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 , 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 Despite this important conclusion, certain elements of current screening methods and vulnerability assessments still remain incomplete and unrealistic

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., ³GLVDGYDQWDJHG FRPPXQLWLHV´ RU ³'$&V´) 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 (³HQYLURQPHQWDO LQMXVWLFH´), lack of resources to mitigate and adapt to rising climate-related threats in DACs, and low political will and prioritization to ³VDIHJXDUG´ marginalized ³WKRVH (Ibid.). Both worldwide and in the United States, Q ¥Þ ‘a"ëú —eK U µ ' $

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 crosssectional and narrow ³YXOQHUDELOLW\´ 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¶s growing climate gap. I will address this central inquiry in two parts. First, XVLQJ D ³IUDPHZR DQDO\VLV´ consider whether existing vulnerability assessments even provide the appropriate toolkit to answer VSHFLILF TXHVWLRQV DERXW (and if so, how) the /RV $QJHOHV¶ FOLPD 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

LITERATURE REVIEW

In the following section, I delve deeper into literature about the climate gap. In order for us to understand curr

(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 $ Q J H O H V & R X Q W [burden and susceptibility to deterioration, lack of insurance access, disproportionate costs of 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 UG H H 2 ¶ 1 H L O O H 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) D Q G 2 ¶ 1 H L O O 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 S H R S O H ¶ V H[SRVXUH WR climate hazards. Taken together, this literature

What are Climate Change Vulnerability Assessments (CCVAs)?

A climate change vulnerability assessment (CCVA) is one of the most oft-utilized tools in trying to ³measure´ 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 ³big´ 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 ³indicators´ 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 ³indicators´ can work simultaneously to flesh out several facets of the word ³vulnerability´ 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 alway G [(t70.9992 re W* n BT /F3 12 T:7(ke)4(r0 g 0 G [(a)4(nd)-

> S[CLIMATE GAP: CONTEMPORARY UNDERSTANDINGS

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 pollution to the climate gap; rather, they measured public health effects as a proxy. With results even bleaker

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. ³ F X P X O D W L Y H L P S D F W V ´ The concept of ³cumulative impacts´ is longitudinal and takes into account a c R P P X Q L W \ ¶ V demographic profile, chronic exposure (rather than acute), and adaptive capacity in order to truly assess its vulnerability. Their findings reiterate * D O O R S L Q ¶ V D V V H U W L R Q W K D W there are factors beyond exposure that determine an individual¶ V Y X O Q H U D E L O L W \ (Q J O L V K H W D O

