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Investigating the relationship between environmental quality, socio-spatial segregation and the social dimension of sustainability in US urban areas

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ABSTRACT

This work is intended to assess the relationship between the three dimensions of sustainability (environmental, economic, and social) and residential segregation broadly across US urban areas. Multivariate indices of segregation and sustainability are created using data aggregated to 933 US Census Core-Based Statistical Areas (CBSAs). The relationship between segregation and sustainability (and dimensions, independently) is analyzed across the CBSAs using correlation and spatial analyses. Results show an inverse relationship between segregation and sustainability, where increasing urban segregation corresponds to decreases in sustainability. Social and economic dimensions of sustainability are negatively correlated with segregation while the environmental dimension is positively correlated. Spatial analysis reveals regional associations between the measures with most of the lower sustainability scores and higher segregation scores occuring mainly in the South. The findings demonstrate an inverse relationship between segregation and sustainability as well as between the environmental and social dimensions. These correlations indicate a need to consider inequalities, and the social dimension of sustainability more broadly, when planning urban revitalization efforts. Spatial scale is also imperative to understanding and improving the social outcomes for all members of the community.

1. Introduction

Sustainability has long remained an ideal in urban spaces throughout the world and is broadly associated with practices intended to improve or maintain environmental quality. Grounded in the seemingly simple concept that equilibrium between competing economic and environmental goals is critical for long term success, it actually represents a far more complicated balance between three interconnected dimensions: environmental, economic, and social. This complexity has resulted in struggles to both define and measure sustainability in a consistent manner. Despite the challenge to pin down a singular definition, it is important to remember that sustainability is not an absolute value, but instead a threshold that we base our relative successes upon. It is a yardstick to measure progress through time. With this in mind, the goal of sustainability should be improvements within any dimension that come without sacrifices to the others.

A focus on the environmental and economic dimensions of sustainability misses the critical link to equity, or the equal allocation of assets, opportunities, and burdens across a population. Failure to move toward equity will result in a failure to achieve sustainability (Agyeman & Evans, 2002). Here, we will investigate sustainability in all urban areas of the US through the lens of equity by quantifying the relationship between one component of social equity (residential segregation) and the dimensions of sustainability. This analysis addresses a need in both the social sustainability and segregation literature to establish a clear, quantitative link between the level of ethnic and racial segregation in a city and the decline of sustainability (and its individual dimensions).

1.1. Sustainability in urban systems

Efforts to address sustainability began more than four decades ago as concerns over urban growth practices mounted and humans began to understand their impacts on the global environment. What began as concerns over near-term impacts of pollution from industrialization took shape as a more defined vision for the future following the World Commission on Environment and Development's (WCED) report (Brundtland, Khalid, Agnelli, Al Athel, & Chidzero, 1987). Though international in scope, it was important in laying the foundation for a path to sustainability and clearly identifying the three dimensions as integral and equal components. In a multitude of research and policy initiatives,

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each of the dimensions were assessed at levels ranging from local to global.

Around the time of the WCED report, suburbanization was pushing urban boundaries outward and converting natural landscapes into sprawling neighborhoods at an unprecedented pace. Increases in roadways and cars followed, leading to additional concerns over resource consumption. Sustainability initiatives of that period were driven by concerns over drive-times and the protection of distant landscapes from which resources were extracted. As health concerns related to the deteriorated conditions of inner cities and locations of industrial facilities mounted, the focus of sustainability expanded to encompass a broader array of environmental topics.

Broadened sustainability measures have included everything from the straightforward topics of health and education to the more complex issues of social cohesion and equity. The challenges of defining and measuring the social dimension have led to a slower incorporation of initiatives involving social outcomes (Opp, 2017). This lack of attention to social measures, especially equity, has led in part to many of the challenges and setbacks in sustainability policy. Though considered in earlier research, the social components were often assumed to align with the other two, such that social conditions would automatically improve along with economic and environmental conditions. Mounting evidence to the contrary shows that social sustainability is not inherently linked to the other two dimensions, though the conceptualization and assessment of social sustainability remains a work in progress (de Fine Licht & Folland, 2019; Littig & Griessler, 2005).

1.2. Environmental equity and residential segregation in urban systems

Examination of sustainability through the lens of equity helps to clarify some of the current issues. Namely, what is the impact of inequality on the sustainability of urban areas? Environmental equity (both process and outcome) is concerned with how environmental impairment influences a place (Cutter, 1995). Within this framework, there are three types of equity guiding the outcomes: social, generational, and procedural. The role of socioeconomics and demographics in environmental outcomes falls under social equity. Sustainability and generational equity are synonymous in that they both consider present actions within the context of what is fair to future generations (Weiss, 1989). Procedural equity depends on non-discriminatory rules and enforcement by government entities that will influence the other two forms of equity directly.

A central tenet of urban sustainability is that of equal access and opportunity. If any residents are unable to access public benefits and satisfy basic needs, sustainability cannot exist (Opp, 2017; Sampson, 2017). While certain public goods are not spatially dependent (e.g. income, knowledge), the location of residences in relation to community assets plays a critical role in how benefits are dispersed. The opposite concept has long been employed in the environmental justice movement, where inequitable exposures to environmental disamenities are the primary focus (Warner, 2002).

The most common disparities influencing community well-being and sustainability are those of race and ethnicity (Allen & Sachs, 1991). Not only do racial and ethnic disparities tend to drive outcomes, they also correlate with other elements of social equity, such as income, education, and access. These are all shown to influence vulnerability of populations, thus reducing the sustainability and resilience of the system (Neff, 1985; Vojnovic & Darden, 2013; Watson, Logan, & Tomar, 2008). Treating segregation as an equity component of the social dimension reduces the conceptual impact by assuming all other measures are evenly spread amongst the population within an aggregation unit (Fischer, Stockmayer, Stiles, & Hout, 2004; Rajaonson & Tanguay, 2019). By separating the segregation measure, it is possible to assess the relationship between population disparities and the overall sustainability of the urban area.

Clustering of racial and ethnic groups can be explained through a combination of internal (e.g. cultural and religious ties) and external (e.g. economic conditions and societal barriers in housing and employment) forces. The existing spatial and demographic variations result in diverse patterns of residential distribution, which in turn correspond to disparities in community measures of well-being and vulnerability (Summers & Smith, 2014; Tulve, Ruiz, Lichtveld, Darney, & Quackenboss, 2016; Zhang, Robinson, & Hite, 2018). These patterns, along with their drivers, are similar in most countries. They often begin with social inequalities based on income, labor, and welfare systems, but can develop into more deep-seated norms over time (Andersen, 2019; Sisson, 2020).

