CLIMATE CHANGE VULNERABILITY:

A HISTORICAL PERSPECTIVE OF CLIMATE INJUSTICE IN LOS ANGELES

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EXECUTIVE SUMMARY

With the effects of climate change growing more apparent, communities across the globe are increasingly worried about their vulnerability to the worst of the impacts. In Los Angeles County, a place that is particularly susceptible to present and future climate-related hazards (Wilson et al. 2010; Wilder et al. 2016), research over the last decade has attempted to better define and quantify "vulnerability," with the hopes of informing policymakers and empowering community members. As a means towards this end, studies have strived towards greater sophistication and accuracy in their modelling of climate vulnerability. Across the board, they have found that existing environmental inequities between demographic groups (i.e., "environmental injustice") will only intensify under a changing climate. This exacerbated inequality between communities has been termed the "climate gap" (Shonkoff et al. 2011). Despite this important conclusion, certain elements of current screening methods and vulnerability assessments still remain incomplete and unrealistic (English et al. 2013; Cooley et al. 2012). In this paper, I therefore propose to extend the timeline of the model into the past (1980-present) and extrapolate towards the future. Given the recent literature on climate impacts, demography, and human geography in Los Angeles, I anticipated that creating a longitudinal model would modify current vulnerability indices (statistically) significantly. Results indeed show that the average Angeleno's vulnerability to different climate exposure decreased over the study period; nevertheless, at either extreme of the index, there was a "stratification" or intensification of the status quo (i.e., low-vulnerability populations became less affected; simultaneously, higher-vulnerability ones suffered greater burdens). While previous studies theoretically intuit these findings, the added temporal element herein highlights the importance of enhancing the empirical accuracy and pragmatism of policy tools, both specifically in climate change vulnerability assessments and more generally.

Key terms: *Climate gap, vulnerability, screening, assessment, environmental injustice*

INTRODUCTION

While climate change is a global phenomenon with vast implications, not all regions and communities are experiencing its consequences equally (Moss et al. 2001; Kersten et al. 2010). Furthermore, on both large and small geographic scales, low-income communities of color (i.e., "disadvantaged communities" or DACs) have been repeatedly shown to disproportionately suffer from growing climate-related hazards and impacts (Gwynn and Thurston 2001; Pastor et al. 2010; Wilson et al. 2010; Paolisso et al. 2012; Shonkoff et al. 2011). The reasons for this disparity between privileged and disadvantaged communities are numerous: baseline differences in current exposure ("environmental injustice"), lack of resources to mitigate and adapt to rising climate-related threats in DACs, and low political will and prioritization to "safeguard" those marginalized (Ibid.). Both worldwide and in the United States, this "climate gap"– as measured in differential public health outcomes, economic loss, and sociodemographic inequity– has widened over the last thirty years and is projected to continue doing so (Shonkoff et al. 2011; Sadd et al. 2011; English et al. 2013). Therefore, for constituencies that are keen on promoting general welfare and equity, it has become increasingly relevant to study and measure the climate gap under a more specific scope (Klinsky et al. 2017).

Los Angeles County, in particular, has been a recent focus for such discourse and literature surrounding climate vulnerability (Pastor et al. 2010). Here, the climate gap is especially stark and apparent; to this day, social and environmental disparities are high, and the region is particularly prone to climatic variabilities (Wilson et al. 2010; Mitchell and Chakraborty 2015; Wilder et al. 2016). In addition, the area is famously notable for a diverse, vast population that is highly segregated, coupled with a complex geography consisting of discrete microclimates– these factors only exacerbate the severity of the gap (Morello-Frosch and Jesdale 2006). Nevertheless, with strong political will on the state level, California has been trying to ameliorate some of the existing disparities (and prevent future magnification) across all counties, including Los Angeles (Pastor et al. 2010; Cooley et al. 2012). Accordingly, community organizations, municipal agencies, and academic institutions on the local level, as well, have begun to study this issue more thoroughly over the last decade (Ibid).

Stakeholders have since developed over a dozen tools for modeling, analysis, and policymaking, but most operate within the unified framework of a climate change vulnerability assessment (CCVA). The popularity of the CCVA approach stems from its transparency, user-friendliness, computational ability, and policy influence (English et al. 2013; Füssel and Klein 2006; Tonmoy et al. 2014). Its ability to more fully dissect the vulnerability and equity dimensions of the climate gap make it a utilitarian choice for many in climate policy research, more so than methodological alternatives like groundtruthing and community-based participatory research (Sadd et al. 2011). In fact, thanks to their spatial analysis and its ability to generalize vast quantities of data, CCVAs have been the key instrument in detailing the *contemporary* intricacies of the climate gap in Los Angeles (Hinkel 2011; Tonmoy et al. 2014; English et al. 2013). As our understanding in the field has grown over the last decade, however, the assessment framework has increasingly failed to explain the mechanisms behind the countywide trend towards escalation, mostly arising from its cross-sectional and narrow "vulnerability" focus (Cooley et al. 2012; English et al. 2013).

Therefore, the goal of this project is to better understand the main drivers of Los Angeles' growing climate gap. I will address this central inquiry in two parts. First, using a "framework analysis," I consider whether existing vulnerability assessments even provide the appropriate toolkit to answer specific questions about Los Angeles' climate gap issue (and if so, how). In the second and more quantitative section, I use spatial analysis to look at the (statistical) significance of expanding the dataset longitudinally. Because the climate gap, by definition, links together climate change and demographics, I add both countywide population and climate data from the last thirty years to English et al.’s (2013) Climate Change Vulnerability Screening Method and Cooley et al.’s (2012) Climate Change Social Vulnerability Index. Based on a survey of the literature, my prevailing hypothesis is that in developing this long-term dataset, I would see an *amplification* of the results from previous County-focused climate gap studies, paralleling Samson et al.‘s (2012) conclusions on the national scale. Based on my findings, which corroborate this notion, I expect that the research herein will advance the collective knowledge of vulnerability assessments and equitable climate policy on local scales. Equipped with this information, I hope local advocates and stakeholders could more astutely address exacerbated disparities, while also providing an alternative framework for other constituencies to adopt in the future.

LITERATURE REVIEW

In the following section, I delve deeper into literature about the climate gap. In order for us to understand current details, methodological lapses, and more realistic depictions of the problem within the Los Angeles region, we must understand its larger context on a national and global level. Here, I attempt to overview the most recent synthesis of climate-related vulnerability and equity concerns, the bulk of which originates from the Environmental Justice movement and its scholarly analysis. After outlining the basic premise of the theory, as well the significant methodological hurdles that still exist, I will guide us through some practical ways to overcome these challenges and better explore existing disparities. Finally, upon review of climate vulnerability assessments and their capacity to bridge some of the existing gaps in the literature, I will examine Los Angeles as a microcosm ("case study") of the larger topic, with the hope that it can elucidate how to move forward in the field.

WHAT IS THE CLIMATE GAP?

Even before the 1980s, when the Environmental Justice (EJ) movement began gaining momentum, there were already activists and researchers that had studied how communities of color are disproportionately exposed to environmental harms– on global, national, and regional scales (Pulido 2000). With the release of the United Church of Christ's "Toxic Waste and Race in the United States" (1987), consensus further solidified around the idea of "environmental racism" (Ibid.). Since then, the concept of disproportionate environmental harm and disparity has expanded beyond race to include socioeconomic status, educational attainment, disability, and many other demographic factors (Ibid; Marshall 2008; Nguyen and Marshall 2018). Still, even as newer studies have continually expanded definitions of "environmental injustice," the basic premise holds: one's demographic profile inherently determines their *vulnerability* to environmental harm

(Morello-Frosch and Jesdale 2006; Paolisso et al. 2012; Kingsley 2015; Wilder et al. 2016). Pulido (2000) asserts that this inexorable link between identity and environmental burden extends back even earlier than often recognized; in the case of Los Angeles County, "People of color are disproportionately exposed to a particular set of environmental hazards. Such patterns... are the result of urban development in a highly racialized society over the course of 150 years" (32). In short, research in this field has demonstrated that socio-environmental dis/advantage is a fully entrenched phenomenon, possibly lasting more than a century.

A much more recent subsection of this body of literature has been dedicated to exploring climate specifically (Pastor et al. 2010; Shonkoff et al. 2011; Kingsley 2015; McChesney 2016; Wilder et al. 2016). The "climate gap," a term only recently coined to encapsulate disproportionate climate-related burdens on DACs (Shonkoff et al. 2009), nonetheless takes root in the larger and longer-established EJ framework. Like Pulido (2000), Shonkoff et al. also had a regional focus on California (and Los Angeles) in "The Climate Gap: Environmental Health and Equity Implications of Climate Change and Mitigation Policies in California"; still, they made generalizable claims that harken back to larger issues of inequity. First, they documented baseline environmental disparities like the urban heat island effect and pollution hotspots. Next, they used long-range data from the late 80s to show that these disparities have only sharpened since the onset of noticeable climatic changes. Moreover, they used the expanded definition of "disadvantaged communities" to include a myriad of demographic predictor markers, such as race, socioeconomic status, age, disability, and even immigration status. Unsurprisingly, they found that all marginalized groups correlated with worse life outcomes. Their results suggest that this gap stems from the low capacity of these communities to mitigate or adapt to increasingly worsening climate risks. In California, but also in other places (Wilder et al. 2016), higher burdens can include: infrastructure negligence and susceptibility to deterioration, lack of insurance access, disproportionate costs of mitigation/adaptation plans, lack of healthcare access, increased health burdens under cap-and-trade, and cumulative impacts of higher pollutant exposure. With this analysis, the researchers showed that accepted ideas about environmental injustice apply to a "climate gap" context, as well.

Building on a similar premise, Pastor et al. (2010) parallel Shonkoff et al.'s (2009/2011) conclusions in "Minding the Climate Gap." Focusing specifically on inequitable distributions of air pollution ("hotspots") in California that are exacerbated by climate change, they took a step further in claiming that (ineffectual) climate *policy* (e.g., cap-and-trade), and not just climate risks themselves, could worsen existing disparities. They closely studied the implications of a particular bill called the California Global Warming Act (AB 32), in which state and local authorities would gain vast control over curbing greenhouse gas and particulate matter emissions. Given that the crux of AB 32 is a cap-and-trade mandate– a free-market scheme to incentivize polluters to reduce their footprint– the researchers were afraid that some regulatory choices (e.g., indiscriminate allowance allocations, grandfathering, and over-permitting) "*could* widen the climate gap by worsening disparities in emissions burdens by race/ethnicity" (21). In order to avoid this worst-case scenario, they emphasized that upcoming studies should highlight and flesh out existing vulnerabilities and equity concerns, so that the state could take appropriate action and consider those most at-risk. They asserted that only under more informed circumstances could new climate policy work to the maximal benefit of everyone, and especially DACs.