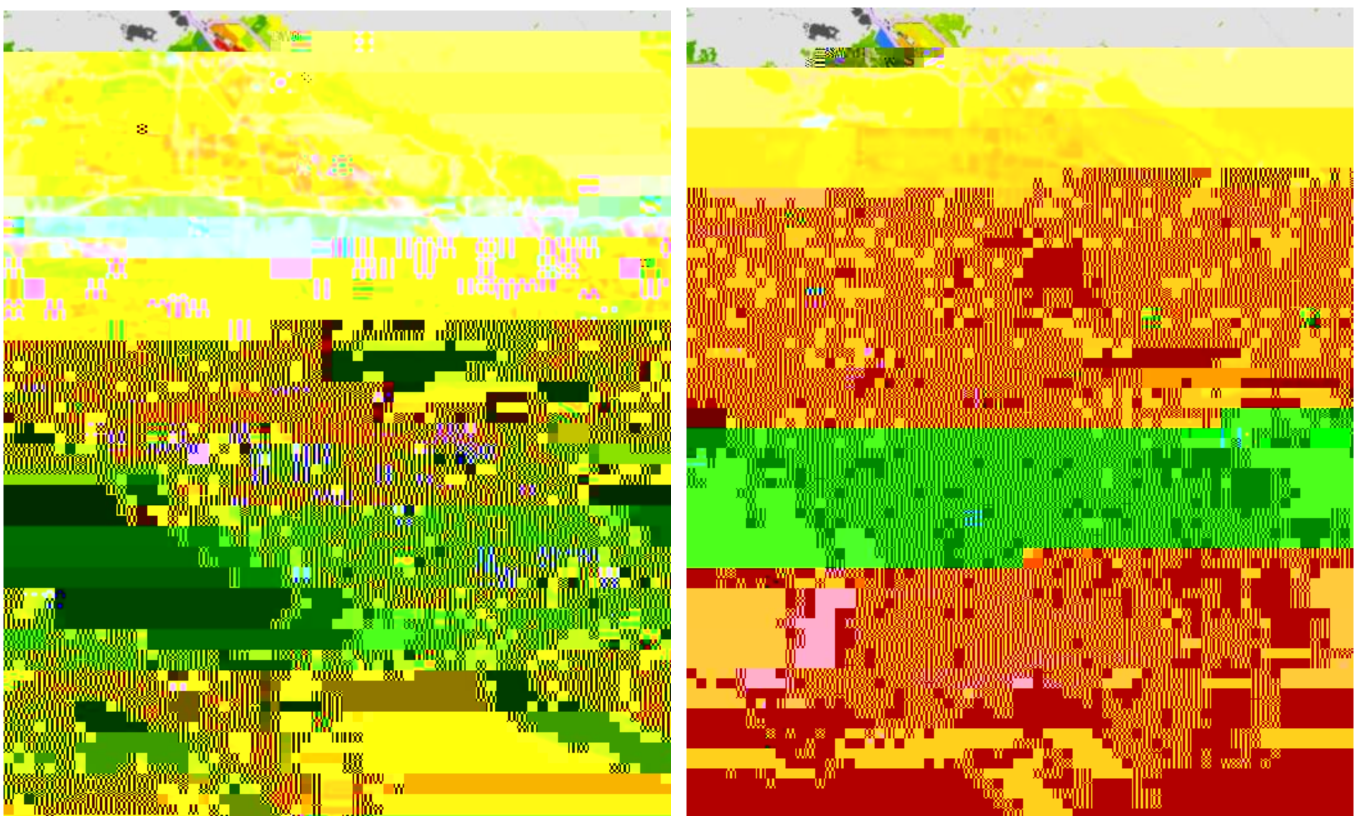

Figure 1. A comparison between calculated hazard exposure (1=lowest, 5=highest) for census tracts across the County *(left)* and ³ F X P X O D W L Y H L P S D F W V ´ *(right)*, which additionally weighs social

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" (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 often be situated at the geographic boundaries of the County, whether at the beach or at the urban-wildland interface ("foothills"), high exposure (Ibid.). However, they tend to 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' vulnerability landscape through a "climate justice" 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 "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

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

> 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. 2011; Jiang and Hardee 2 ¶ 1 H L O O H, W DO, and purported on the local level (Cooley et al. 2012; English et al. 2013), 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 R I / R V $ Q J H O H V ¶ K X P D Q 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 pollu W L R Q ³ K R W V S R W V ´ Z K L F (2008) contended can increase mean exposure by 1-40% for ³ Q R Q -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., ³ O L Q H D U trends´). Of course, there are other *non*-linear considerations as well, such as the effect of cap-and-trade¶ V L P S O H P H Q W D W L R Q, the growth of the Los Angeles-Long Beach Port Complex and automobile/cargo traffic, and increasing development in

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up with various and creative ways to increase the capacity and accuracy of current models. As can be seen in Table 1 below, the

"Climate Change Vulnerability Screening Method"	*RYHUQPHQW (QJOLVK HW	N	N	Y
"Health Impacts Index"	$FDGHPLF 3DVWRU HW	N	N	N
"Climate Impact and Social Vulnerability Analysis"	&RQVXOW *RYHUQPHQ &RROH\ HW	Y	N	Y
"Environmental Justice Screening Method"	*RYHUQPHQW 6DGG HW DQ	N	Y	Y

3

I will include some nonlinear factors that have not 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 the 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 [illegible] 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 where I found strong correlation and convincing causality, it was of interest to extrapolate the current time series (climatLF DQG GHPRJUDSKLF WUHQGV LQWR WKH IX

RESULTS

CLIMATIC INDICATORS

Extreme

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¶V UHVLGHQWV ZHUH WKHUHIRUH LQF of being highly exposed *and* highly vulnerable to this climatic indicator. In fact, 6 million, or 59%, of the &RXQW\¶V FXUUHQW SRSXODWLRQ UHVLGHV LQ DUHDV WKD during the summer months, considered a medium exposure by IPCC and CalEPA standards. About 460,000 people, or less than 5% of the County¶V SRSXODWLRQ OLYH LQ DUHDV

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 (1-20%). 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 matter2les9-8(e)6

SOCIODEMOGRAPHIC INDICATORS

Sociodemographic indicators

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 (wHDOWK LQIHUUHG KDV UHPDLQHG DQ LPSRUWDQW KD FOLPDWLF LQGLFDWRUV ,Q OLQH ZLWK (NVWURP DQG 0RVH socioeconomic capital are often the best assurances of general safeguard 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 LQWHUHVWLQJ UHVXOWV &RLQFLGLQJ dates with vulnerabilities were 3UDFH YV 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 FOLPDWH¶V LPSDFW For example, Malibu, Ca and adjacent communities (e.g. ET Q nf(S)-3(air 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. I W L V G L I I L F X O W W R D V F H U W D L Q Z the -P L O O ´ Q H L J K E R U K R R G, mid-city, Lakewood (D J J) also 5 R F N paralleled the aggregate averag

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 a decade; 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.

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, considerations over the wellbeing of its highly vulnerable constituents (Muraida et al. 2015) Second, the SGC employed CalEnviroScreen as a screening method to site F D Q G L G D W H ³W D U 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 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

Program (SHOPP), LTF, and Local Roads. Given that none of the underlying assessment models for these bills and programs are truly dynamic, realistic, or 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 distribution 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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