A foundation of research in the fields of sociology and epidemiology builds on the premise that uneven distribution of demographic groups will result in an unequal distribution of resources (e.g. information, money, jobs, and services) and isolation of minority populations (Galabuzi, 2004; Liu & Geron, 2008; Massey & Denton, 1993; Mitchell, 1999; Sampson, 2009; York et al., 2011). Some outcomes commonly attributed to residential segregation, and consequently influencing sustainability, are greater risk of health problems, higher poverty and crime rates, lower employment and less education (Ousey & Kubrin, 2009; Reid, Weiss, Adelman, & Jaret, 2005). In addition to harms felt within a segregated community, there is mounting evidence of impacts that extend beyond the immediate isolated areas (Fowler, 2016; Goodling, Green, & McClintock, 2015).

While the Massey and Denton's conceptualization of segregation remains a cornerstone in the field of sociology, the approach is not without critiques, primarily the lack of accounting for spatial variation among the neighborhood units (O'Sullivan & Wong, 2007). Massey and Denton (1988) handle spatial clustering as a dimension of segregation, but a combination of new methods and improved technologies have resulted in more sophisticated measures of spatial variation. Much of this work addressed the early criticism of traditional social segregation indices and their failure to account for spatial patterning, limited spatial scales, and ability to make assumptions of causation (Alba et al., 2014; Feldmeyer, Harris, & Scroggins, 2015; Grannis, 2002; Iceland, Weinberg, & Steinmetz, 2002; Jargowski, 2009; Lloyd & Shuttleworth, 2012; Morrill, 1991; Wilkes & Iceland, 2004; Wong, 1997). One example uses spatial clustering as a modifier for all dimensions of segregation to better assess the spatial component (Reardon & O'Sullivan, 2004). Brown and Chung (2006) also call for a simplified approach that leans more heavily on geographic concepts, contending that segregation occurs at a local level and should therefore not be assessed using global indices like dissimilarity. Local indices, such as Local Moran's I, have the capability to measure spatial clustering and better assess the patterns of segregation (Anselin, 1995).

Incorporating both the social and spatial isolation in a measure of segregation captures more of the possible outcomes associated with minority distribution. This concept of place is important with respect to sustainability outcomes through concentrations of risk but should also be considered as a product of stigmatization. Referred to also as territorial stigmatization, the marginalization of groups based on physical location and symbolic association with a place is associated with both cultural and structural norms in a society (Sisson, 2020). In US communities, practices such as Redlining represent an example of the historical challenges that must be overcome to create equity within communities.

1.3. Connections to environmental quality

In urban spaces, many recent efforts to improve sustainability focus on increasing the amount and quality of green infrastructure. Urban revitalization through green infrastructure investment is a popular route taken by cities trying to improve air quality, outdoor recreation spaces, and drive economic improvements (De Sousa, 2003; Koh, 2018). These projects may convert abandoned properties or polluted lands to parks or other open natural areas. Despite the clear benefits of this work, there are also examples of revitalization displacing low income residents (Easton, Lees, Hubbard, & Tate, 2020; Sumka, 1979). This process is referred to commonly as environmental, or green, gentrification, and has emerged as an important area of research to grapple with the negative social outcomes associated with these revitalization efforts (Checker, 2011; (Rigolon & Nemeth, 2020)

Environmental, or green, gentrification is well documented and an unintended consequence of urban revitalization efforts (Anguelovski, Connolly, Masip, & Pearsall, 2018; Gould & Lewis, 2017; Pearsall, 2010). Investments in abandoned lots or former industrial sites prioritize the construction of parks, green spaces, and the addition of trees to address air quality, noise control, safety, and recreational opportunities while also improving local habitat and ecological conditions. Multiple studies have also demonstrated successes resulting from green infrastructure investment to help bring businesses and residents back and improve well-being (Collier et al., 2013; Mell, 2009; Pakzad & Osmond, 2016). While these improvements help segments of the population, they also contribute to higher costs of living that displace others (Immergluck & Balan, 2018; Kern, 2016). As the potential risks become better known, there are more instances of communities pushing back against green investments that don't address their needs and raise concerns over future affordability (Alkon, Cadji, & Moore, 2019). If these examples of place attachment and community engagement were tapped into, the outcome of investments may better align with local populations and result in better sustainability outcomes.

The impact of displacement resulting from revitalization is related not only to the potential shift of environmental burdens spatially, but to the social harms created among the displaced population. Related research in Europe addresses the issue through the lens of social capital and place attachment. In Hungary, efforts to spatially desegregate the minority Roma population have resulted in well-being declines (Mereine-Berki, Maloviks, Toth, & Cretan, 2017; Malovics, Cretan, Mereine-Berki, & Toth, 2019). This was found to be the result of processes that weakened the robust social ties within the community and strong connection to place. Social stigmatization, not spatial proximity, has shown up as the primary issue leading to declines in access that drive outcomes based solely on ethnicity. Prioritization of shared public spaces and how these relate to place attachment among marginalized populations is also an important theme in the European research (Malovics, Cretan, Mereine-Berki, & Toth, 2019). Of particular interest there is both the scale at which studies are conducted and the potential well-being harms caused by integration of marginalized populations. Similar social and place attachments in US cities would be expected to result in comparable declines in well-being that may negate any local improvements in environmental or economic sustainability. While this research is not intended to show where displacement may have occurred, there is an important connection between the concepts of urban revitalization and displacement that should be noted and paid attention to in future planning.

Despite the knowledge that segments of the population are harmed following displacement, there is little quantitative evidence to support how these actions impact the sustainability of the urban system in its entirety. More broadly, there are few current attempts to analyze the connections between environmental quality, segregation, and sustainability holistically across entire urban areas. There is an important connection between sustainability and segregation that has remained unmeasured here. Measuring the current status of sustainability dimensions, it is possible to compare how they align with neighborhood segregation of minorities in US urban areas. The goal of this research is to provide evidence that more progress can be made in overall urban sustainability through investments in social initiatives that improve equity and address the distribution of amenities.

2. Methods

Assessment of both sustainability and segregation in urban areas is accomplished through the construction of a multivariate indices. Sustainability is evaluated across three dimensions: economic, social, and environmental; while urban segregation includes both sociological and spatial measures. Census classified Core-Based Statistical Areas (CBSAs) are used for aggregation of data and testing. CBSAs encompass approximately 90 % of the U.S population in 2017 and cover all major urban cores in the U.S (US Census 2017a). Metrics for the economic and social dimensions of sustainability are population standardized within these areas.

