ENVIRONMENTAL RESEARCH
INFRASTRUCTURE AND SUSTAINABILITY

LETTER

Effects of climate migration on town-to-city transitions in the United States: proactive investments in civil infrastructure for resilience and sustainability

Alexandra Maxim and Emily Grubert

School of Civil and Environmental Engineering, Georgia Institute of Technology, GA, United States of America

* Author to whom any correspondence should be addressed.

E-mail: gruberte@gatech.edu

Keywords: climate change, managed retreat, climate migration, infrastructure systems, planning, spatial analysis

Supplementary material for this article is available online

Abstract
Climate change is a hazard risk amplifier and contributes to changing precipitation and temperature patterns that alter an area’s risk profile. Existing infrastructure is often ill-equipped to absorb shocks associated with increased hazard frequency and severity, but active measures to implement holistic resilience plans are rare and often limited in scope. As climate change progresses, climate change-induced migration is becoming more frequent and likely, with probable changes to regionally specific needs for resilient infrastructure. People relocating to areas with actual or perceived lower risk is expected to add demand for built infrastructure and change governance needs as receiving communities grow. Anticipating demand growth can enable proactive rather than reactive investment. Here we analyze the impact of anticipated climate migration patterns on community growth in the United States (US), leveraging the US Environmental Protection Agency’s Integrated Climate and Land-Use Scenarios dataset to illustratively evaluate how domestic migration might alter regional patterns for a particularly salient target of infrastructure planning: ‘tipping points’ where towns become cities and experience qualitative changes in infrastructural and governance complexity. Projected 2010–2100 town-to-city rapid urbanization patterns are different from historical (1950–2010) patterns in the US, notably shifting from the Southwest (including California) to the Southern Plains (including Texas). Climate change is expected to shift this pattern north and east, contributing to land use change and new demand for civil infrastructure in places where past development strategies might not be regionally appropriate. Urban futures are not predetermined: this illustrative analysis highlights that despite deep uncertainty, sufficient information about climate change, migration patterns, and generalizable best practices for infrastructural development exists to support proactive planning for migration. Proactive and regionally appropriate investment in civil infrastructure in regions expected to attract climate migration can facilitate resilience, sustainability, and justice under climate change, emphasizing safe, sufficient, and equitable infrastructure.

1. Introduction
Anticipating the effects of climate change is crucially important for the design and deployment of long-lived civil infrastructure. Climate change will alter both baseline conditions, like temperature and precipitation (Xu et al 2020), and amplitude of extreme events, like floods, droughts, wildfires, and storm events (Wilbanks and Fernandez 2014). These changes to climate conditions and extreme weather events have direct and indirect impacts on civil infrastructure systems (Zscheischler et al 2018), including energy, water, wastewater, transportation, and buildings. Under climate change, not only does infrastructure face routine challenges like disinvestment and obsolescence, wherein aging infrastructure is unable to serve its full intended function due
to issues like lack of maintenance or outdated design (Lemer 1996 and Miller et al. 2018), but infrastructure design itself faces obsolescence. Maintenance standards, replacement schedules, sizing guidelines, and more do not reflect challenges of long-term climate nonstationarity (Lopez-Cantu et al. 2020). Thus, for functionality under climate change, flexibility and agility are critical attributes for both existing and new infrastructure (Chester and Allenby 2020).

Compounding the infrastructural adaptation challenge, investing in long-lived civil infrastructure represents a commitment to a specific place and specific expectations about how the infrastructure will be used. Planners, policy-makers, and infrastructure managers make decisions that affect urban infrastructure, but generally at the level of local government (Adger 2010) rather than in contexts that weigh the relative benefits and challenges of multiple locations for investment. As such, much of the major effort to invest in adaptation has been focused on adapting-in-place in large metro areas (Araos et al. 2016). Investment, planning, and adaptation can be proactive, anticipating future needs (with the risk of guessing wrong), or reactive, responding to problems that have already emerged (with the certainty of prior harm). There is a non-negligible level of uncertainty that accompanies proactive planning since the future is largely unpredictable (Zandvoort et al. 2018). Recognizing ontic uncertainty, or that associated with inherently unknowable dynamics, however, can aid in framing resilience goals by centering this uncertainty (Taylor et al. 2021).

