (modeled on risk pooling) can also help fiscally constrained local governments to manage disaster risk costs[98,99]. Philanthropic groups can help too, such as the Rockefeller Foundation's 'Rebuild by Design' initiative after Hurricane Sandy that helped vulnerable coastal communities to access federal disaster recovery funds, while implementing innovative adaptation projects[100].

City case studies in the climate-debt loop

Emerging innovations, especially those demonstrated by municipal case studies, can help to identify ways to disrupt the climate-debt doom loop. Evidence from these examples varies by local context and constraints, but it can still convey tools and trade-offs. For example, although Boston, MA's Climate Ready Boston initiative may lack cross-institutional alignment[80], San Antonio, TX has linked climate risk to borrowing[81]. Miami's Forever Bond introduced mixed equity outcomes[19], but Virginia Beach's voter-backed debt for flood risk reduction helped the benefits to outweigh a higher debt service[91]. Figure 4 maps each case to the loop mechanisms in Fig. 1.

Conclusion

Ultimately, the climate-debt doom loop is not just a municipal challenge in the USA, but is a reflection of deeper structural choices and priorities. Without systemic integration, market incentives may continue to prioritize short-term fiscal stability over long-term resilience, and inequitably so. Therefore, the issue lies in whose risk is recognized and prioritized, and which vulnerabilities remain an afterthought. Disrupting this dynamic will require a thoughtful combination of technical solutions, aligned coordination, political will, governance reform and an explicit commitment towards financial equity.

Data availability

The data that support the findings of this study are available from the corresponding author upon request.

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Author contributions

A.M., E.K. and A.A. conceptualized the manuscript and led the writing. A.M., E.K., A.A., J.M., T.D., E.S. and O.W. contributed financial policy analysis. E.K. and A.R.G. provided interdisciplinary climate risk framing. A.M., A.A., E.S., E.K. and O.W. contributed to case study development. T.D. and J.M. provided subject matter expertise to refine the review. All authors reviewed, edited and approved the final manuscript.

Competing interests

The authors declare no competing interests.

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