2.1. Sustainability index

Sustainability is evaluated using metrics aligned with three dimensions: economic, social, and environmental. The data and framework for assessment of sustainability comes from a report developed by the National Academies of Sciences, Engineering and Medicine (NASEM, 2016). This report outlines the principal indicators and metrics for assessing urban sustainability. From the five indices listed in the NASEM publication, sustainability measures for the CBSAs are chosen based on spatial alignment, temporal availability and whether they are used by a majority (more than three of the five indices). Final measures used for the creation of a sustainability index are shown in Table 1. This includes

Table 1
Three Dimensions of Sustainability with indicators and metrics used for assessment in US CBSAs in 2017.

Sustainability Dimension	Indicator	Metrics
Economic	Income	Per capita income (US Census 2017a)
	Unemployment	Unemployment rate (US Census 2017a)
	Energy	Energy consumption per capita (USDOE, 2019)
	Financial Health	Percent of households under housing stress (US Census 2017a) Median Home Value (US Census 2017a)
	Transportation	Per capita daily vehicle miles traveled per day (USDOT, 2018)
Social	Education	Literacy rate (Reardon et al., 2019)
	Public Health	Years of potential life lost (UWPHI, 2019) Child Mortality Rate (UWPHI, 2019) Percent with health insurance (US Census 2017a)
	Equity	Violent Crime Rate (UWPHI, 2019) Income Inequality – GINI coefficient (UWPHI, 2019)
	Housing and Buildings	Home ownership – Percent renters (US Census 2017a) Percent with severe housing problems (UWPHI, 2019)
	Citizen Participation	Percent voter turnout in last federal election (MIT Election Data and Science Lab Massachusetts Institute of Technology, 2016) Population belonging to social association (County Business Patterns CBP, 2016)
Environmental	Air Quality	Air Quality Health Index (USEPA, 2017)
	Greenhouse Gas Emissions	Per capita greenhouse gas emissions from all sources (Dewitz, 2019; Yang et al., 2018)
	Water	Percent of waterways with impaired status (USEPA, 2017)
	Land	Acres of green space per capita (Dewitz, 2019; Yang et al., 2018) Square meters of tree canopy per capita (Dewitz, 2019; Yang et al., 2018)
	Natural Hazards Vulnerability	Multi-hazard risk index – PRISM (Buck, Summers, Hafner, Smith, & Harwell, 2019)

15 indicators and 21 metrics across the three dimensions.

Economic measures are intended to capture present characteristics of individual- and community-level sustainability that will also influence the economic trajectory of the urban area in the future. Within this dimension, measures are intended to represent the standard of living and consider the wealth or financial stress of residents. Environmental measures are intended to capture current conditions of the air, water and land within the urban boundaries. Apart from greenhouse gas emissions and natural hazards vulnerability, which depict threats to the natural environment and from the natural environment respectively, the values represent the general quality of a resource. The social dimension captures a portion of social equity along with measures of health and community well-being. These include a broad range of individual and built environment characteristics that represent current conditions and some insights into future trajectory.

Metric values are collected for all CBSAs and standardized by population where necessary. Index values (e.g. Air Quality Index, Multi-Hazard Risk Index) and proportional values (e.g. percent impaired waterways) are kept without modification. Prior to final index creation, all non-proportional measures are min-max standardized (0–1) to create final metrics and averaged within each dimension. To create the final sustainability index is created by adding the three dimensions.

2.2. Segregation index

A segregation index is used to analyze local patterns of segregation for five ethnic and racial minority groups. Data comes from the U.S. Census' American Community Survey (ACS) 2017, 5-year estimates at tract level from Table DP-05 (US Census, 2017b). The first minority designation is based on ethnicity, defined in the U.S. Census as Hispanic/Latino. The second minority designation, based on self-identification with a social group, is based on race. There are four minority racial groups in the U.S. Census: Black or African American, Asian, American Indian or Alaskan Native (AIAN), and Native Hawaiian/Pacific Islander (NHPI). The third minority population designation requires the use of ancestral origins to identify the Middle Eastern and North African communities (MENA). Identification of ancestral origins is achieved by using data from the U.S. Census' American Community Survey (ACS) 2017, 5-year estimates at tract level from Table B-04006, which delineates 112 ancestries (US Census, 2017a). Based on census designations, this group includes individuals who descend from Afghanistan, Egypt, Iraq, Jordan, Lebanon, Morocco, Palestine, Syria, Saudi Arabia, "other" Arabic countries, Armenia, Somalia, Sudan, and Turkey. These encompass a majority of the core MENA countries, recognized as the "Arab World" by the World Bank and United Nations Development Fund (UNDP, 2016; WorldBank, 2016). The NHPI population is not included in the analysis here since it represents less than one percent of the overall population and constitutes a majority only in Hawaii. The remaining five groups each constitute a minority of the U.S. population, but exist in localized clusters, or majorities, across the U.S.

Census tracts form the base unit of analysis and represent the closest census aggregation to a neighborhood. While not perfect, most neighborhoods are somewhat organized by social and economic characteristics with people congregating by convenience, shared interests, or economic status. As a result of extensive demographic data collected at this level, the U.S. Census Bureau requests that housing and socioeconomic characteristics of tracts be kept as uniform as possible when boundaries are drawn (Census, 1993). This ensures a baseline similarity within tracts despite the tendency for change as time passes.

To create the final segregation index, the Estimation of Local Sociospatial Segregation across Areas (ELSSA), there are two components of segregation represented – (1) a five-dimensional segregation index (Massey & Denton, 1988) and (2) a measure of local spatial clustering within counties and CBSAs. These measures are attributed to tracts, counties, and CBSAs, with average county index values and degree of spatial segregation reported. The tract (where clustering exists) and county index values are available in Appendix A. An overview of this conceptual approach is presented in Fig. 1.

Social segregation is represented by five dimensions (Duncan, Cuzort, & Duncan, 1961; James & Taeuber, 1985; Lieberson, 1981; White, 1986). Within each dimension, measures are chosen to best align with the temporal and spatial availability of the data. Brief descriptions of the calculation for each dimension are listed here.