Thus, from these above two articles, we see that it can be difficult to unpack the reasons for a growing climate gap, given the complexity of the mechanisms involved. In the case of Shonkoff et al. (2011), the underlying driver was climatic variations and their socioeconomic consequences; for Pastor et al. (2010), climate law and policy were arguably even more crucial. A third process that could potentially affect the severity of the climate gap is often harder to measure and examine: population dynamics (Samson et al. 2012; Jiang and Hardee 2011; O'Neill et al. 2014; Tonmoy et al. 2014). While not generally talked about on the state level in California, there are nevertheless global and nationwide analyses that have explored this option. For example, Samson et al. (2012) described how 20th century demographic changes in the US– suburbanization, Sunbelt city growth, and coastal developments– most of which were unrelated to climatic changes, inadvertently amplified climate burdens for the average American (equivalent to additional 1.3ºC of warming). Jiang and Hardee (2011) and O'Neill et al. (2014) arrived at an analogous conclusion in their own studies, as well, except they looked at demographic trends worldwide and their effect on people's exposure to climate hazards. Taken together, this literature suggests that population dynamics help define the climate gap on large scales, although there might be competing processes not yet described (Tonmoy et al. 2014).

While it can often be very tough to fully understand the causes behind the climate gap, especially when the scope of study is very large, it can still be fruitful to try to learn more. One of the main ways in which researchers have attempted to do that is through inductive reasoning, building up from undeniable truths and axioms about the climate gap itself (Moss et al. 2001; Wilson et al. 2010; Klinsky et al. 2017; McDowell et al. 2016). For example, we know that by definition, the climate gap is fundamentally rooted in vulnerability and equity concerns; it seeks to study disparities in communities' vulnerability to climate change, in an effort to bridge them and achieve equity (Shonkoff et al. 2009/2011; Pastor et al. 2010). While "vulnerability" and "equity" are vague terms in-and-of-themselves, there have been more successful and concrete approaches to analyzing them in the climate equity scholarship. Wilson et al. (2010), Hinkel (2011), and Tonmoy et al. (2014) notably advocated for a quantitative assessment of vulnerability based on agreed-upon *indicators*, laying the theoretical groundwork for subsequent "climate change vulnerability assessments" (CCVAs) conducted on the regional level (including in Los Angeles, which I discuss in later sections). Likewise, Moss et al. (2001), Wilson et al. (2010), McDowell et al. (2016), and Klinsky et al. (2017) have focused on measuring equity, oftentimes relying on mixed methods like groundtruthing, literature reviews, and policy analyses. Hinkel (2011) also raises questions about other tenets of the climate gap, such as a community's "resiliency" and "adaptive capacity," neither of which neatly fall under the umbrella of "vulnerability" or "equity" assessments. Nonetheless, these definitional deconstructions of the larger "climate gap" concept, even if murky, provide avenues for more detailed and precise narratives.

As such, the big takeaway is that while climate gap research is a developing discipline with very different approaches, there is methodological and ideological unity among scholars– their overall goal is to increasingly refine current models to make them more realistic, and in terms of policy, they are striving to "level the playing field" (Kingsley 2015, 20). They aim to accomplish these tasks through a variety of different instruments, including: maps, statistics, conceptual frameworks, literature/policy surveys, community-based participatory research, and theoretical assessments. And given that there is still room for improvement (Tonmoy et al. 2014), it can be an exciting time for novel studies to introduce new data, ultimately radically changing our understandings and the trajectory of this field. It is therefore my hope that with this project, where I more deeply examine some of these tools (particularly CCVAs) within the context of Los Angeles County, I will be able to provide new insights for what is at stake– for local communities, decisionmakers, and the environmental justice movement as a whole.

WHAT ARE CLIMATE CHANGE VULNERABILITY ASSESSMENTS (CCVAS)?

A climate change vulnerability assessment (CCVA) is one of the most oft-utilized tools in trying to "measure" the climate gap, usually on small scales where vulnerability differentials are large (Hinkel 2011). By definition, CCVAs rely heavily on computational analytics and quantification to give stakeholders a better idea of how "big" the climate gap in a given area is. The foundational scheme is usually a map, a framework, or a scientific document, which draws upon concrete measures of vulnerability known as "indicators" and compiles them into a single, user-friendly instrument, as is the case in Sadd et al. (2011), English et al. (2013), and Cooley et al. (2012). Together, these "indicators" can work simultaneously to flesh out several facets of the word "vulnerability" and the inevitable differentials that we see: people's ability to adjust, their ability to cope, their exposure to increasing climate variability, and their baseline sensitivities to short-term and long-term weather events (Hinkel 2011). As such, CCVAs offer some of the best hope for those who seek to intimately understand how climate change impacts people and in what ways, especially policymakers and their constituents.

Unfortunately, given the complexity of the climate gap and its multidimensional nature, theory dictates that CCVAs are always going to fall short of perfectly modeling reality (Tonmoy et al. 2014). Important to their success are adequate "geographical and temporal scales, aggregation, and nonlinearity" (Ibid., 775). As Füssel and Klein (2006) acknowledge, however, this can be quite difficult to achieve due to the vague definitions of vulnerability and equity in the first place, only to be compounded by computational deficiencies and algorithmic inconsistencies between models. As a way to standardize a baseline for future indicator-based vulnerability assessments (IBVAs), Tonmoy et al. (2014) advocate to use the IPCC definition: "vulnerability is the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (776). Furthermore, Deas (2015), Liévanos (2018), and Wilson et al. (2010) argue that the best "vessel" to demonstrate this theoretical underpinning and its real-world implications is through mapping. By including all necessary and warranted "indicators," maps can really elucidate climate change burdens in an easy-to-use, scalable, and flexible way. Despite its theoretical imperfections, a geographical IBVA is still heralded as the golden standard within climate justice and policy circles, for its practicality and pragmatism (Pastor et al. 2010). Thus, for the continuation of this paper, the climate gap will be viewed through the lens of the CCVA.

CASE STUDY: CLIMATE VULNERABILITY IN LOS ANGELES

As mentioned before, Los Angeles is an especially good case study for unpacking the climate gap. According to Pastor et al. (2010), the County is in a unique position because, at once, it is particularly environmentally burdened compared to other areas in the US, while it is also at the center of California's ambitious plan to tackle climate change. For these reasons, a lot of the initial interest and scholarship around the climate gap has developed in Los Angeles; after all, the term originated in Shonkoff et al.'s (2009) study, where they mainly contextualized their definition based on the disparity patterns they noticed here. Since then, others have described the ways in which the County is markedly vulnerable, especially in the three main factors that Gallopin (2006) identified: exposure, population sensitivity, and adaptive capacity (English et al. 2013; Pulido 2000; Morello-Frosch and Jesdale 2006). In addition, Los Angeles, while a large area, is still on the order-of-magnitude that Hinkel (2011) and Tonmoy et al. (2014) agree is appropriate for quantification, and not mere theoretical speculation. Thus, in the next section, I review the specifics of the climate gap in Los Angeles more extensively, as well as how my project could expand our current knowledge.

LA'S CLIMATE GAP: CONTEMPORARY UNDERSTANDINGS

The climate gap in Los Angeles, both current and projected, closely mirrors the statewide and national status quo (Pastor et al. 2010). On the three fronts previously cited– exposure levels, population sensitivity, and adaptive capacity– the County sees wide disparities that are only growing worse (English et al. 2013). Numerous studies have successfully quantified and measured various notions of this differential vulnerability historically and at present (Burillo et al. 2018; Ekstrom and Moser 2013; English et al. 2013; Maizlish et al. 2017; Nahlik et al. 2017; Pulido 2000; Marshall and Nguyen 2018; Morello-Frosch and Jesdale 2006; Mitchell and Chakraborty 2015; Marshall 2008; Jerrett et al. 2005; Houston et al. 2004; Drury et al. 1999; Shonkoff et al. 2011; Pastor et al. 2010). For instance, Mitchell and Chakraborty (2015) were able to show a spatial correlation between urban heat islands, as well as hotter, more arid climates, with the presence of a disadvantaged community. Adding onto this analysis, Nahlik et al. (2017) maintained that central parts of the City, which are often characterized by older housing stock that is cheaper and seldom has air conditioning, are more vulnerable to extreme heat; this is where marginalized people are also more likely to live. And in the case that air conditioning and good insulation are actually viable options, Burillo et al. (2018) then argued that lower electric grid capacities and higher grid failures are still more likely to affect DACs due to geography, poor infrastructure maintenance, and less reliable energy supplies. The situation in Los Angeles therefore clearly aligns with larger-scale descriptions in Wilson et al. (2010), Wilder et al. (2016), and others.

Of course, while extreme heat and thermal inequities are obvious indicators for an existing climate gap, air quality/pollution is another climate hazard no less important to consider. Usually exacerbated by extreme heat, but also caused by variabilities in point (factories, refineries, waste sites) and mobile (passenger cars, cargo transport) sources of emission, poor air quality is often more localized than other weather phenomena and thus can more strongly highlight differential climate burdens (Morello-Frosch and Jesdale 2006; Marshall 2008; Marshall and Nguyen 2018; Jerrett et al. 2005; Pulido 2000; Houston et al. 2004; Drury et al. 1999). Marshall (2008) and Marshall and Nguyen (2018), also spatially, determined the specific disadvantaged communities that are at stake during chronic and acute poor air quality. While the latter paper found that there were meteorological considerations when assessing disparities across the Los Angeles Basin, demographics still largely determined the location of emissive sources, thereby exacerbating issues of environmental injustice and inequity. Likewise, Jerrett et al. (2005) took a similar approach, but they focused less on the "efficiency" of policy solutions to the climate gap; rather, they measured public health effects as a proxy. With results even bleaker than in previous studies, they saw that mortality increased within the vicinity of point sources and mobile sources, alike, and was much higher among certain neighborhoods and areas (Downtown, South LA, Pomona Valley, and the San Fernando Valley), as well as certain demographics (Black, working-class Latino). Also, they discovered that previous health conditions, such as ischemic heart disease, resulting from chronic exposure to PM 2.5, 10, and other pollutants, increased comorbidity. Lastly, Drury et al. (1999) and Morello-Frosch and Jesdale (2006) noted that air quality concerns paralleled Pulido's (2000) assertions of "environmental racism" by substantiating that past policy decisions, such as residential segregation, cap-and-trade "hotspots," and certain environmental laws (RECLAIM), further augment patterns of unequal public health outcomes. These trends mimic those apparent on the state level, as well (Pastor et al. 2010).