One major reason to investigate proactive civil infrastructure adaptation alternatives is that existing, reactive responses to climate change are both costly and highly inequitable. In the US (a high wealth country), low wealth and structurally marginalized groups already experience (1) increased exposure to risk, (2) increased susceptibility to risk, and (3) lower adaptive capacity versus higher wealth and less marginalized groups (Islam and Winkel 2017). For example: low-income communities, particularly in rural and predominately Latinx areas, are more prone to wildfires in California (Davies et al. 2018), and flooding disproportionately impacts black neighborhoods (Frank 2020). Reactive spending that allocates funds (1) after a disaster has already hit and (2) with the intent of enabling recovery to pre-disaster (inequitable) conditions is not only costly, but disproportionately damaging for communities of color and low income, given the link between wealth inequality and hazard-driven damage recuperation (Howell and Elliott 2019). Proactive adaptation-in-place that centers equity and justice in mitigating the effects climate change has on lower wealth communities, which are largely communities of color, could alleviate some of these challenges by anticipating and planning for future harm (Markkanen and Anger-Kraavi 2019). In practice, though, even proactive metro resilience strategies emphasize solutions designed to preserve existing cities and core infrastructures, assuming a basically knowable future based on historical risks (Taylor et al. 2021).

A second dimension of adaptive infrastructural investment, then, is whether to adapt in place or adapt by moving. With the major exception of managed retreat from coasts as an adaptive strategy (Siders et al. 2019 and Hino et al. 2017), the idea of facilitating and planning for strategic relocations under climate change is much less discussed than adaptation in place, particularly relative to infrastructural needs in potential receiving communities (though see (Mach and Siders 2021)). In part, this is due to extremely complex and sensitive considerations related to where people are encouraged or allowed to live. Given the cost, lifespan, and societal role of long-lived civil infrastructure, and given the American Society of Civil Engineers (ASCE) Code of Ethics professional principle of ‘consider[ing] the current and anticipated needs of society’ (ASCE 2020), evaluating the potential for proactive investments in regions expected to be fundamentally better suited to a climate-changed world is relevant for evaluating adaptation strategies. Just as adaptation-in-place can be proactive or reactive, with highly differentiated impacts on people, so too can migration-based adaptation, with mobility ranging from fully voluntary decisions to move through disruptive involuntary displacement (Bettini and Gioli 2016, Desai et al. 2021, Mach and Siders 2021 and Wiegel et al. 2019). For example, communities of color are more likely to migrate after a catastrophic storm event (e.g., Hurricanes Katrina and Maria) (Fernandez 2018).

Proactive planning can facilitate equity and resilience if done well, but it is at odds with the current model of highly reactive infrastructural investment. Investment attention tends to focus on failures, with little emphasis on preventative maintenance or proactive investment. Reactive spending on infrastructure is an unsustainable approach that often perpetuates systemic injustices by allocating funds to protect property, focusing on repairs that prioritize places with highest monetary value (Howell and Elliott 2019). Moreover, reactive spending often results in resource allocation to long-lived infrastructures not designed for future climate changed conditions (Lemer 1996 and Chester and Allenby 2020), an issue that could be exacerbated by ongoing damage from climate change. Such spending is large and reduces financial resource availability for other approaches: major climate and weather disasters have caused over $1.7 trillion in economic damages over the last 40 years, with most of the damages in the last 10 years (NOAA NCEI 2020). The US funding gap for preventative and proactive investment in infrastructure systems is projected to reach almost $6 trillion by 2039 (EBP and ASCE 2021).

Recognizing the risk of reactive investment as climate change progresses, and actively shifting to justice-focused investment models, is important for improving resilience in vulnerable communities. Preemptive investment outside of emergency settings could enable more equity-focused decision making. Efforts to
move toward more proactive planning include ongoing proposals to increase federal funding for community resettlement programs by the Department of Housing and Urban Development and the Federal Emergency Management Administration (HUD 2021, FEMA 2021a, 2021b).

Figure 1 presents a framework for considering both of dimensions for adaptive infrastructural investment under climate change described above: (1) timing relative to disaster events, and (2) location relative to populations. This work focuses specifically on understanding potential opportunities for proactive investment in civil infrastructure to enable adaptive and strategic migration under climate change in the US (figure 1, lower right).

Migration to lower-risk areas, alongside projected population growth associated with urbanization, could increase burden on local infrastructures and institutional capacity. When rapid population influxes are not expected, as is often observed with extraction boomtowns, haphazard infrastructure development can lead to major scaling challenges (Smith and Haggerty 2020). In a climate migration context, unplanned community growth could lead to climate sprawl and climate gentrification (Forsyth and Peiser 2021), since efforts to make urban spaces more climate friendly can challenge environmental and social sustainability goals with eco-gentrification and displacement (Rice et al 2020). Forsyth and Peiser argue that new town or new neighborhood construction that receives individuals from many locations, labeled ‘new community’ retreat, can leverage comprehensive planning to achieve benefits like the ability to match infrastructure to incoming residents needs’ and population size, consciously develop land that is less valuable as a greenfield, and foster community ties, though the need for large initial investments poses challenges (2021). The opportunity to proactively plan for growth in existing ‘climate destination’ communities in climate change-resilient locations has been less explored (Main 2020). Proactive planning for town growth could potentially mitigate challenges of sprawl and gentrification while leveraging opportunities to design new infrastructure according to principles of sustainability and justice—but at the risk of planning around population growth that might not happen.