- *Evenness dimension*: dissimilarity index used to assess the proportion of the minority group that would have to move between tracts in order to achieve evenness. Based on the minority and total populations at both the tract and county levels.
- *Exposure dimension*: isolation index used to characterize the extent to which a group member is likely to interact only with other members of the same group. Considers minority proportional representation and very small numbers can result in low measures of exposure if there are very few members of the group present, despite being evenly distributed. The calculations require only information regarding tract and county minority populations along with the total population of each tract.
- *Concentration dimension*: measured using the spatial concentration of a group compared to the theoretical minimum and maximum potential of that group. In this case, the maximum concentration would exist if all members resided in a single spatial unit. Calculation requires data for the spatial extent of each census tract in a county along with total, minority, and majority populations. At the county level, the total, minority and majority populations are also needed. Computing this measure in each county requires an individual ordering of tracts from smallest to largest land area and summation of population values following this order. This final index is a value between negative one and positive one with zero representing equal relative concentration of the population in census tracts across the county. A negative one value means the majority population in the county is concentrated to the maximum possible extent, and positive one means that minorities are concentrated to the maximum extent.
- *Centralization dimension*: represents the degree to which a minority group is located near an urban center. This measure involves multiple urban centers and the tracts surrounding each one. To calculate this measure, all Census Based Statistical Areas (CBSAs) and Census Based Places (CBPs) are mapped and merged into a single file along with centroids of all U.S. Census tracts . Using the centroids, a "near" analysis is run in ArcMap 10.3 to create a distance table for all tracts. Every tract is then associated with the nearest urban center and sorted for the creation of the index.
- *Clustering dimension*: represents spatial proximity and is measured by estimating the average distance between members of the same group and between the different groups. This index is used to establish the extent to which minority groups cluster or adjoin one another. The final dimension value is the average of group proximities weighted by the fraction of each group in the tract and county. All distances in the calculation of this measure are based on tract centroids, calculated to fall within tract boundaries, and measured in meters.

A tract-level measure, using Anselin Local Moran's I, is developed to capture the spatial component of segregation and represent local disparities (Anselin, 1995). The Local Moran's I, which requires adjacency of tracts, is chosen as the spatial measure due to its higher precision (Brown & Chung, 2006). Tests for spatial autocorrelation are done using the Cluster and Outlier Analysis in ArcMap 10.3 with no threshold distance and inverse distance parameters ($\alpha = 0.05$) (ESRI, 2016). Two outputs of this analysis are used: 1) The z-scores represent the intensity of clustering, and 2) the cluster/outlier feature of the analysis identifies statistically significant tracts as either high-high (HH), high-low (HL), low-high (LH), or low-low (LL) relative to other tracts. The tract z-scores for those existing as a significant cluster (HH or HL) and exceeding a population threshold for significance (greater than one standard

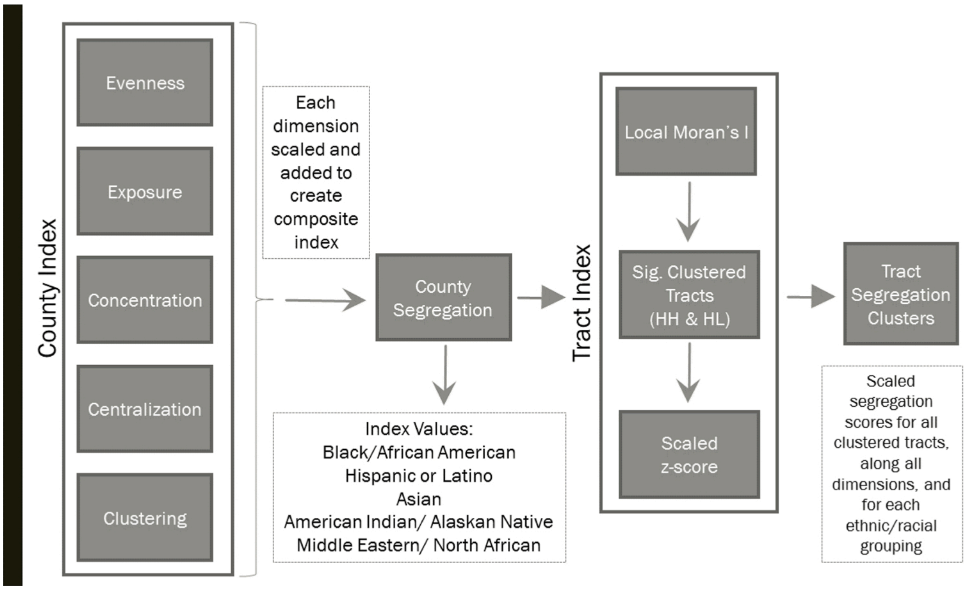

Fig. 1. Conceptual framework for the development of the US Neighborhood Segregation Index in 2015. In this framework, the five dimensions of segregation (Massey & Denton, 1988) are used to create a county-level index for the entire US. A Local Moran's I using census tract populations is conducted to identify significant clusters of minorities. Z-scores resulting from this test are scaled and used to weight their respective county segregation scores. The result is both a global segregation score at the county level and a scaled local segregation score for all clustered census tracts. Each index value can be deconstructed along the five dimensions of segregation.

deviation above the national average for each minority (Table 2)) are used to scale the social dimensions index.

To create a measure for use at the county and CBSA-level, the sociological dimensions of segregation are combined to create a composite index. This is done by first scaling each dimension and adjusting for directionality before combining in an additive framework with each receiving equal weight. Standardization and adjustment create values between zero and one, with one representing the highest amount of segregation in that specific dimension. Min-max standardization is used for all dimensions except for the absolute concentration, which requires first taking the absolute values of the index prior to min-max standardization. Following standardization, the five dimensions are summed to yield a final segregation index between zero and five for all U.S. counties. Zero is the least amount of segregation possible and five represents maximum segregation. For comparison in the sustainability framework, the average of this index value is taken for all counties within each CBSA. County scores are derived by multiplying the average county segregation index by the z-score absolute values of clustered tracts. The result is a set of county values representing both social dimensions and the intensity of spatial isolation experienced. The county values are then averaged across each CBSA.

Despite its sole use in CBSAs for this research, the segregation values are calculated for all contiguous U.S counties and tracts. Residential segregation can exist just as easily outside of urban areas and this should be reflected in the development of an index. Similarly, the uneven distribution of minority populations across the U.S. landscape has changed in the decades since the last iterations of this type of research were carried out. Urban clusters are expanding and suburban hubs have become a more common presence in many areas (Farrell, 2016; Reibel & Regelson, 2011). This multi-nodal urban landscape is an important consideration in determining neighborhood centralization. In addition, gentrification and shifting patterns of business location and connectivity in many cities have made past theories of location isolation obsolete. Shifting to a census tract/county analysis allows for a more consistent landscape to be created and accommodates the idea that multiple urban hubs clearly exist.