Yet a third subcategory of the climate gap in Los Angeles is coastal flooding. However, this one is unique in that it diverges slightly from the national narrative. Unlike the Chesapeake Bay Region, where Paolisso et al. (2010) summarily documented how coastal African American communities face racial barriers towards effective adaptation to increased flooding, the "riskscape" in Los Angeles County is a little more complex. This is because the County's coast is even less monolithic– both its topography and its demographics are extremely varied. While researchers have generally found familiar patterns of disparity and disproportionate burden among beach communities, they showed that the heterogeneity and complexity of Los Angeles' coast is important to consider (Ekstrom and Moser 2013; Cooley et al. 2012). More specifically, Ekstrom and Moser (2013) laid out how disadvantaged populations are often settled in low-lying, marshy areas such as Venice and Wilmington/San Pedro, which are more susceptible to seawater inundation and levy breaches; meanwhile, more privileged communities nearby have established in "safer," higher-elevation bluffs like Palos Verdes and Pacific Palisades. Similarly, Cooley et al. (2012) found that the same burdened DACs also often have the least adaptive capacity. They lack the resources and social capital to fend off rising tides, usually encountering numerous difficulties in relocating, weatherizing their homes, and/or recovering from major flooding events. Thus, this climate hazard can be a formidable challenge to many of Los Angeles' DACs; although it is important to note that, as a whole, coastal Angelenos are statistically more well-off and better-placed to handle environmental burdens than those further inland (Ibid.).

In fact, it is this last point that makes our case study of Los Angeles particularly interesting and challenging to research. On average, coastal areas like Del Rey, El Segundo, and Malibu suffer from high exposure to hazards (flooding, poor air quality, and/or wildfires), but they are not nearly as "affected" as DACs further inland. This might seem counterintuitive, since I have so far marshalled evidence supporting the notion that LA's climate gap closely mirrors national and global trends. But, Sadd et al. (2011) acknowledged in "Playing It Safe," the connection between exposure, population sensitivity, and adaptive capacity is not always clear-cut. To demonstrate this point, they developed a screening tool, the Environmental Justice Screening Method (EJSM), which focused on air quality and land use. Their overall conclusion was that high-impact areas are *not* always necessarily highly vulnerable. While the link has been previously demonstrated to be true on larger scales, and even generally across Los Angeles County, there are still notable discrepancies (Figure 1). The researchers had to make a correction to their model in order to more realistically represent ongoing environmental injustice: "cumulative impacts." The concept of "cumulative impacts" is longitudinal and takes into account a community's demographic profile, chronic exposure (rather than acute), and adaptive capacity in order to truly assess its vulnerability. Their findings reiterate Gallopin's (2006) assertion that there are factors beyond exposure that determine an individual's vulnerability (English et al. 2013).

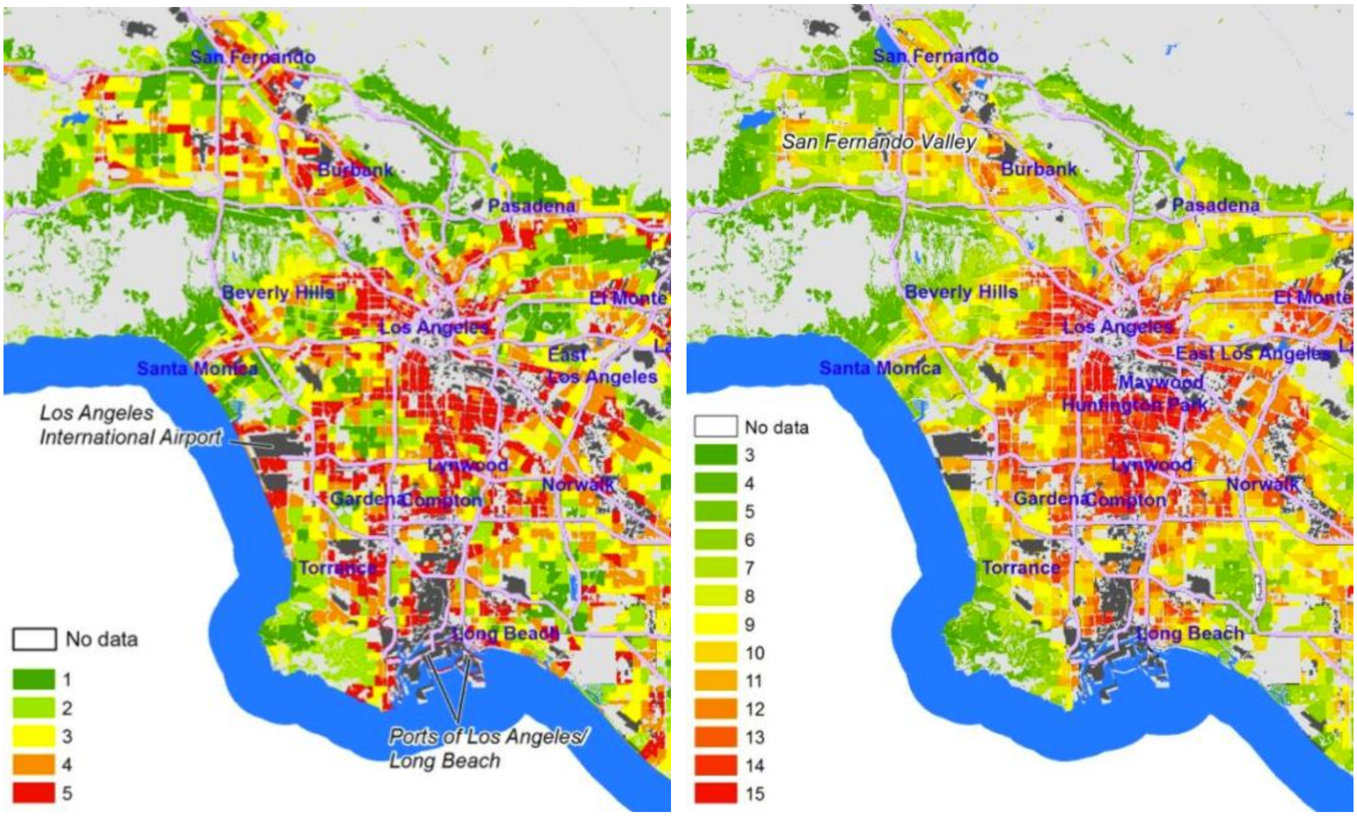

Figure 1. A comparison between calculated hazard exposure (1=lowest, 5=highest) for census tracts across the County (*left*) and "cumulative impacts" *(right)*, which additionally weighs social

and environmental vulnerability factors (Sadd et al. 2011). Note that the correction shifts the distribution of total impact to the core interior, centered around Downtown.

Later studies, such as English et al. (2013), have attempted to extend this notion of "cumulative impacts" beyond air quality and land use to other climatic factors such as flooding, wildfire, extreme heat; adaptive capacity was included, too, using proxies such as air conditioning ownership, tree canopy cover, and impervious surface cover. In adding this data, previous conclusions from the Environmental Justice Screening Method gained added credibility and analytic accuracy. As can be seen in Figure 2, which visually summarizes their results, a face-value approach to climate vulnerability in Los Angeles falsely suggests that the climate gap here is rather small or "egalitarian" in nature (top panel). Indeed, in some instances, privileged communities suffer the brunt of the impacts, like when there are inundations in Del Rey or wildfire at the fringes of the San Fernando Valley (Figure 1). Since these advantaged populations may often be situated at the geographic boundaries of the County, whether at the beach or at the urban-wildland interface ("foothills"), they are bound to risk disaster and high exposure (Ibid.). However, we must remember that exposure is just one piece of the puzzle; population vulnerability and adaptive capacity are equally as important. English et al. (2013) explained their findings by detailing what cumulative impacts entail, including consistent patterns of DACs suffering closer proximity to industrial areas, higher poverty, and worse health outcomes (e.g., emergency room visits during heat waves). These metrics were heavily weighted. Therefore, factoring in tenets of environmental injustice– in this case, exemplified as "cumulative impacts"– English et al. not only made a moral argument for considering marginalized communities, but also made a methodological breakthrough by examining Los Angeles' climate vulnerability landscape through a "climate gap" lens. In this way, their model is inherently more reflective of the current circumstances as they play out in the real world, and as a result it has better predictive powers than most vulnerability assessments preceding it ("Framework for Addressing Climate Change in Los Angeles County"; Kline 2014).

Since then, many climate change vulnerability assessments (CCVAs) in Los Angeles have adopted this "climate gap" framework by looking beyond exposure towards equity and vulnerability considerations that are holistic ("A Greater LA: Climate Action Framework"; "California Healthy Places Index Map"; "CCHVIz"; "Framework for Addressing Climate Change in Los Angeles County"; Hall et al. 2018; Kingsley 2015; McChesney 2016; "Regional Opportunity Index Map"; Raval et al. 2017). Towards this aim, these CCVAs are continually growing more sophisticated in addressing important aspects of the climate gap, such as growing climate risks, inequitable environmental policy, and baseline disparities between communities (Ibid.). Nevertheless, a major limitation still exists for them. It is the "population dynamics" dimension that I had earlier mentioned in "What is the Climate Gap?" English et al. (2013) confessed that "we could not incorporate additional components of vulnerability, such as environmental education and social networks into our index due to a lack of available data…. Therefore, this method captures existing population vulnerabilities in general, and does not capture projected future impacts" (15). Similarly, Cooley et al. (2012) stated that their "analysis did not use population projections because these projections are not available at the census tract level. The actual rate and distribution of population growth, and social and economic change will play a key role in shaping vulnerability in the future" (19). These authors are correct; in the case of Los Angeles County, there is still little available information predicting future population dynamics. However, there are clues in LA's past that allow us to add demographic considerations to our discussion of its climate gap.