To inform planning processes for proactive town growth, we thus leverage climate and land use modeling to investigate whether robust conclusions about potential climate-driven migration patterns in the US can be drawn even from highly uncertain information. Given the expected need for both greenfield civil infrastructure development and adjustments to infrastructure, institutions, and governance associated with scale transitions, as when a town becomes a city, we evaluate how climate change might alter regional patterns of new urbanization in the US in order to inform regionally appropriate conversations about resilient growth plans. For example, best practices for rapid development in the desert Southwest might not be best practices in the Great Lakes region. Thus, this research asks: where are micro areas, which serve as proxies for towns, expected to become metro areas, which serve as proxies for cities, under current expectations of climate migration patterns in the US through 2100? Using the US Environmental Protection Agency (EPA)’s Integrated Climate Land Use Scenarios (ICLUS) dataset for the Continental US (CONUS), we compare scenarios with similar population growth rates, with and without accounting for anticipated impacts from climate change. This work adds to the literature by (1) evaluating the geography of anticipated climate migration recipients at the town level and (2) exploring how early planning and decision making could aid in sustainable and resilient infrastructure design. The piece concludes with planning recommendations focused on understanding these processes in the climate destination framework (Main 2020), with particular attention to actions that could be taken now to enhance opportunities for strategic, managed, and safe migration to climate destinations by ensuring receiving communities are available and prepared.
2. Methods

This research combines the EPA’s ICLUS v2 model with historically informed population size and growth rate thresholds to assess where CONUS micro areas (as proxies for towns) are projected to become metro areas (as proxies for cities) by the year 2100. Additionally, we explore the anticipated land use changes associated with the transition from town to city. The remainder of this section describes (1) data, (2) major assumptions, and (3) the analytic approach.

2.1. Data

This research uses population and land use projections from the ICLUS v2 model (US EPA 2015) by the US EPA for CONUS, which is designed to evaluate US population and land use changes over time and under multiple climate change scenarios (US EPA 2015). The ICLUS v2 model integrates multiple variables to project total population and land use classifications for multiple scenarios and years (2020–2100), including county-level census population from the year 2010 and fertility, mortality, domestic migration, and immigration scenarios from the US Census Bureau. Climate change is modeled using running ten-year averages for projected January and July humidity-adjusted temperature and summer (June–August) and winter (December–February) precipitation from general circulation models (GCMs) under different Shared Socioeconomic Pathway (SSP) and Representative Concentration Pathway (RCP) assumptions, which are scenarios for patterns of socioeconomic global change and greenhouse gas concentration trajectories, respectively.

Here, we investigate six total scenarios: for each of two SSPs (2, the ‘Middle of the Road’ scenario; and 5, the ‘Fossil-fueled Development’ scenario) (Riahi et al. 2017), we evaluate one scenario with no climate change assumptions (designated ‘NOCC’ by ICLUS) and two scenarios with climate change assumptions (RCP4.5, an intermediate GHG trajectory with emissions peaking around 2040, for SSP2; and RCP8.5, considered an extremely high GHG trajectory, for SSP5), based on two different climatic models [GISS-E2-R from the NASA Goddard Institute for Space Studies (Schmidt et al. 2006) and HadGEM2-ES from the Met Office Hadley Center (Collins et al. 2011 and Davies et al. 2005)]. The GISS-E2-R and HadGEM2-ES climate models are relatively unrelated (Knutti et al. 2013 and Belda et al. 2015) and have been used (alongside other models) in other studies seeking to investigate a range of GCM outputs (Martinich and Crimmins 2019). Given high variability across models and a lack of explicit downscaling necessary for capturing high resolution climate trends (Jiang et al. 2018), we present results from both GCMs where relevant and focus on identifying robust trends. The main text includes the SSP5—RCP8.5 results, and the less extreme SSP2—RCP4.5 results can be found in the supplementary information (https://stacks.iop.org/ERIS/1/031001/mmedia).

The ICLUS v2 model projects total population and land use classifications for each spatial unit with a resolution of 90 m × 90 m (US EPA et al. 2017). As defined by ICLUS, the spatial unit can be categorized as a metro statistical area, micro statistical area, county or parish. A metro area contains an urban core population of 50 000 or more (proxy for medium to large cities), while micro areas contain 10 000 or more (proxy for towns). Counties and parishes are rural areas with no urban core (US EPA et al. 2017).

The US Census Bureau’s delineation file for 1950, which includes all metro delineated areas by county (US Census Bureau 2016) was used to evaluate historical growth patterns from 1950–2010. This file was joined with current county shapefiles by FIPS code to reproduce the data spatially in QGIS.