Table 2
U.S. Average Populations for Ethnic and Racial Minority Groups in 2017. Source: U.S. Census and the Migration Policy Institute. Calculations for Native Hawaiians/Pacific Islanders not included due to national average being below 1 percent.

Ethnic/Racial Group	Mean U.S. Percent (%)	Tract Calculated Mean Percent (%)	Mean + 1 Std. Deviation (%)
Black/African American	12	13.78	37.05
Hispanic or Latino	16	15.86	35.87
Asian	6	4.70	13.59
American Indian/ Alaskan Native	1	0.88	5.47
Middle Eastern/ North African	2.5	0.71	2.55

The primary aim of this paper is to examine the relationship between segregation and sustainability. Following the construction of indices to measure these attributes across all CBSAs, this is accomplished statistically using a correlation analysis and visually through scatterplots and bivariate choropleth maps. A correlation analysis, Pearson's R ($n = 933$, $\alpha = 0.05$), was used to determine the strength and directionality of the association between the two overall indices. The dimensions of sustainability will also be tested using the same statistical and spatial methods.

3. Results

There are two sets of results presented here. The first is an analysis of the segregation patterns across the U.S. in both urban and rural settings. Locations and concentration of segregation are analyzed in conjunction with the quantification of sociological drivers represented by the five-dimensional index, ELSSA. The second set of results looks at the relationship between segregation measures and the dimensions of sustainability in urban areas of the U.S. This involves the statistical and spatial comparison of the two indices.

3.1. *Segregation patterns*

The map in Fig. 2 illustrates both the distribution of the five assessed minority populations and the relative concentration based on a combination of the spatial and sociological assessments. Evident in this map are the regional concentrations of minority populations. While the size of tracts plays into the visualization to an extent, there is still a clear pattern to the clusters among each population.

Examples of tract level segregation patterns (Fig. 3) are shown as evidence of index utility in population-dense metro areas. Eight major CBSA metro areas are shown in the panels with the same minority groups and segregation scores ranked for each. While the minority

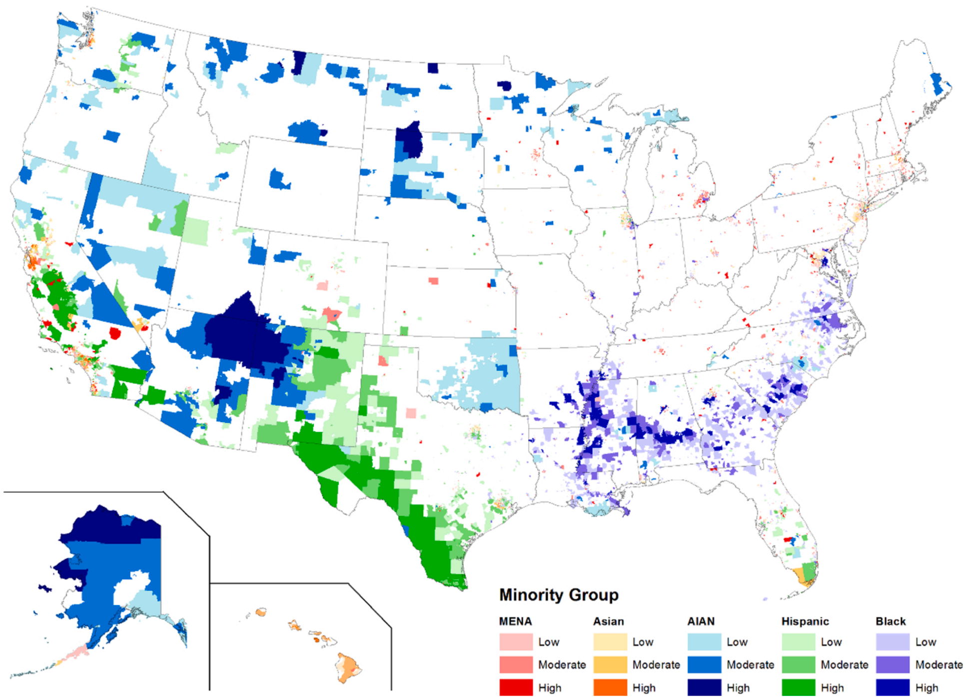

Fig. 2. U.S. Segregation patterns across all 2017 census tracts. Location of tracts and concentration of segregation is shown for each of the five minority groups.

groups present are different across these cities, patterns of segregation are evident in each.

Shown in the radar graph (Fig. 4), the evenness and concentration dimensions contribute the most to overall segregation. This indicates that most of the minority groups are spread disproportionally through urban areas and tend to concentrate in smaller areas. This is significant, for instance, when considering urban investments and the potential for further concentration or the disruption of social networks.

3.2. *Segregation and sustainability comparisons*

The initial test of how segregation correlates to sustainability is carried out using the aggregated index values for CBSAs (all scores are available in supplemental materials). County segregation scores for each minority group are averaged together within every CBSA to generate an overall index score for segregation. This score can then be compared to the overall and index dimensional values of sustainability (economic, social, and environmental) using a Pearson's R ($n = 933$, $\alpha = 0.05$). The results, shown in Table 3, indicate that overall sustainability tends to be lower in CBSAs with higher levels of segregation. Among the dimensions of sustainability, only environmental scores are positively associated with segregation. Social sustainability experiences a significant decline as segregation increases.

The relationship between segregation and the dimensions of sustainability components is clearly visible when graphed (Fig. 5). Both social and economic measures tend to decrease as segregation increases. Again, only environmental sustainability increases with segregation.

When the overall index values are compared, sustainability similarly declines with increasing segregation. The relationship is not as strong, as suggested by the correlation value (r=-0.34). A spatial analysis of this relation using a bivariate choropleth map reveals how this relationship differs across the country (Fig. 6). The map displays the corresponding sustainability and segregation index scores for all CBSAs in the contiguous U.S. Each index is mapped using quantiles and split into three classes for visualization. Of interest in this map are the CBSAs falling within the High-Low and Low-High categories, indicating existence of an inverse relationship between the two values.