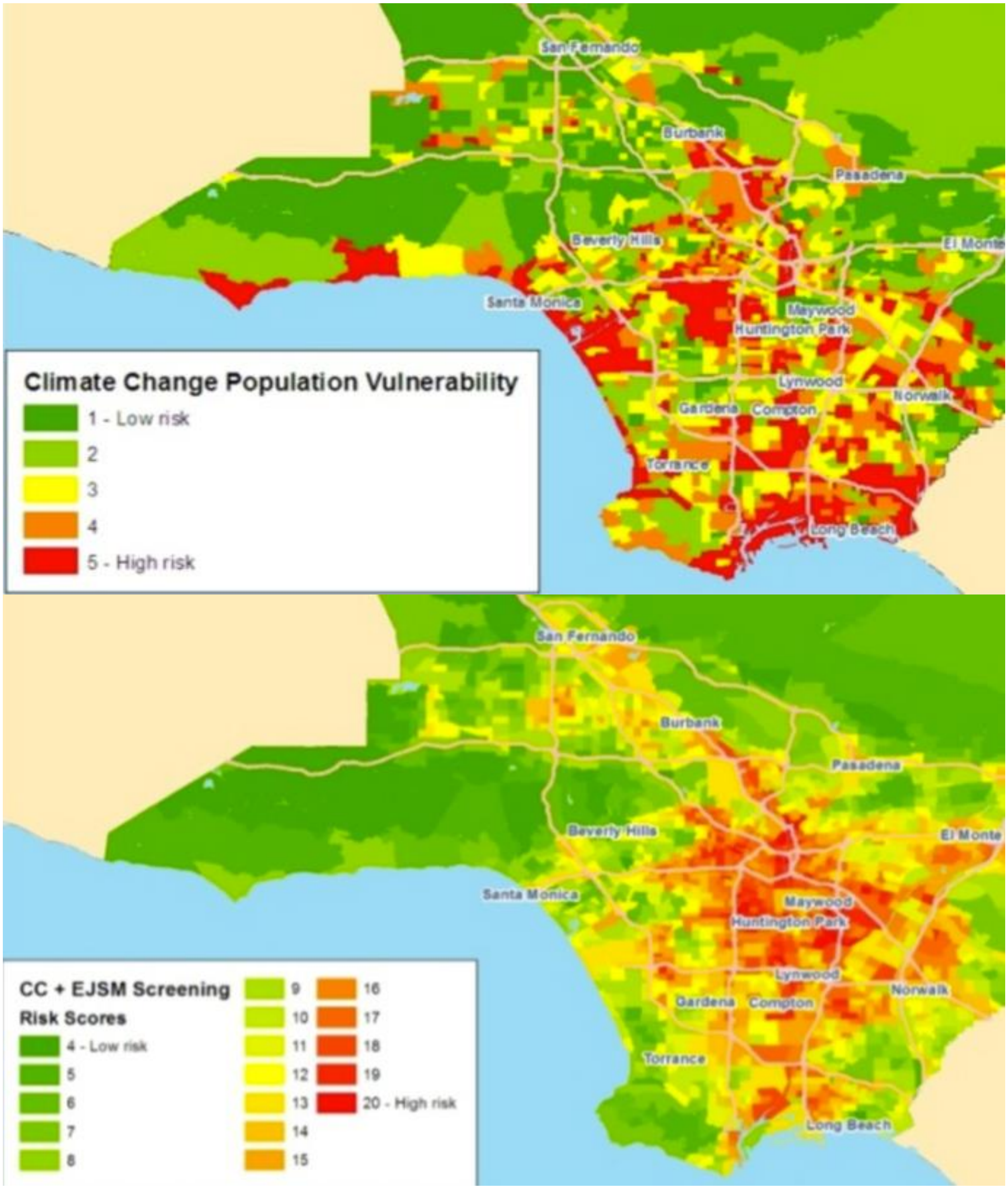

Figure 2. English et al.'s (2013) correction to their Climate Change Population Vulnerability index *(top)* using Sadd et al.'s (2011) Environmental Justice Screening Method *(bottom)*. Equity concerns and "cumulative impacts" significantly shift the distribution of vulnerability scores across the County, much like in Figure 1.

LA’S CLIMATE GAP: ALTERNATIVE CONSIDERATIONS

Given that population dynamics are very important in understanding the climate gap, as empirically demonstrated on the national and global levels (Samson et al. 2012; Jiang and Hardee 2011; O’Neill et al. 2014), and purported on the local level (Cooley et al. 2012; English et al. 2013), it will be the goal of this project to incorporate demographic considerations into Los Angeles County’s climate change vulnerability models. But before I delve deeper into how I will go about undertaking this task, I first cover in this section what Los Angeles’ population dynamics have historically looked like, as well as any evidence that they have amplified disparities.

While we can peer far into the past, as Pulido (2000) did in “Rethinking Environmental Racism,” it makes more sense to focus on the last thirty or so years, the time frame over which scholars agree the local climate gap has widened (Shonkoff et al. 2011; Pastor et al. 2010; Sadd et al. 2011). So, for the period since the late 1980s, ethnographic studies have generalized that the Los Angeles area has simultaneously experienced rapid demographic changes, reflecting the larger national trends of “flight,” in-migration, and exchange (Teranishi 2005; Pastor et al. 2011; Myers 2000, 2016). As case in point, in San Bernardino County alone, there was an influx of over 100,000 Black migrants between 1990 and 2000; on the other hand, Los Angeles County has seen an exodus of roughly 35,000 AA folks over the same period (Teranishi 2005, Pastor et al. 2011). At the same time, Myers (2000/2016) described (without quantification) how there has been a simultaneous trend of “reverse white flight.” White people of privilege, notably millennials, have been flocking to the City for better economic opportunities and a more cohesive social fabric, often spurring displacement and gentrification (Ibid.). Of course, this comes at the expense of disadvantaged communities, and it means that “out-migrators” (“emerging” foci of Black presence) are relegated to commutable “fringe” areas that are often more polluted and arid: Lancaster, Palmdale, Moreno

Valley, San Fernando Valley, and San Bernardino County (Sieg et al. 2004; Marshall 2008; Mitchell and Chakraborty 2015). And, if they do manage to stay in the LA Basin and combat pervasive demographic trends, they often have to contend with worsening pollution, crowding, infrastructural degradation, and job scarcity (Pastor et al. 2011). As such, when the various components of Los Angeles' human geography are studied together, a larger picture of growing inequality transpires (Ibid.).

Inevitably, climatic factors have only further compounded the demographic trends of the last thirty years. Morello-Frosch and Jesdale (2006) and Marshall (2008), looked at how, for example, reinforced (re)segregation among communities has only entrenched public health disparities that result from air pollution and poor air quality. Even after controlling for socioeconomic status (SES), Blacks and Hispanics were much more likely to see elevated lung cancer risks than their White counterparts, especially in areas that are increasingly segregated (as measured per the Segregation Index [Morello-Frosch and Jesdale 2006]). Likewise, residential segregation correlated with environmental inequality and pollution "hotspots," which Marshall (2008) contended can increase mean exposure by 16-40% for "non-Whites" over Whites. Based the latest data from the California Department of Public Health, these truths have held relatively constant over the past three decades (i.e., "linear" trends). Of course, there are other *non*linear considerations as well, such as the effect of cap-and-trade's implementation, the growth of the Los Angeles-Long Beach Port Complex and automobile/cargo traffic, and increasing development in fire-prone areas– all of these are important socioeconomic and political factors that, while significant, may unfortunately prove to be outside the scope of my project as well, due to their unpredictability and strong nonlinearity (Pastor et al. 2010; Viswanathan et al. 2006; Nguyen and Marshall 2018; Moran and Kanemoto 2016; Houston et al. 2004; Heald and Spracklen 2015;

Tonmoy et al. 2014). Nevertheless, they all could potentially worsen the climate gap and should not be fully discounted, even if they have not been entirely fleshed out or quantified in recent literature.

The premise that demographic trends have a large impact on the climate gap has also been demonstrated “in reverse” (Kahn 2000). In other words, Kahn (2000) showed that the demographic-climatic interface is actually a two-way interaction, where sometimes changes in climate vulnerability can, in fact, influence demographic trends (similar to the argument in Samson et al. 2012). His study posited that environmental regulation (specifically, air pollution reductions) led to much of the growth in San Bernardino County since 1980 (84.7% growth). Before 1980, the region endured many days of “high ozone”; thereafter, upon serious implementation of the Clean Air Act, air quality improved drastically in the Inland Empire, allowing for more college students, families, and retirees to out-migrate from Los Angeles County. This specific migration pattern differs starkly from the one we see today, where the out-migration from LA County is disproportionately made up of disadvantaged populations. Thus, we can conclude that demographic changes and environmental (climate) vulnerabilities are highly linked, on the local level, too, sometimes leading to unexpected circumstances. The climate gap in Los Angeles, much like on the national level (Samson et al. 2012) could therefore only be more fully explained if we account for population dynamics in a more inclusive, holistic fashion.

FRAMEWORK ANALYSIS: CCVAS IN LOS ANGELES

In Los Angeles County, there have been numerous attempts at quantifying climate change vulnerability, most of them in the form of indicator-based assessments (Table 1). Much like I am attempting to refine current understandings of the climate gap and climate vulnerabilities across the region, governmental agencies, consulting firms, and academic institutions have already come up with various and creative ways to increase the capacity and accuracy of current models. As can be seen in Table 1 below, the CCVA dataset for the County is quite diverse, with some overlap and redundancy only bolstering evidence of climate-related disparities.

Table 1. A summary of 17 different climate change vulnerability assessments (CCVAs) that directly study Los Angeles County (both local and state level). This is not an exhaustive list. Each CCVA is marked based on the aggregation and longitude of its dataset. As of the present, there is no CCVA that meets all three criteria, as outlined by Tonmoy et al. (2014).

Name	**Source**	**Longitudinal Climate Dataset? (Y/N)**	**Longitudinal Demographic Dataset? (Y/N)**	**Aggregated Dataset? (Y/N)**
“A Greater LA: Climate Action Framework”	Governmental	Y	N	Y
“California Healthy Places Index”	Governmental	N	N	N
“Climate Change & Health Vulnerability Indicators”	Governmental	N	N	N
“Framework for Addressing Climate Change in Los Angeles County.”	Governmental	Y	N	Y
"California's Fourth Climate Change Assessment"	Governmental	Y	N	Y
"Regional Opportunity Index”	Governmental/Academic (UC Davis)	N	N	Y
"Climate Change and Health Profile Report"	Governmental Maizlish et al. (2017)	N	N	Y
"ASTHO Climate Change Population Vulnerability Screening Tool"	Governmental English and Richardson (2013)	N	Y	Y

"Climate Change Vulnerability Screening Method"	Governmental/Academic English et al. (2013)	N	N	Y
"Health Impacts Index"	Academic Pastor et al. (2010)	N	N	N
"Climate Impact and Social Vulnerability Analysis"	Consultant/ Governmental Cooley et al. (2012)	Y	N	Y
"Environmental Justice Screening Method"	Governmental/Academic Sadd et al. (2011)	N	Y	Y
“Cal-Adapt”	Governmental	Y	N	Y
“CalEnviroScreen”	Governmental	N	Y	Y
"CCVA for the City of Pasadena"	Consultant/ Governmental Rincon Consultants	Y	N	N
"Social Vulnerability Index"	Consultant/ Governmental Ekstrom and Moser (2013)	N	Y	N
"Safeguarding California Plan"	Governmental	Y	N	Y

Many of these indices, however, do not have a longitudinal demographic dataset (only 4 of the 17), which I argue is a very important lapse in analysis. Furthermore, of the four that entertain demographic trends in their assessment, none incorporate it into a longitudinal climatic model. As Tonmoy et al. (2014) assert, CCVAs should also make sure that that assessments are “intersectional” to most realistically describe contemporary riskscapes; that is, data should be aggregated and computed holistically, so that certain vulnerability concerns do not overshadow others (public health ramifications outweighing adaptive capacity, for example). In my project then, I will attempt to tackle some of these deficiencies that the national and local literature sets identify. At the fore of my research will be demographic longitude and data aggregation, although

I will include some nonlinear factors that have not yet been scrutinized, such as household carbon footprint.