2.2. Major assumptions

This work focuses on town-to-city transitions under SSP5—RCP8.5 despite its status as an unlikely, worst case outcome with no policy intervention (Hausfather and Peters 2020) because it represents the most extreme case available, thus providing a directional indicator of where locations are most robust to climate change given the backdrop of societal context (e.g., where there are already towns).

We define the town-to-city (micro to metro area) transition as growth with a minimum projected 2010–2100 compound annual growth rate (CAGR) value over 2% (90th percentile for SSP5 scenarios). This growth rate implies an ending population six times that of the starting population over our analytical period.

2.3. Analytical approach

Figure 2 highlights the analytical flow for this project. The two major target outputs were an inventory of historically delineated metro areas and projected town-to-city transitions.

ICLUS projected population data were used to compute CAGR and imported into QGIS for mapping and into Python for plotting (supplementary figures).

The ICLUS land use classification raster dataset was imported into QGIS to attain percentage of each group type for 2020 and 2100: water, protected, working/production, and developed (supplementary table 1). The raster for each scenario was split by value (0–18) for land use classification using the raster calculator tool.
Figure 2. Flow chart. A list of metro delineated counties were downloaded from US Census Bureau for 1950, imported into excel and joined with county shapefiles by FIPS code in QGIS. Total population data and land use rasters from the year 2100 were downloaded from the ICLUS v2 portal for each scenario combination. Total population was imported into excel to compute CAGR and then imported into Python to make the line plots (supplementary figures). Land use rasters were imported into QGIS for computation of the percent land use in specific categories, then exported to Python to create bar plots (supplementary figures).

Table 1. Summary statistics for micro areas with projected 2010–2100 CAGR >2% by scenario.

| Scenario          | Number of micro areas with CAGR >2% | Total 2100 population | Largest 2100 population | Smallest 2100 population | Average 2100 population |
|-------------------|-------------------------------------|------------------------|-------------------------|--------------------------|--------------------------|
| SSP2 NOCC (2100)  | 0                                   | 0                      | 0                       | 0                        | 0                        |
| HadGEM-SSP2- RCP4.5(2100) | 0                                   | 0                      | 0                       | 0                        | 0                        |
| GISS-SSP2- RCP4.5(2100) | 0                                   | 0                      | 0                       | 0                        | 0                        |
| SSP5 NOCC (2100)  | 76                                  | 14 367 707             | 408 448                 | 102 050                  | 189 049                  |
| HadGEM-SSP5- RCP8.5(2100) | 64                                  | 11 617 386             | 388 146                 | 118 627                  | 181 522                  |
| GISS-SSP5- RCP8.5(2100) | 71                                  | 13 063 384             | 381 787                 | 84 352                   | 183 991                  |

Then, the zonal histogram tool was used to count the number of pixels described with that land use classification within the polygon overlay of the spatial unit, provided by ICLUS. Each land use classification type within each polygon was converted into a percent using excel (equation (1)):

\[
\text{percent land use}_i = \frac{\text{land use count}_i}{\text{total spatial unit count}} \times 100
\]

\(i = \text{land use type(e.g. urban, cropland etc . . .)}\)

3. Results

Table 1 lists the summary statistics for each scenario for the micro areas that have a growth rate (CAGR) over 2% from the year 2010 to 2100, including the middle-of-the-road scenario SSP2 and RCP4.5 projections for context.

Figure 3 depicts projected town-to-city transitions in CONUS under SSP5 (high fertility, high domestic migration, and medium immigration) (US EPA et al 2017) with and without climate change impacts ((a): scenario SSP5 NOCC; (b): SSP5—RCP8.5, GISS-E2-R; (c): SSP—RCP8.5, HADGEM2-ES).

As figure 3 shows, between 1950 and 2010, new cities (i.e., those that were not effectively expansions of existing 1950-era metros) largely developed in the interior dry West, with some infill between Eastern metro areas, in addition to metro expansion. Without climate change models, SSP5 projections for town-to-city transitions are concentrated in the Southern half of the country, particularly the Southern Plains (including Texas), with continued Western and Southeastern urbanization. That is, urbanization patterns are expected to change
Figure 3. (a) Micro areas with projected 2010–2100 CAGR over 2% for the scenario SSP5 without a climate model. (b) Micro areas with projected 2010–2100 CAGR over 2% for the scenario GISS-E2-R—RCP 8.5—SSP5. (c) Micro areas with projected 2010–2100 CAGR over 2% for the scenario HADGEM2-ES—RCP 8.5—SSP5.
even without incorporating climate change effects. Projected effects of climate change on CONUS town-to-city transitions vary based on model, but both climate scenarios evaluated here project fewer town-to-city transitions in the dry west and far south Texas versus the no climate change SSP5 scenario. ICLUS v2 model projections based on GISS-E2-R (figure 3(b)) include substantial northward pressure on town-to-city transition potential, with substantial influence in the Midwest, while those based on HadGEM2-ES do not (figure 3(c)).