CBSAs with high sustainability and low segregation are represented by the darker blue color at the bottom left corner of the legend. Most of the CBSAs fitting in this category are located in the Northeast and Midwestern U.S. CBSAs with low sustainability and high segregation, represented by the coral color at the top right corner of the legend, are located in the Southern U.S. Looking at this data statistically provides further evidence of the inverse relationship. If index values are designated high or low based on being greater or less than the U.S. median, then 64 % of the CBSAs fit in the high-low or low-high category. Of these CBSAs, 14 % are in the bottom quartile for sustainability and top quartile for segregation (low-high designation).

4. Discussion

The rapid growth of urban landscapes has led to an understandable focus on improving sustainability, particularly within the environmental dimension. While this growth continues, a notable shift in patterns of development has brought an increased awareness of the social dimension of sustainability. This attention stems from persistent, or worsening inequalities among segments of the population and between neighborhoods. Improved environmental conditions in urban cores and industrial sites have renewed the vitality of downtowns and formerly lower-income neighborhoods, drawing many residents back to live, shop, and recreate in these spaces (Albro, 2019; Koh, 2018; Zidar, Belliveau-Nance, Cucchi, Denk, & Kricun, 2017). Given the increases in social, economic and environmental measures, it would seem that urban revitalization is an excellent solution to the problems associated with growth, and revitalization initiatives are often pitched this way. Missing from this analysis, however, is a broader accounting of the inequalities that exist within most cities. Following site clean-up, the environmental burden will likely fall on the shoulders of the same marginalized population and inequalities will persist, though with a new spatial pattern (Hochstenbach & Musterd, 2018). Capturing this pattern requires either in-depth qualitative studies or an adequate scale of analysis.

The need to address inequality as a component driving sustainability and well-being outcomes is becoming more prevalent in the literature along with the recognition that better methods and data are required to capture social structures and neighborhood inequalities (Sampson, 2017). There is mounting evidence that spatial inequalities in

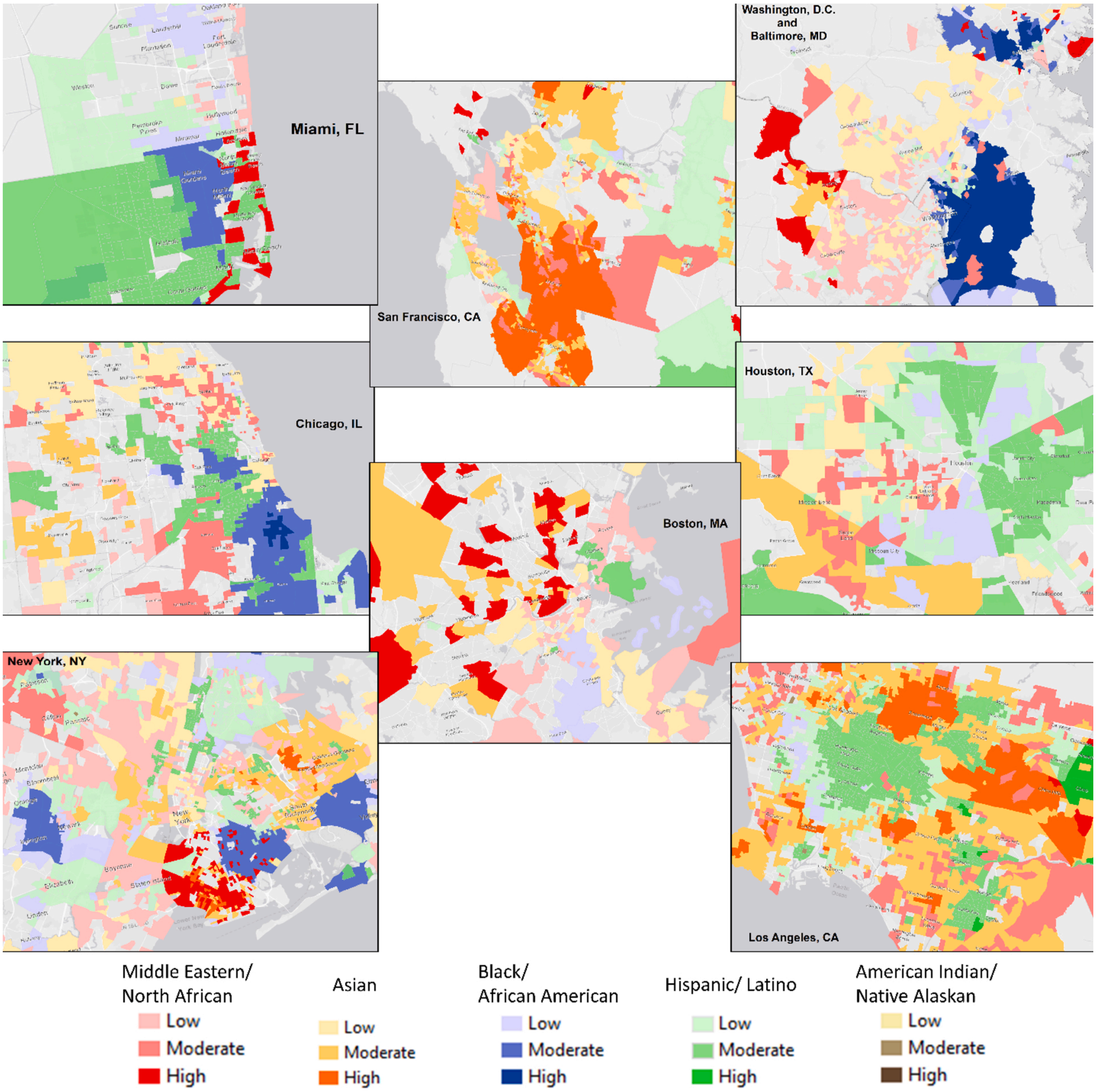

Fig. 3. Census tract segregation in 9 major U.S. cities (Miami, FL, Chicago, IL, New York, NY, San Francisco, CA, Boston, MA, Washington, DC, Baltimore, MD, Houston, TX, and Los Angeles, CA).

socioeconomic characteristics correspond to negative consequences for disadvantaged populations. This is the result of multidimensional processes, from poverty to racism and stigmatization, that align with certain neighborhoods (Jargowski, 2009; Sisson, 2020). These processes can be exacerbated through rapid neighborhood change, such as through revitalization projects. Previous research has shown clearly that improving the environmental and built amenities can change the spatial patterning and associations of neighborhoods (Checker, 2011; Goodling et al., 2015; Sumka, 2017). When neighborhoods are revitalized, more often than not they will contain different residents. Those who are being displaced to another location will suffer the same well-being outcomes as before, just in a new place (Sumka, 2017). It has become clear, based on mounting evidence, that initiatives meant to improve sustainability through urban revitalization do not benefit current residents in any meaningful way. It is far more likely that they are harmed by these actions. In order to address this, it is imperative that urban sustainability measures must incorporate measures of inequality at appropriate scales to better capture the impacts. As consistent evidence mounts, perhaps more care will be taken to protect the current residents and promote neighborhood diversity without displacement.