METHODS

In order to answer my research question and test my prevailing hypothesis (that demographic trends are significant when assessing climate vulnerability metrics across LA County), I emulated some of the methods described in the Literature Review section. Given Tonmoy et al. (2014), McDowell et al. (2016), and Hinkel's (2011) rationale for using a quantitative spatial approach on regional scales, I focused on using common indicator-based metrics. These metrics included an aggregation of 23 climatic/demographic "predictor markers" (e.g., extreme heat, income levels, flooding, race, age, etc.); their interaction, as empirically determined in Cooley et al. (2012), was calculated as a "Z-score" (vulnerability score), going from Z~-2 (very low vulnerability) to 2 (very high vulnerability). From there, using available datasets, I extended this assessment longitudinally in order to measure changes in the climate vulnerability scores over time. Finally, statistical tests were then used to analyze the data and determine its implication for current climate change vulnerability assessments.

As mentioned in previous sections, Shonkoff et al. (2011) and Pastor et al. (2011) remark that the early 1990s signaled a concurrent turning point for both climatic and demographic variables; this means that the research design most suitable in this case is a quasi-experimental difference-in-difference model that tests for treatment over a time period spanning both before and after this "shift." As a result, the first step was to determine the period and area of study. Informed by the literature and the confines of the available data, 1980-present seemed most apt. Since many of the indicator-based data relies on U.S. Census data (e.g. Cooley et al. 2012; English et al. 2013), the measure of time was discrete at decadal intervals, and the measure of area was contiguous at the census-tract level for Los Angeles County, the base geographic unit (controlled for equivalency). Based on methodologies devised in English et al. (2011) and Cooley et al. (2012), climatic and demographic indicators were then evaluated over this study period in a longitudinal fashion. Since climate vulnerability is a function of exposure and risk, vulnerability index score maps were overlaid with a time series of maps of past exposure to extreme heat, particulate matter, coastal flooding, and wildfire in order to identify areas with coexisting high social vulnerability and high exposure to climate change disturbances. High vulnerability here is defined as 66th percentile Z-scores or *higher*, as computed per 19 sociodemographic indicators (Cooley et al. 2012). The areas of overlap indicated those locations with heightened risk of being impacted by these climate changes as a result of exposure and social vulnerability.

From there, I consolidated/aggregated both climatic and demographic data into a respective "index" for each. Using shapefiles from UCSD's Scripps Institute and the County of Los Angeles for a comprehensive climate risk raster (4 indicators), and analogous data from the Pacific Institute and U.S. Census (2010) for sociodemographic profiling (19 indicators), I then imported the layers into ArcGIS. These indices were methodologically duplicated for the following four temporal datapoints: 1980, 1990, 2000, and 2010. After visually representing different configurations for various component layers, noting potential patterns that emerge, I exported the data and began running correlations, both for individual layers and in the aggregate. Much like in Cooley et al. (2012) and English et al. (2013), Z-scores were calculated under this scheme, as a quantitative assessment of whether there is significant statistical linkage between sociodemographic data and climate vulnerability scores in LA census tracts for each static cross-section. Finally, from the dataset and its statistical processing, I longitudinally determined whether or not sociodemographic trends have been important in affecting climate vulnerability over the last thirty years. In cases where I found strong correlation and convincing causality, it was of interest to extrapolate the current time series (climatic and demographic trends) into the future and "increase" the dataset.

RESULTS

CLIMATIC INDICATORS

Extreme Heat: Over the study period (1980-2010), there was a marked and ubiquitous increase in the number of extreme heat events across the County. The largest increases in the number of days exceeding the local high heat threshold were in the inland and southern parts of the basin. The magnitude of extreme heat was measured in terms of the number of days that the daily maximum temperature exceeds the 95th percentile historical local high-heat threshold during the summer months (May 1 through September 30). Results were compiled at the 2 sq. km grid cells from raster datasets from Scripps Institute. By definition, the 95th percentile high-heat threshold is the local temperature exceeded 7.6 days per year, on average, over the summer months. The 95th percentile temperature fell within 80–90 degrees Fahrenheit in many of the coastal and mountainous census tracts, and reached over 100 degrees in much of the valleys and deserts. For example, in Pomona, the number of days exceeding the local high heat threshold (101°F) increased from 5.4 days under historic conditions to 13 days over the 30-year interval. The coast experienced considerably smaller increases. In Santa Monica Bay and the Palos Verdes Peninsula, for example, the number of days exceeding the local high heat threshold (79.4°F) increased from 4.6 days under historic conditions to 8.6 days over the same time period. Surprisingly, the desert areas also did not note a substantial surge in extreme heat exposure; from the dataset, relatively smaller changes in land use and surface imperviousness, as well as an invigorated monsoon season, are most likely responsible. Nevertheless, extreme heat risk increased in all areas of the County; degree of severity merely depended on geography.

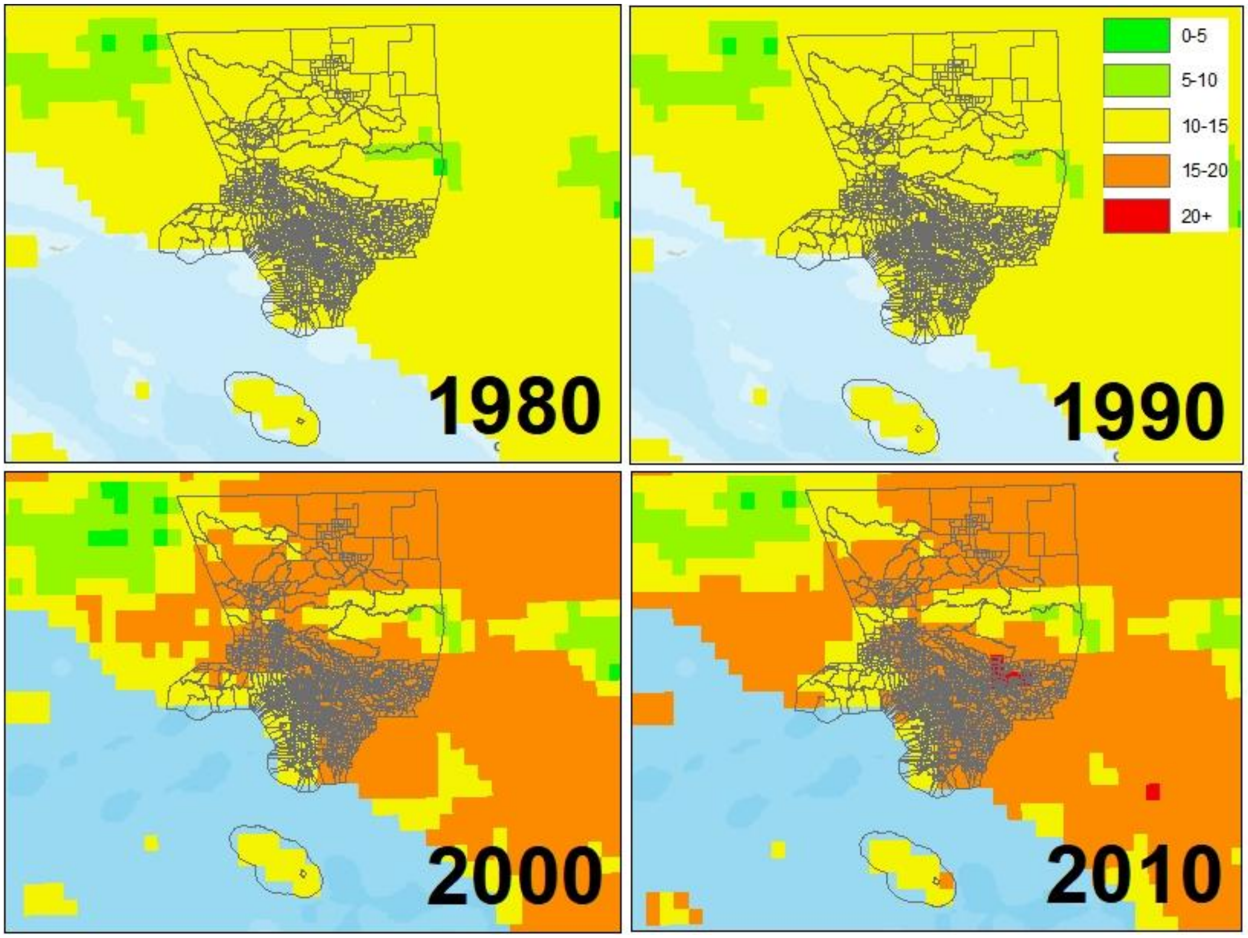

Figure 3. The four panels above show the progression of extreme heat risk in the Los Angeles Basin over the past three decades, as measured in days above the 95th percentile temperature threshold during the hottest months. Note that the main area of increasing severity is the inland portion of the San Gabriel and Pomona Valleys.

Given that the nature of rising temperatures and extreme heat burdens was pervasive across the board, a large portion of the County's residents were therefore increasingly at risk of being highly exposed *and* highly vulnerable to this climatic indicator. In fact, 6 million, or 59%, of the County's current population resides in areas that yearly have 9.2 to 11.4 days of extreme heat during the summer months, considered a medium exposure by IPCC and CalEPA standards. About 460,000 people, or less than 5% of the County's population, live in areas that have seen more than

11.4 days per year of extreme heat during the study period, considered high exposure under the same metrics. Of those with high exposure to extreme heat, however, about 38%, or 175,000 people, also lived in areas with high social vulnerability. Spatially, these were concentrated in areas of South Los Angeles along the Harbor Freeway corridor (spanning from Carson to Manchester Square), southeastern sections of the San Gabriel and Pomona Valleys, and the northeastern portions of the San Fernando Valley. The remaining 62% of those with high exposure were evenly split among low and medium social vulnerability, distributed quite evenly among the rest of the County. Nonetheless, robust climate models predict that these figures will change drastically over the next century, with further rise in the high-exposure ratio (Walton et al. 2018). Under the IPCC's A2 scenario, 7.7 million Angelenos, about 76% of the population, would face more than 38 days of temperatures that currently occur on the hottest 7.6 days of the year. Of those with high exposure to extreme heat, a much higher proportion of about 37%, or 3.75 million people, will also live in areas with high social vulnerability.

Figure 4. A cross-sectional view of coastal flooding in the Long Beach/Port of LA/Orange County area *(left)* and in the Marina del Rey complex and its environs *(right)*, under 0.5m of flooding, typical for very strong storm surges historically. By 2050, CalAdapt predicts that this level of inundation will be the new norm.