SSP2 scenarios have much lower population growth overall (using medium fertility, high domestic migration, and medium immigration Census Bureau Scenarios (US EPA et al 2017). No SSP2 projections included town-to-city transitions (supplementary figures S1(a)–(c)). Figure S2 shows projected total regional population in micro-areas across the years 2020–2100 alongside census population values for 1990, 2000 and 2010 for SSP2 and SSP5 with and without climate models, for reference. Figure S3 shows projected regional developed land use in panel (a) and working/production land use in panel (b) for 2100 by scenario. Higher population associated with SSP5 translates to higher developed land area and lower working/production land area across regions, noting that shifting regional urbanization patterns could change the relationship between developed and working/production lands. For example, the relative value of residences is likely quite different for Southwestern ranchland versus Northern Plains corn belt land, particularly given expectations for the effect of climate change on crop productivity (Martinich and Crimmins 2019 and Wienhold et al 2018) and demand for land for wind and biomass energy resources (Williams et al 2021).

4. Discussion

Our analysis of the ICLUS v2 model suggests that under SSP5—RCP8.5 assumptions, the geography of town-to-city transitions in CONUS will move north and east relative to both historical patterns and a no-climate change SSP5 scenario (figure 3), consistent with expectations for the changing geography of relative CONUS climate risk (Xu et al 2020 and Shaw et al 2020). Notably, the climate model with the higher influence of climate on migration patterns (GISS-E2-R) projects a particular shift in such transitions to the Midwest, a region with a legacy of older, relatively industrial urban centers and emerging competition for land use associated with energy and climate transitions. This projected future departs from recent historical patterns of town-to-city growth concentrated in the interior West and the outskirts of existing metros. We caution, however, that projections are not predictions: we use this illustrative analysis to argue that evidence of changing migration geographies under climate change is robust and sufficient to inform proactive planning. Specific best practices for future development might differ substantially from best practices for recent historical development, given differences in both baseline and future climatic conditions in different regions. For example, existing risks (e.g., extreme cold) might pose new vulnerabilities to newcomers unfamiliar with managing those risks, and planning for long-term challenges like increased flooding (Northern Plains) and extreme heat that has not historically been a problem (Midwest) (Martinich and Crimmins 2019) will require different design, skill, and deployment patterns than largely greenfield projects in the dry Southwest.

Although SSP5—RCP8.5 is considered an extreme scenario, we argue that it provides a useful view of locations that might be particularly robust to climate change, and thus highlights patterns to inform proactive infrastructural investments to facilitate adaptation through strategic migration. Further, some of ICLUS’ limitations suggest that the impact of climate change on internal CONUS migration patterns might be underestimated. We anticipate that incorporating downscaled climate models and accounting for climate hazard rather than rolling average temperature and precipitation alone would indicate a higher, and earlier, potential that climate change would prompt migration. Indeed, climate migration is already underway. According to a March 2021 general population survey of US residents commissioned by the real estate brokerage Redfin, about half of respondents planning to move in the next year said that increasing natural disasters or extreme temperatures contributed to that decision, and 36% said that rising sea levels contributed (Katz 2021).

Accumulating evidence suggests that under climate change, people will move, in possibly predictable or even planned ways (Lustgarten 2020 and Mach and Siders 2021), but current plans to accommodate this movement are inadequate (Horton et al 2021). As such, our analysis suggests that leveraging available information to identify robust trends can guide planning for migration and potentially facilitate proactive, justice-centered infrastructure investment to prepare (Stoker et al 2021). Recognizing both that migration is proceeding and that existing systems lead to structural disadvantage for specific groups can inform better future performance, and again highlights that we already have sufficient information about potential future risks to inform better decision making.

4.1. Planning recommendations: leveraging best practices to improve outcomes under deep uncertainty

How can towns that set out to become climate destinations, characterized by an interest in growing with some level of adaptive capacity, successfully plan for flexible and resilient infrastructure that serves both the receiving community and possible new residents (Main 2020)? In regions well suited to growth that are likely to be robust
to climate change, proactive, thoughtful investment could enable adaptive migration and improved resilience and sustainability (Main et al 2021), even as relocation adds demand for built infrastructure systems and more complex governance as receiving communities grow. Anticipating demand growth in advance of widespread migration can give towns time for proactive planning, with the opportunity to center justice and sustainability principles from the outset. A core argument of this work is that despite deep uncertainty about climate changed futures, existing knowledge is sufficiently robust to inform proactive planning. Indeed, the relevant timelines of need for community consultation, long-lived infrastructure development, and other activities are long enough that normative goals of justice and sustainability essentially require proactive planning under deep uncertainty. Furthermore, as elucidated by the ‘climate destinations’ concept (Main 2020), urban futures are not deterministic: excellent planning can lead to better, designed outcomes. That is, the future is what we make it.