In the US, racial and ethnic inequalities are a central feature of most urban areas (Wachsmuth, Cohen, & Angelo, 2016). Incorporating them as a component of sustainability is important to track progress but does not effectively reveal the impacts they have on the current outcome. There is an urgent need in the US to quantify these impacts in a meaningful way. The results presented here represent a step in that direction and are intended to broadly quantify the relationship between racial/ethnic inequalities and the dimensions of sustainability. While regional patterns exist, the evidence clearly reveals a relationship that places the environmental dimension in opposition to the other dimensions. This, along with the positive correlation between the environmental dimension and segregation, should raise some red flags regarding current practices to improve sustainability.

Urban revitalization and gentrification are discussed here because of their link to sustainability initiatives and the historic focus on the environmental dimension. Efforts to revitalize disinvested areas operate

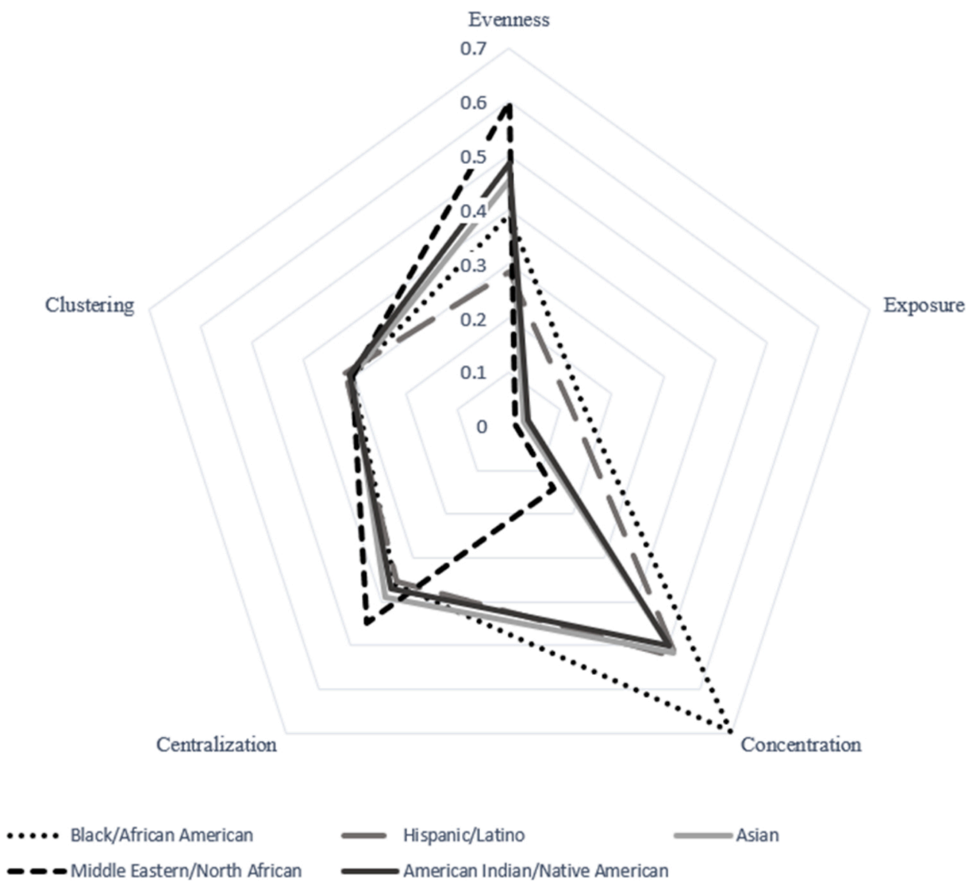

Fig. 4. Radar graph showing the five minority groups index scores across the social dimensions of segregation.

Table 3
Pearson's R Correlation results. Overall index scores and dimensions of sustainability (economic, social, and environmental) compared to overall index score for segregation across all U.S. CBSAs in 2017 (n = 933, α = 0.05).

	Econ Sustain	Social Sustain	Env. Sustain	Sustainability
Econ. Sustain				
Social Sustain	0.410258743			
Env. Sustain	−0.092159922	−0.220960872		
Sustainability	0.797524348	0.7483875	0.212283444	
Segregation	−0.193499216	−0.651390792	0.278298034	−0.390477667

with the assumption that improvements in infrastructure, both built and natural, will carry over to the social and economic environments. Revitalization efforts in urban cores, often touting mixed land use and affordable housing options, have indeed brought residents and activities back to many downtown areas. They have also broken up social networks and community ties essential to the residents living there. Disruption of social networks and access to services can result from even a small shift if the population lacks resources and transportation. Therefore, using a segregation index that accounts for social drivers is essential. Isolation and systematic displacement of people leads to negative outcomes that are difficult to overcome. According to most research, poorer urban residents are being displaced to the fringes of cities and ending up in areas lacking resources (Anguelovski et al., 2018; Bostic & Martin, 2003). If this is the case, there may be a small increase in diversity near revitalization projects, but the patterns of segregation will simply shift to new, similarly disinvested areas surrounding the city. Looking for these changing patterns of segregation, along with assessing the comparative sustainability of these urban complexes, will potentially reveal a connection between urban green infrastructure projects and the resulting population shifts that influence overall sustainability.

As with any research conducted using secondary, aggregated data, the topic of modifiable aerial unit problem (MAUP) must be considered (Wong, 1997). Within both indices, using tracts, counties and CBSAs as a base can lead to issues with aggregation, where significant error may be introduced as groups become more heterogeneous with increasing unit sizes. Averaging index values to the CBSA could exacerbate this as well. Census tracts were originally created to be as homogenous as possible. However, as populations shift and new units are created, the boundaries become less meaningful in the social setting. The zoning effect is also of concern when political lines are drawn for aggregation. The boundaries of aggregation can become arbitrary as they are redrawn over time and for different purposes. A final concern somewhat related to MAUP is the representative size of aggregate areas for each group. This becomes important when looking at tract map showing segregation. The AIAN group, despite a small overall population, stands out as a result of the tract size. Since tract boundaries are related to population, sparsely populated tracts will be larger spatially. While the segregation in these tracts is significant, the population represented by this area is not nearly as large.