Flooding: The discrepancy between the various counties along the South Coast reflect the economic, and not only physical, geography of the region. In Los Angeles County, inundation is often restricted to the maritime coast, rather than the riverside communities (except in extremely rare scenarios). Currently, around 10,000 people are exposed to coastal flood risk, and due to topography, that number has not changed much recently. Since 1980, sea level has risen at least 8cm along the County's coast, with swell and surge topping over 2m during unusually strong storms and high tide. Social vulnerability, however, was generally low throughout the County, with the exception of San Pedro and Venice.

Sea level rise and exposure likewise showed strong regional trends. Impacts from sea level rise were largely clustered in the Marina del Rey area and the Los Angeles Port region. Approximately 18% of those exposed to coastal flooding lived in areas with high social vulnerability. About 43% of those exposed to flooding from sea level rise lived in areas with a medium social vulnerability. The remainder lived in areas with low social vulnerability. Notably, just beyond the reaches of the County, neighboring Orange and Ventura exhibited much higher susceptibility to impact, where roughly 7,000-9,000 highly vulnerable people are at expected risk under either scenario, respectively. Economic and land use policy generally explain this dichotomy: in Los Angeles, the most valuable properties (least vulnerable) tend to be located along the ocean; in Ventura and Orange County, by contrast, the most valuable properties are in the hills overlooking the coast (Cooley et al. 2012; Ekstrom and Moser 2012).

Wildfire: Currently, large swaths of the region are affected by wildfire risk, both in its primary effects and latent air quality concerns. Of those living in areas with high exposure to wildfire, about one-half was also living in areas with high social vulnerability. Per the US Forest Service, modeled probability of past wildfires (1980-2010) was highest in the San Gabriel foothills

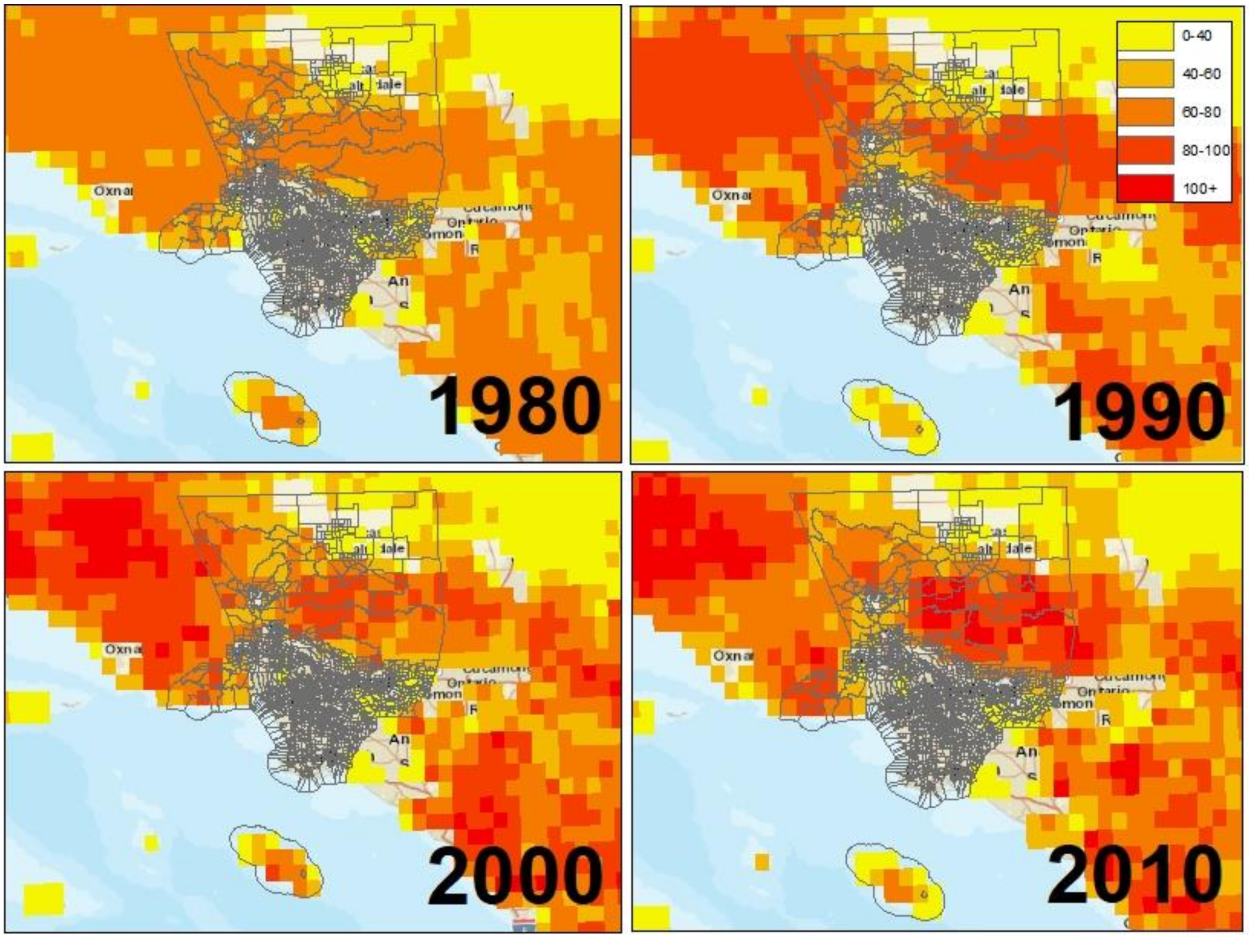

Figure 5. The four panels above show the progression of wildfire risk in the Los Angeles Basin over the past three decades, as measured in average acres burned per 16km^2 grid cell. The main regions of increasing wildfire risk are the San Gabriel foothills, the Santa Monica Mountains, and the Conejo Valley. Conversely, some areas along the southeastern fringes of the County show that fuel loads are decreasing, signaling ecological degradation.

(including the Verdugo Range) and along the coast, especially in the Santa Monica Mountains, and Palos Verdes Peninsula. During this time, the probability of wildfire increased substantially across much of Southern California. While frequency did not change substantially per census tract, the duration and size of each wildfire event rose significantly, likely as a direct result of higher temperatures and an increasingly sharp and encroaching wildland-urban interface (WUI). Because of the bimodal behavior of wildfire in this region– Santa Ana vs. midsummer typologies– the wildfire threat also extends beyond Los Angeles County, since Riverside, Orange, and San

Bernardino are often downwind of the most at-risk areas. Thus, figures for social vulnerability and exposure extent might actually be underestimated using current available data.

Air Quality: Using data from Kleeman et al. (2010) and SCAQMD, average particulate matter concentration and correlated factors were assessed for the County during the same study period. Under historic climate conditions, an estimated 6.6 million Angelenos lived in census tracts with PM2.5 levels above the California Air Resources Board (CARB) standard. While that number has decreased quite significantly going into 2010 (4.7 million affected), the distribution of reductions was not uniform spatially across the County. Coastal areas (including the Port of Los Angeles), as well as southern portions of the San Gabriel and San Fernando Valleys, for example, saw much greater percentile declines (ca. 40%) than the South Bay or Gateway Cities (10-20%). Nevertheless, baseline PM2.5 concentrations normally positively correlated highly-polluted inland locales with high Z-scores, so the South Coast Air Basin and the Valleys (San Fernando, San Gabriel, and Pomona) still experienced the highest exposures during this time period. As a result, about 75% of those with high exposure also lived in areas with high social vulnerability. In addition, those in areas with high exposure and high vulnerability saw correlation of particulate matter with extreme heat, as defined in the previous section (R^2=0.84). Furthermore, trends of improving air quality have actually recently reversed since 2012 (CalEPA) due to increasing temperatures and growing industrial output in the County; therefore, in extrapolating for the future, by 2050, an estimated 8.4 million residents are expected to live in census tracts with PM2.5 levels projected to be above the California standard, which is categorized as high exposure.

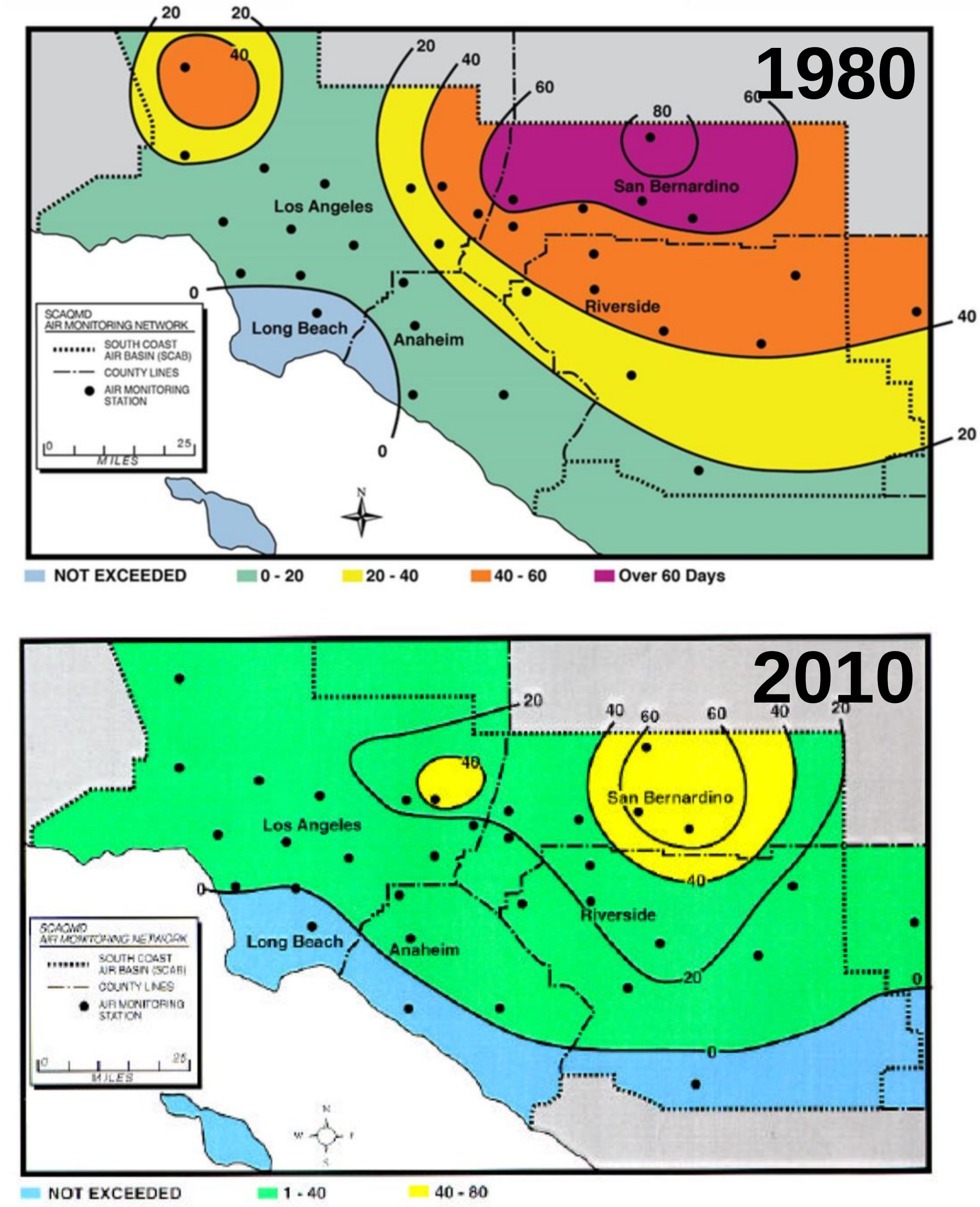

Figure 6. The four panels above show the overall decrease in air quality concerns in the Los Angeles Basin between 1980 and 2010, as measured in days above the CARB standard for particulate matter and other airborne pollutants. There were drastic reductions in regions historically most severely at-risk for poor air quality; yet, equity concerns remain because improvements have been geographically “piecemeal.” Additionally, note that aggregate data was not available in raster form to be analyzed in ArcGIS for the years 1980, 1990, and 2010, thus sociodemographic interactions were only precisely calculated for 2000.