Although operationalizing town-to-city transitions will require investigation of specific local contexts, some best practices for proactive planning, supported by existing evidence that can be leveraged in the face of anticipated climate migration, are broadly applicable. Several key principles for planners balancing the needs of both existing and potential future residents in a nonstationary climate include:

(a) Develop expansion and growth management plans that are comprehensive and span all relevant infrastructure systems (Stoker et al 2021 and Friedmann Resources 2001). Consider regional needs, and the fact that recent examples of such plans might be inappropriate due to regional differences in where recent versus future growth is expected.

(b) Leverage zoning regulations, especially inclusionary affordable housing, to reduce the impact of gentrification that follows intense green development (Rice et al 2020 and Rigolon and Németh 2018).

(c) Prioritize density over sprawl, to minimize land-use tradeoffs (cropland to impervious surfaces) (Forsyth and Peiser 2021).

(d) Create teams comprising members of multiple asset management systems (e.g. wastewater, transportation, housing, etc), nonprofits, and community based groups to ensure representation at the decision table (Rigolon and Németh 2018).

(e) Explicitly plan for increased complexity in local governance needs associated with ensuring justice and implementation of best practices as community size and structure changes, alongside simultaneous climate change (Moss et al 2021).

(f) Introduce and/or participate in structures that facilitate local/regional migration resettlements (Climigration 2021 and NLC 2021).

(g) Encourage collaboration for city managers across the nation and internationally trying to facilitate just and equitable access to infrastructure for people being displaced by climate change (Climigration 2021 and NLC 2021).

(h) Emphasize growth with adaptive capacity, in particular by working at the local level to ensure no displacement of existing residents and investment in community resilience (Rigolon and Németh 2018).

(i) Rigorously evaluate infrastructure maintenance standards, replacement schedules, and sizing guidelines to reflect challenges of long-term climate nonstationarity and to be functional under regionally-relevant climate change, by increasing their flexibility and agility (Lopez-Cantu et al 2020 and Chester and Allenby 2020).

5. Conclusion

Human migration in response to climate change is already happening, including in the United States (Moss et al 2021). Given the extreme hardship and amplification of injustices that can accompany forced migration, proactive planning to enable largely voluntary migration with explicit support mechanisms and an emphasis on justice is potentially critical to enabling resilience and sustainability in response to climate change (Desai et al 2021 and Mach and Siders 2021). Continued attention to who is migrating, and how existing vulnerabilities interact with migration plans (Siders 2019), is deeply important for ensuring material well-being and distributional justice for all. Also important to consider is how potential receiving communities might develop, including via intentional, proactive investments in becoming attractive for voluntary migrants (Stoker et al 2021). Similarly, the ethical and intergenerational implications of designing transformational changes to societal organization in response to climate change (Mach and Siders 2021) merit extremely careful consideration, including choices to invest in existing versus potential future cities.

We suggest that existing towns in regions likely to be attractive destinations under climate change, which are different from regions that have historically seen town-to-city transitions, can integrate ‘climate destination’
planning (Main 2020) with other infrastructural investments intended to increase resilience and sustainabil-
ity in potentially valuable ways. Though less discussed in the literature than the question of where people
might need to retreat from, where people could retreat to in a world relying on managed, strategic retreat as
a response to climate change also requires decisions, planning, and investment. We focus specifically on the
point that not all potential climate destinations are necessarily already large cities, and special attention to how
infrastructure and governance might change in the face of both scale and climate change will be particularly
important for towns that could grow to city scale. Expansion does not need to lead to displacement, sprawl, and
other planning challenges, but best practices for infrastructural expansion likely differs in US regions expected
to host future town-to-city transitions versus those that have had many such transitions in the recent past.
We show that climate change is likely to shift patterns of town-to-city transitions to the Midwest and Cen-
tral regions through 2100, departing from the recent historical (1950–2010) pattern of such transitions in the
Pacific, Mountain and South regions. This urbanization is also expected to shift land use from cropland to
urban developed lands, changing regional infrastructure dynamics and demands. Anticipating likely effects
of climate change on communities and settlement patterns, while leveraging existing planning best practices,
can help facilitate a just transition emphasizing material well-being and distributional equity by informing
infrastructure planning and deployment for resilience and sustainability.

Acknowledgments

Maxim is a scholar in Health Policy Research Scholars, a national leadership program supported by the Robert
Wood Johnson Foundation. It supports scholars from diverse disciplines and backgrounds in applying and
advocating for policy changes that improve health and equity (www.healthpolicyresearch-scholars.org).