While the segregation index has several identified weaknesses, this

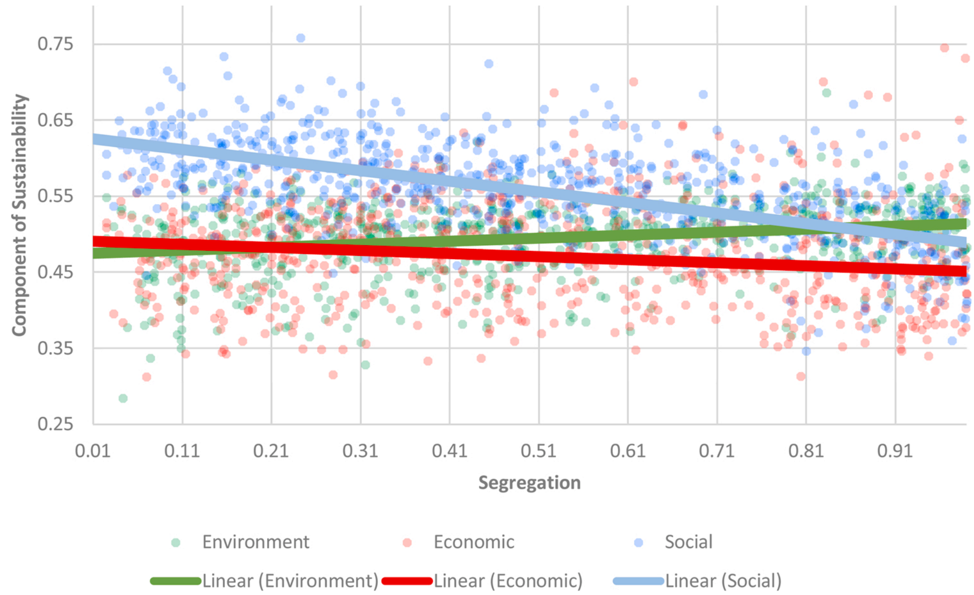

Fig. 5. Scatterplot graph showing the relationship between dimensions of sustainability and segregation. Trend lines included to make the relationship clearer.

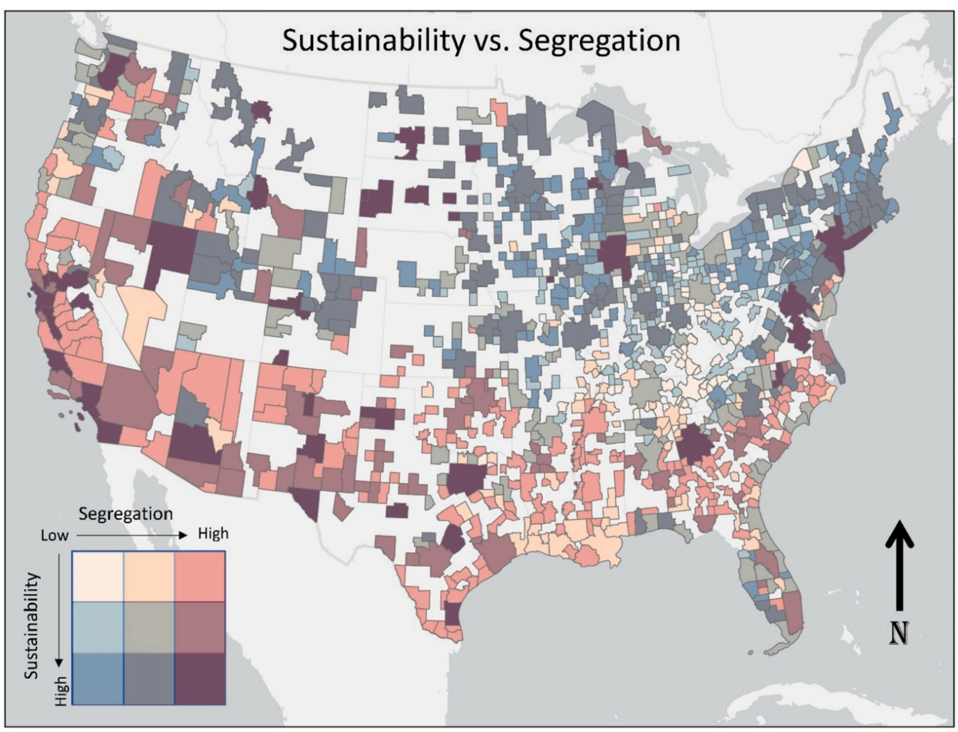

Fig. 6. Bivariate choropleth map displaying segregation and sustainability index values for all US CBSAs. Sustainability scores are shown in blue with darker shades representing higher values. Segregation scores are shown in red with darker shades representing higher values.

research is the first to expand the segregation concept to all areas of the US and compare with measures of urban sustainability. Increasing the spatial extent permits inclusion of suburban, exurban, and rural areas, which play an integral role in sustainability outcomes (Lichter, Parisi, Taquino, & Grice, 2010; Lichter, 2012). Providing a consistent method for analysis across all cross-sections of the U.S. will aid greatly in future conversations about integration and resource distribution. In addition, as data is collected over time, changes in segregation patterning may reveal important insights into how the shift of burdens changes for marginalized populations.

5. Conclusion

Displacement of populations in revitalized urban areas is likely a critical element in sustainability outcomes. Evidence presented here suggests that an inverse relationship exists between the environmental dimension of sustainability and the socio-economic dimensions. Along with this, neighborhood segregation levels appear to have a negative correlation with the sustainability more broadly. Whether the social impacts of displacement or some other processes are causing this relationship is still not clear. However, these results indicate a need for further research to look at temporal patterns of sustainability and segregation in conjunction with changing urban landscapes. Considering the implicit powerlessness of the displaced groups and the fragmenting of social support networks, there is undoubtedly a negative impact on the social and psychological well-being among these populations that may be related to improvements in urban areas. Making a clear connection between the deleterious effect on displaced minority populations and the actions in urban areas meant to improve environmental and economic sustainability is imperative to understanding and improving the social outcomes for all members of the community. It is also critical to understand the significance of the social impact on urban systems in their entirety. Continued change should bring about greater sustainability and an equitable distribution of benefits.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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