SOCIODEMOGRAPHIC INDICATORS

Sociodemographic indicators during the study period have also changed drastically, interacting with climate hazards in a dynamic fashion over time. Compiled from U.S. Census, Southern California Association of Governments (SCAG), CA Department of Public Health, CalEPA, and CARB datasets, high social vulnerability, both at baseline levels and as related to changing climate exposures, was shown to have grown increasingly geographically segregated and heterogenized since 1980. While there are over 19 sociodemographic indicators (summarized in Methods section, adapted from Sadd et al. 2011), there were three that most significantly spatially reconfigured over the time series, and which interacted strongly with climate-related risks and exposure: race, income levels, and disability.

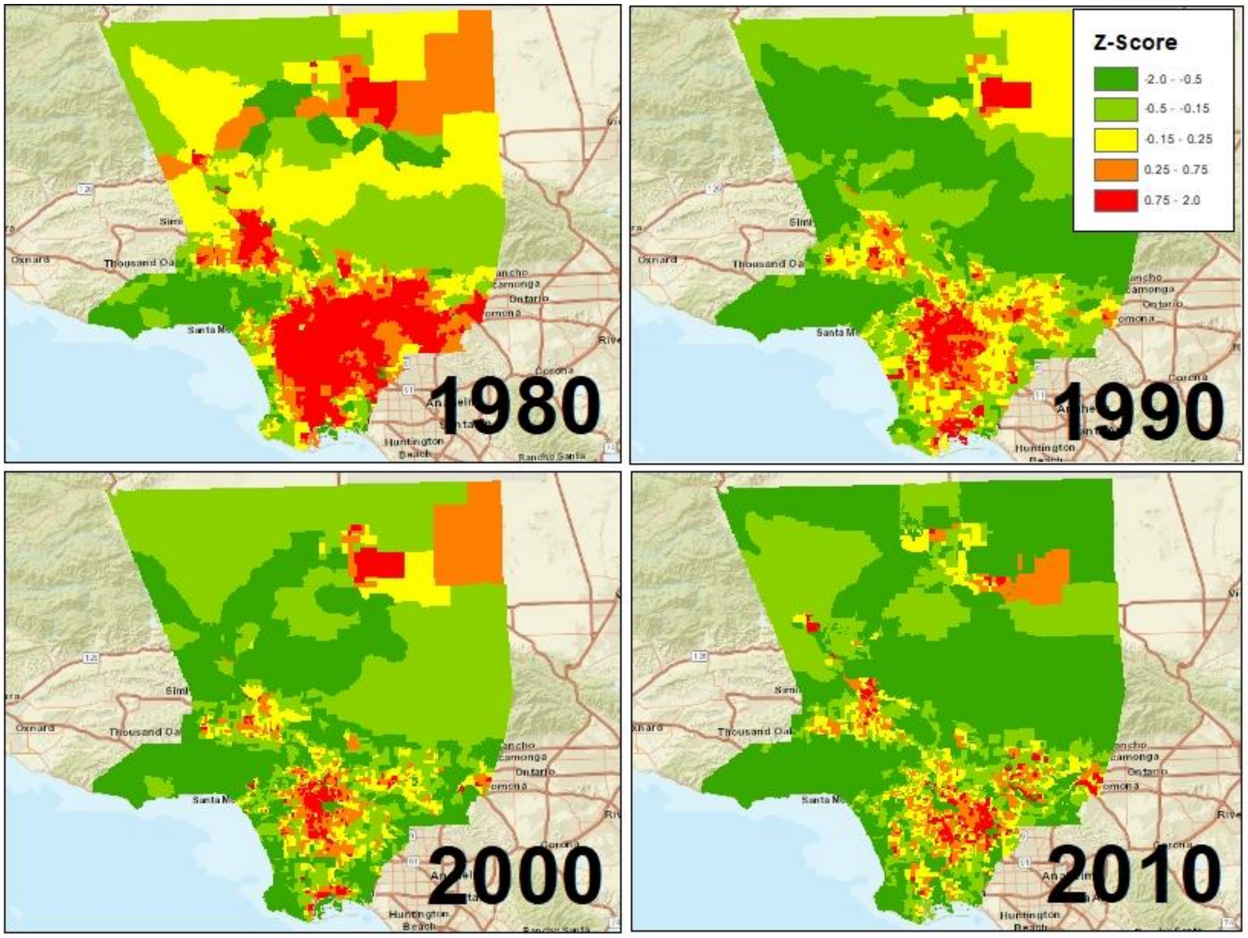

Figure 7. The four panels above show the overall decrease of sociodemographic vulnerability to climate change in the Los Angeles Basin over the past three decades, as rated cardinally through Z-scores (-2<Z<2). The higher the Z-score, the higher the categorical or predicted vulnerability for the census tract. Note that certain areas have gotten "redder" by 2010, however, mostly in the densely populated inland and southeastern portion of the County, coinciding greatly with areas of increased extreme heat risk.

Race: Examined at the County level, an average individual's or community's racial profile became less predictive of its vulnerability to different climate hazards. Z-scores generally showed a decrease of -0.31 (cardinalized in standard units of 1) for this predictor marker over the thirty-year period. However, spatial analysis shows that while the average vulnerability of people of color has attenuated in the aggregate, pockets or "hotspots" of social vulnerability grew substantially coincidentally. Areas of the Antelope Valley, South/East Los Angeles (Alameda and Harbor Freeway Corridors), and Pacoima/Sylmar in the San Fernando Valley, for example, saw +0.2 to +0.8 increases in their vulnerability Z-scores. As a result, the distribution of census tracts, calculated on a sliding scale of vulnerability, has shifted away from normality and homogeneity to heterogeneity. This suggests that certain neighborhoods that skew overwhelmingly towards people of color, controlled for other predictor markers beyond race, and that are already highly vulnerable (Z-score>+0.167), saw only an intensification of their vulnerability over the last three decades. This suggests spatial segregation, which, compounded by correlated climatic indicators such as air quality and extreme heat, may highlight the climate gap and equity concerns previously discussed.

Income Levels: Trends found here closely mirrored those of racial Z-scores (countywide decrease of -0.12), although the some of the "hotspots" found here also ran the gamut of several other coastal and foothill communities. Census tracts in Venice, San Pedro, the western San Gabriel Valley, northern Long Beach, southwestern Pomona Valley, for example, also reported increases of over Z=+0.2 (higher vulnerability) for the study period, some of which already exhibited positive (more vulnerable) baseline scores historically. Heterogeneity and noncardinality of the sampled census tract Z-scores did not change as drastically as with race over time. Therefore, one can assume that, especially for those with annual incomes higher than $75,000, that financial stability (wealth inferred) has remained an important harbinger of one's personal/collective risk to climatic indicators. In line with Ekstrom and Moser's (2012) argument, monetary resources and socioeconomic capital are often the best assurances of general safeguarding, whether in adaptation or mitigation.

Disability: As both qualitatively and quantitatively assessed in the literature, disability is often correlated with age (R^2=0.67 for disabled vs. 65+ years old in Los Angeles County in 2010), as well as other demographic predictors. As such, disability and its Z-scores cannot be quite distilled without accounting for autocorrelation, which is beyond the scope of this project. Nonetheless, similar spatial treatment for the County during the study period has revealed several interesting results. Coinciding with the "race vs. climate" maps, the greatest vulnerabilities were seen in similar hotspots, namely industrialized Central and South/East Los Angeles, as well as in marginalized communities along the coast (Venice, San Pedro, and parts of Long Beach). Beyond that, however, there were unexpected regions of the County that demonstrate the complexity of climate's impact on populations. For example, Malibu, foothill-adjacent communities (e.g., Sierra Madre, Glendora), and areas in far northern Los Angeles like Porter Ranch, generally fared much worse in extreme wildfire and air quality events. While resource-rich and "resilient" under the other sociodemographic metrics, these oftentimes retirement and disability-focused communities are characterized by a relative lack of adaptability ($Z<0$). From these findings, one can gather that while the layering of over 23 assessment indicators is efficient and succinct, the demarcation of individual sociodemographic indicators is often important in distilling specific demographic-climatic interactions for policy purposes, as in the case of disability and wildfire.

ANALYSIS/DISCUSSION

Given the results from this longitudinal study, this expanded CCVA elucidates new findings that have not been recounted before in previous literature. The central trend inferred from the data is that the average Angeleno became less socially vulnerable, but more highly exposed to climatic changes between 1980 and 2010. As noted, Z-scores for the sociodemographic indicators, pretty much across the board (15 of 19) *decreased* substantially, yielding that baseline social vulnerability, as purely calculated from sociodemographic inputs, has also *decreased*. At the same time, climatic factors– extreme heat, flooding, wildfire, and poor air quality– seemed to get much worse (in some cases, like extreme heat, nearly doubly) and affect more highly vulnerable people disproportionately. This opens up an interesting logical conundrum: if in the aggregate, average vulnerability scores are going down, can general exposure simultaneously increase?