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary
information files).

Funding statement

No funding was received for direct support for this article.

ORCID iDs

Alexandra Maxim https://orcid.org/0000-0003-3323-4201
Emily Grubert https://orcid.org/0000-0003-2196-7571

References

Adger W N 2010 Social capital, collective action, and adaptation to climate change Der Klimawandel: Sozialwissenschaftliche Perspektiven
ed M Voss (Wiesbaden: VS Verlag für Sozialwissenschaften) pp 327–45
Araos M, Barrang-Ford L, Ford J D, Austin S E, Biesbrook R and Lesnikowski A 2016 Climate change adaptation planning in large cities:
a systematic global assessment Environ. Sci. Policy 66 373–82
ASCE 2020 Code of Ethics https://asce.org/code-of-ethics/
Belda M, Holtsanová E, Halenka T, Kalvová J and Hlávka Z 2015 Evaluation of CMIP5 present climate simulations using the Köp-
pen–Trewartha climate classification Clim. Res. 64 201–12
Bettini G and Gioli G 2016 Waltz with development: insights on the developmentalization of climate-induced migration Migration and
Development 5 171–89
(US EPA) Bierwagen B, Morefield P, Witt J, Choate A, Cohen J, Groth P, Spindler D and Theobald D 2017 Updates to the demo-
graphic and spatial allocation models to produce integrated climate and land use scenarios (Iclus) (final report, version 2)
https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=322479
Chester M V and Allenby B 2020 Toward adaptive infrastructure: the fifth discipline Sustainable and Resilient Infrastructure 6 334–8
Climigration 2021 What we do https://climigration.org
Collins W J et al 2011 Development and evaluation of an Earth-system model—HadGEM2 (climate and Earth system modeling)
https://gmd.copernicus.org/preprints/4/997/2011/gmd-4-997-2011.pdf
Davies I P, Haugo R D, Robertson J C and Levin P S 2018 The unequal vulnerability of communities of color to wildfire PLoS One 13
e0205825
Davies T, Cullen M J P, Malcolm A J, Mawson M H, Staniforth A, White A A and Wood N 2005 A new dynamical core for the Met Office’s
global and regional modelling of the atmosphere Q. J. R. Meteorol. Soc. 131 1759–82
Desai B, Bresch D N, Cazabat G, Hochrainer-Stigler S, Mechler R, Ponserre S and Schewe J 2021 Addressing the human cost in a changing
climate Science 372 1284–7
EBP and ASCE 2021 Failure to act: economic impacts of status quo investment across infrastructure systems https://infrastructurereportcard.org/wp-content/uploads/2021/03/FTA_Econ_Impacts_Status_Quo.pdf

FEMA 2021a Building Resilient Infrastructure and Communities (BRIC) https://fema.gov/grants/mitigation/building-resilient-infrastructure-communities

FEMA 2021b Hazard mitigation assistance grants https://fema.gov/grants/mitigation

Fernandez B 2018 Outmigration begins in Puerto Rico following hurricane Maria https://americanactionforum.org/research/outmigration-begins-puerto-rico-following-hurricane-maria/

Forsyth A and Peiser R 2021 Lessons from planned resettlement and new town experiences for avoiding climate sprawl Landsc. Urban Plann. 205 103957

Frank T 2020 Flooding disproportionately harms Black neighborhoods (EE News) https://scientificamerican.com/article/flooding-disproportionately-harms-black-neighborhoods/

Friedmann Resources 2001 Urban growth management in other communities (part 2, chapter 10) (city of Albuquerque) https://cabs.gov.ca/council/projects/completed-projects/2004/planned-growth-strategy

Hausfather Z and Peters G P 2020 Emissions—the ‘business as usual’ story is misleading

Hino M, Field C B and Mach K J 2017 Managed retreat as a response to natural hazard risk Nat. Clim. Change 7 364–70

Horton R M, de Sherbinin A, Wrathall D and Oppenheimer M 2021 Assessing human habitability and migration Science 372 1279–83

Howard J and Elliott J R 2019 Damages done: the longitudinal impacts of natural hazards on wealth inequality in the United States Soc. Probl. 66 448–67

HUD 2021 Grants information https://hud.gov/program_offices/spm/gmmgnt/grantsinfo

Islam S N and Winkel J 2017 Climate change and social inequality UN working paper (www.un.org/esa/desa/papers/2017/wp152_2017.pdf) p 32

Jiang Y, Kim J B, Still C J, Kerns B K, Kline J D and Cunningham P G 2018 Inter-comparison of multiple statistically downscaled climate datasets for the Pacific Northwest, USA Sci. Data 5 180016

Katz L 2021 Formerly redlined areas have 25% more home value at high flood risk (Redfin Real Estate News) https://redfin.com/news/redlining-flood-risk/