One culprit, it seems, is that low-vulnerability communities have seen disproportionately large reductions in their risk since 1980, outweighing the heightened risk among already high-vulnerability populations. In other words, those disadvantaged have seen their vulnerability *and* exposure grow, while those privileged have generally safeguarded themselves from the same worsening climate hazards. This distribution therefore suggests a stratified hierarchical system, whereby the mean or median community (averaged over the whole County) sees improvements in their climate-related risks, while at either end of the vulnerability spectrum (very high or very low), there was an intensification of the extremes. It is difficult to ascertain whether or not a "run-of-the-mill" neighborhood (e.g., Eagle Rock, mid-city, Lakewood) also paralleled the aggregate average's reduction in vulnerability; most likely, the trend is highly site-specific. Still, it highlights that certain policy measures have been effective in curtailing people's susceptibility to climate risks over the last thirty years, whether it be through tree planting programs, home weatherization, more comprehensive public transport and improved mobility, or better access to fresh produce and shrinking food deserts (Nahlik et al. 2017; Zabin et al. 2016; Raval et al. 2017; Mitchell and Chakraborty 2015; Houston et al. 2004; Sadd et al. 2011). After all, reductions in vulnerability have outpaced the gains.

The growing climate gap (the *bifurcation* or stratification in observed Z-scores and its strong correlation to climate risk) is concerning, however. As discussed in the previous section, the main areas of concern within Los Angeles' demographic profile were: race, income levels, and disability. These have historically been, and continue to be, some of the biggest hurdles in achieving social equity and justice (Pastor et al. 2011; Shonkoff et al. 2011; English et al. 2013; Sadd et al. 2011; Morello-Frosch and Jesdale 2006); the fact that these predictor markers have recently seen the most stratification, especially within a climate-related context, is not surprising. While previous studies, including Cooley et al. (2012) and English et al. (2013), have demonstrated that these three predictor makers most demonstrably illustrate the climate gap, their cross-sectional analysis did not sufficiently show that it has *worsened* over time. Thus, even a simple longitudinal extension of the data (with only a few more decadal temporal points) can already reveal certain trends that were not apparent before. Not only can past trends be easy to infer, but future extrapolations can also be predicted. In this study, the forces behind a growing climate gap– increased climate hazards and a polynomially growing population– was held constant. Based on calculations, estimates for changes in vulnerability and exposure largely agreed with the IPCC and Cooley et al. (2012) calculations (R^2=0.87).

LIMITATIONS

While this research project has its strengths, there were also some methodological and categorical limitations. The main issue encountered was data missing from 1980. In that year, only 5 of the 19 indicators were complete enough to be aggregated into the Social Vulnerability Index (SoVI). For that reason, there might be a skew in the Z-scores due to missing values in the other 14 indicators. Additionally, it was difficult to interpolate yearly for the Social Vulnerability Index, given that the interval between each datapoint was decadal; on the other hand, there was an overabundance of climate data over the same time period, which was difficult to map in ArcGIS. In future research schemes, it would be advisable to fill in any of the data gaps, either by using interdecadal data, or by extending the timeline to the 2020 U.S. Census. With a longer time series spanning more decades, the assumption that the climate gap is widening at a constant rate could also be corroborated or corrected.

More mesoscale and microscale evaluations of the County (focusing on the City, a particular neighborhood, etc.), facilitated by progressively improving climate recording instruments and finer-grid raster aggregation, could also prove to be useful, since indicator-based climate change vulnerability assessments work best on smaller resolutions. This current in lapse in the dataset was most apparent for air quality, one of the more important climatic indicators, where raster and interactive maps for three of the four decades studied were altogether absent. For the other climatic and sociodemographic indicators, better data collection/representation and groundtruthing could increase credibility and capacity for future studies and assessment. If the findings here are to be received more broadly, great care should be taken to ensure that this quantitative procedure is replicated accurately and effectively in a different site or on a larger scale, given the theoretical guidelines laid out in the Literature Review section.

RECOMMENDATIONS

For Researchers, Assessors, and Professionals: Going forward, the most immediate and salient recommendation for stakeholders (both inside and outside the assessment process) is to improve computational accuracy where it matters. In other words, when real-life policies are based on models, assuring that they're realistic and relevant can have real-life consequences. In a narrower sense, the drive towards greater accuracy means that within the impact, vulnerability, and adaptation (IAV) community, professionals, academics, and policymakers will need to continue monitoring the applicability of local indicator-based climate change assessments and tweak them as needed. With the continual advent of better datasets, more concise frameworking, and constituent/community participation, there will be increasing pressure to rehash existing CCVA-related policies and institutions in Los Angeles, as Jiang and Hardee (2010), Tonmoy et al. (2014), and Hinkel (2011) state. Given the receptive and proactive attitude on the local and regional level to make formative changes and address equity concerns (Pastor et al. 2010), Los Angeles County could quickly realize some of these goals; additionally, it could serve as a blueprint for other municipalities that would like to rethink their quantitative approach to climate equity modelling and policy. Unfortunately, as it currently stands, the County lacks computational capacity and political stratagem to move forward as leaders in this field (see Case Study section). One solution (of many) would be brainstorming creative ways to coalesce and gather key institutions and individuals (universities, nonprofits, private-sector consultants) to continue studying the longitudinal aspect of climate change and its social impact. More broadly, such action could also help solidify, for stakeholders but also lay constituents, that there is an ongoing intensification of climate injustice, and that the demography-climate nexus must be more carefully considered and prioritized in day-to-day life.

For Los Angeles Policymakers: The County already recognizes that contemporary CCVAs, as they are incorporated into policy debates and action, are inadequate given statewide and national climate equity goals. Recently, In the County's (2016) report, "A Greater LA: Climate Action Framework," LARC, MTS, and the SGC adopted many tenets of climate justice in their mission to develop a better vulnerability assessment tool, including a focus on: transportation and land use, water, energy, and public health, and coastal resources. By giving this Framework its due credit and concretely engaging in its long-term vision, the County could be committing to a major first step to undo some of the previous limitations of CCVAs, tackle the climate gap, and become a better steward of the climate justice movement, from the local to the global scale. So far, the Framework has the full backing of the existing establishment, including Mayor Eric Garcetti and regional agencies (Los Angeles Department of Water and Power, Southern California Metropolitan Water District, and Metro). Nevertheless, as Raval et al. (2017) point out (and as I claim in this paper), while the outlook herein has lofty goals and compelling provisions, there is still tactical shortsightedness in the plan that continues to stymy the potential breadth and depth of truly equitable and restoratively just policy.

One example, in particular, juxtaposes the the well-meaning intentions of the LA Climate Action Framework and Safeguard California with their inequitable policy results. When the State appropriated money under SB 535 and AB 32 (Greenhouse Gas Solutions Act) to fund investment projects in disadvantaged communities hurt by the growing climate gap (e.g., the Greenhouse Gas Reductions Fund), they prioritized the port and City Council District 15 over much more "deserving" areas in South or East LA (Kingsley 2015; Muraida et al. 2015). This happened for two reasons. First, while San Pedro and parts of Long Beach are considered high-exposure communities, the agency in charge, the Strategic Growth Council (SGC), prioritized economic considerations over the wellbeing of its highly vulnerable constituents (Muraida et al. 2015). Second, the SGC employed CalEnviroScreen as a screening method to select its candidate “target” neighborhoods, which according to Liévanos (2018) and Muraida et al. (2015), is an outdated tool that has recently retroactively taken race and ethnicity out of its algorithm. In this way, we can see how limited and myopic models that fail to take into account a full array of factors, especially race/ethnicity, may have long-lasting consequences for ordinary people. In the end, City Council Districts 8 and 9 in South Los Angeles did not receive much GGRF funding and had to resort to alternate grants (e.g., the Transformative Climate Communities plan, which gives much less money) in order to move forward with some of its projects, including Rail to River along the Slauson Corridor (Muraida et al. 2015). Such financial and sociopolitical debacles could be avoided in the future by investing in smarter tools like a longitudinal CCVA (which better portray reality), as well as by better aligning specific tactical and policy maneuvers with the larger justice-oriented and equity goals of Los Angeles’ climate action.

For the Broader Audience: CalEnviroScreen and the Framework are only a symptom of a much larger problem in the County and the State, however, where dozens of these metrics are either too cross-sectional, technical, or incomplete in their understandings of the baseline vulnerabilities of specific areas and the region as a whole (see Case Study section). Therefore, the goal should be to create a tool-and-policy-driven consensus approach statewide. According to Raval et al. (2017), the following is an inexhaustive list of policies that are mediated by contemporary CCVAs in one way or another: AB 2722 (TCC), SB 535, AB 32, AB 1550, AB 2800, SB 100, SB 775, AB 378, SB 1000, SGC's Affordable Housing and Sustainable Communities (AHSC), CalFIRE's Urban and Community Forestry Program, ATP, State Transportation Improvement Program (STIP), State Highway Operations and Performance

Program (SHOPP), LTF, and Local Roads. Given that none of the underlying assessment models for these bills and programs are truly dynamic, realistic, or nuanced, they do not empower local public policy to pursue equity goals and restorative justice in the most appropriate manner. In this regard, Raval et al. (2017) outline many other instances similar to the GGRF funding case, where good intentions were paved with misguidance and an impractical decisionmaking toolkit. I claim that one oft-overlooked, yet easy solution to this problem is to continually engage in the big questions of climate change, sociodemographics, and an ever-changing political landscape, whether as professionals assessing maps, as policymakers debating in the halls of Los Angeles and Sacramento, or as communities building adaptive capacity. It is therefore my sincere hope that a renewed look at CCVAs, as well as other quantitative indices/metrics in other sociopolitical domains, could help forge a more inclusive, equitable path towards the future.

CONCLUSION

While the "climate gap" is an immensely crucial subject that will continue to define the lives of billions of people over the upcoming century, it is often poorly studied and given little political weight. Oftentimes, much of this dichotomy stems from the fact that the climate gap can seem like an enormous and nebulous challenge, and on larger scales, it can be difficult to concretely quantify or deconstruct (Tonmoy et al. 2014). Even in Los Angeles County, where there have been robust attempts to more realistically capture people's social vulnerability in an increasingly hazardous climate, climate change vulnerability assessments still undoubtedly suffer methodological errors that translate into inequitable policymaking. In showing that merely adding new computational dimensions to quantitative models can elucidate new findings and highlight equity concerns, I made the case that continual updates of these assessments are necessary. Since modifications to accessory and auxiliary policy models are relatively user-friendly and politically uncontroversial, I advocate that the County and the State of California adopt the new framework found herein and continue to build on it. Furthermore, I hope that this conversation about the temporal connection between contemporary changes in both climate and demographics can be further studied, whether here in Los Angeles or elsewhere. Dependent on further research on this subject, population growth, demographic composition, and geographic redistribution of human communities could all prove to be some of the biggest determinants of equity, wellbeing, and even survival itself under a changing climate. In that context, policy measures might be the most effective tool to mitigate and adapt to the new circumstances.

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