Knutti R, Masson D and Gettelman A 2013 Climate model genealogy: generation CMIP5 and how we got there Geophys. Res. Lett. 40 1194–9

Lerner A C 1996 Infrastructure obsolescence and design service life J. Infrastruct. Syst. 2 153–61

Lopez-Cantu T, Prein A F and Samaras C 2020 Uncertainties in future US extreme precipitation from downscaled climate projections Geophys. Res. Lett. 47 e2019GL086797

Lustgarten A 2020 The Great climate migration has begun (NY Times) https://nytimes.com/interactive/2020/07/23/magazine/climate-migration.html

Mach K J and Siders A R 2021 Reframing strategic, managed retreat for transformative climate adaptation Science 372 1294–9

Main K L 2020 New cities—higher ground: building the cities we need for climate change https://events.bizzabo.com/higherground/

Main K L, Mazereeuw M, Masoud F, Lu J, Barve A, Ojha M and Krishna C 2021 Climate action zones: a clustering methodology for resilient spatial planning in climate uncertainty Enhancing Disaster Preparedness ed A N Martins, M Fayazi, F Kikano and L Hobeica (Amsterdam: Elsevier) pp 241–58

Markkanen S and Anger-Kraavi A 2019 Social impacts of climate change mitigation policies and their implications for inequality Clim. Pol. 19 827–44

Martinich J and Crimmins A 2019 Climate damages and adaptation potential across diverse sectors of the United States Nat. Clim. Change 9 397–404

Miller T R, Chester M and Muñoz-Erickson T A 2018 Rethinking infrastructure in an era of unprecedented weather events/ issues in science and technology https://issues.org/rethinking-infrastructure/

Moss R H, Reed P M, Hadjimichael A and Rozenberg J 2017 The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview Glob. Environ. Change 42 153–68

NLC 2021 National league of cities https://nlc.org/

NOAA NCEI 2020 US Billion-dollar weather and climate disasters, 1980—present https://ncdc.noaa.gov/billions/

Riahi K et al 2017 The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview Nat. Clim. Change 7 145–65

Rigolon A 2020 ‘We’re not in the business of housing:’ environmental gentrification and the nonprofitization of green infrastructure projects Cities 81 71–80

Schmidt G A et al 2006 Present-day atmospheric simulations using GISS ModelE: comparison to in situ, satellite, and reanalysis data J. Clim. 19 153–92

Shaw A, Lustgarten A and Goldsmith J (ProPublica) 2020 New climate maps show a transformed United States ProPublica https://projects.propublica.org/climate-migration

Siders A R 2019 Social justice implications of US managed retreat buyout programs Clim. Change 152 239–57

Siders A R, Hino M and Mach K J 2019 The case for strategic and managed climate retreat Science 365 761–3

Smith K K and Haggerty J H 2020 Exploitable ambiguities & the unruliness of natural resource dependence: public infrastructure in North Dakota’s Bakken shale formation J. Rural Stud. 80 13–22

Stoker P, Rumore D, Romaniello L and Levine Z 2021 Planning and development challenges in western gateway communities J. Am. Plann. Assoc. 87 21–33

Taylor Z, Fitzgibbons J and Mitchell C I 2021 Finding the future in policy discourse: an analysis of city resilience plans Reg. Stud. 55 831–43

US Census Bureau 2016 Historical delineation files—October, 1950 https://census.gov/geographies/reference-files/time-series/demo/metro-micro/historical-delineation-files.html

US EPA 2015 ICUS downloads US EPA https://epa.gov/gcx/iclus-downloads

Wiegels H, Boas I and Warner J 2019 A mobilities perspective on migration in the context of environmental change WIREs Clim. Change 10 e610

Wienhold B J, Vigil M F, Hendrickson J R and Derner J D 2018 Vulnerability of crops and croplands in the US Northern Plains to predicted climate change Clim. Change 146 219–30
Wilbanks T J and Fernandez S 2014 Climate Change and Infrastructure, Urban Systems, and Vulnerabilities (Washington, DC: Island Press/Center for Resource Economics) (https://doi.org/10.5822/978-1-61091-556-4)

Williams J H, Jones R A, Haley B, Kwok G, Hargreaves J, Farbes J and Torn M S 2021 Carbon-neutral pathways for the United States AGU Adv. e2020AV000284

Xu C, Kohler T A, Lenton T M, Svenning J-C and Scheffer M 2020 Future of the human climate niche Proc. Natl Acad. Sci. USA 117 11350–5

Zandvoort M, Van der Vlist M J, Klijn F and Van den Brink A 2018 Navigating amid uncertainty in spatial planning Plann. Theor. 17 96–116

Zscheischler J et al 2018 Future climate risk from compound events Nat. Clim. Change 8 469–77