Equitable Transportation Community Explorer (ETCE)

ETCE Technical Documentation

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Glossary and Acronyms

Acronym	Definition
ACS	American Community Survey
BTS	Bureau of Transportation Statistics
CDC	Centers for Disease Control and Prevention
CES	Consumer Expenditure Survey
CMRA	Climate Mapping for Resilience and Adaptation
DHS	Department of Homeland Security
DOI	Department of the Interior
DOL	Department of Labor
USDOT	United States Department of Transportation
EJI	Environmental Justice Index
EJScreen	Environmental Justice Screening Tool
EPA	U.S. Environmental Protection Agency
ETCE	Equitable Transportation Community Explorer
EVI	Environmental Vulnerability Index
FARS	Fatality Analysis Reporting System
FEMA	Federal Emergency Management Agency
FRS	Facility Registry Service
FRS	Federal Reporting System
FTA	Federal Transit Administration
GIS	Geographic Information System
HIFLD	Homeland Infrastructure Foundation-Level Data
HPMS	Highway Performance Monitoring System
HUC12	Hydrologic Unit Code 12
IPCC	Intergovernmental Panel on Climate Change
MCDA	Multi-Criteria Decision Analysis
MRLC	Multi-Resolution Land Characteristics
NCDP	National Center for Disaster Preparedness
NHRI	Natural Hazard Risk Index

Acronym	Definition
NHTSA	National Highway Traffic Safety Administration
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NTD	National Transit Database
PLACES	Population Level Analysis and Community Estimates
PM	Particulate Matter
RCP	Representative Concentration Pathways
RMP	Risk Management Program
STIPs	Statewide Transportation Improvement Programs
TIGER	Topologically Integrated Geographic Encoding and Referencing
TIPS	Transportation Improvement Programs
TRI	Toxic Release Inventory
UPT	Unlinked Passenger Trips
US	United States
USD	U.S. Dollar
USGS	United States Geological Survey
UZA	Urbanized Areas
WSIO	Watershed Index Online

Introduction

In support of the Justice40 Initiative, the Department of Transportation (Department) developed the Transportation Disadvantaged Census Tracts (Historically Disadvantaged Communities) tool which the Department is currently proposing to update and rebrand as the United States Department of Transportation (USDOT) Equitable Transportation Community Explorer (ETCE). The tool is an interactive web application that explores the cumulative burden disadvantage communities experience resulting from underinvestment in transportation in the areas of- Transportation Insecurity, Climate and Disaster Risk Burden, Environmental Burden, Health Vulnerability, and Social Vulnerability. It is designed to be effective in helping increase the understanding disadvantage at the community level. The Explorer uses newly available 2020 Census Tracts and data, adds additional indicators reflective of disadvantage related to lack of transportation investment and updates the methodology used to calculate disadvantage. In the Explorer individual variables and datasets are combined to create a score for each component (Transportation Insecurity, Climate and Disaster Risk Burden, Environmental Burden, Health Vulnerability, and Social Vulnerability). This technical document provides an in-depth explanation of the data and techniques used to select the indicators and construct the indices.

Disadvantage

As set forth in Executive Order (EO) 14008 on *Tackling the Climate Crisis at Home and Abroad*, disadvantaged communities are those that are marginalized, underserved, and overburdened by pollution.[1] Disadvantaged individuals or groups may be more likely to experience negative outcomes such as unemployment, poor health, or reduced access to services and opportunities. In the context of transportation, disadvantaged individuals or communities may also experience negative impacts from transportation sources, which can impact health, or receive fewer benefits from transportation services, which can limit their ability to access jobs, healthcare, education, and other essential services.

The ETCE and ETCE Index use data and methods, including several related directly to transportation insecurity, to establish a data-driven definition of disadvantage. There are several public sector indices and data sources that support the scoring schema and variables incorporated here, including CDC's Environmental Justice Index (EJI), NOAA's Climate Mapping for Resilience and Adaptation (CMRA), and EPA's Smart Location Map; however, this index has been expanded to included specific variables that relate to transportation insecurity.[1] This tool is designed to be effective in helping increase the understanding disadvantage at the community level and target general areas that have experienced historical disadvantage or lack of transportation access.

USDOT's Commitment

USDOT has a commitment to equity in its policies and programs. This includes ensuring that all communities have access to safe and reliable transportation options. Measuring disadvantage is a USDOT priority because it is a key aspect of ensuring that all communities have access to safe and reliable transportation options and identifying and addressing any disparities in transportation access. This tool aims to highlight places where burdens are most concentrated. USDOT is committed to providing equitable, accessible, and legally compliant services to everyone in every community.

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[1] For more information, see here: CEQ-CEJST-QandA.pdf (whitehouse.gov)

[1] EJI's homepage can be accessed here for more information on the tool, including technical documentation and the index: https://www.atsdr.cdc.gov/placeandhealth/eji/index.html.

Cumulative Impacts

Cumulative impacts describe the combined result of multiple environmental, social, or economic impacts. These impacts can be positive or negative and may unfold over time, across locations, or through various activities. The combined impacts can often have a more significant effect than the sum of individual impacts.[2] This cumulative approach provides a comprehensive understanding of how various factors interact to create and sustain disadvantages for individuals or groups. By examining cumulative impacts, decision-makers can identify the communities experiencing the highest combined burdens and begin to target interventions to best benefit communities.

Index Development

USDOT has devised an updated methodology to evaluate disadvantage. This methodology employs a multi-component, cumulative burden framework and is aligned with leading practices such as those used to create EJI. The updated methodology encompasses five key components: Health Vulnerability, Environment Burden, Socioeconomic Vulnerability, Transportation Insecurity, and Hazard and Climate Risk. These components are either borrowed from existing federal indices or are newly developed using federal data sources.

Health Vulnerability assesses the susceptibility of the population to health issues, such as diabetes, asthma, cancer, and mental health challenges, as well as access to medical care. Environmental Burden measures factors that may cause negative environmental impacts, such as pollution, waste management, and land use, on the local community. Socioeconomic Vulnerability measures the extent to which the population is economically and socially vulnerable based on factors such as poverty, age, unemployment, and education. Transportation Insecurity measures the availability and affordability of transportation options and their effect on access to essential services and jobs. It also includes a measure of transportation safety. Lastly, Hazard and Climate Risk Burden measures the population's exposure to hazards and the consequences of climate change, such as natural disasters and extreme weather events.

Index Use

USDOT has created an interactive mapping tool known as the ETCE to assess the level of disadvantage of communities and project areas. This user-friendly tool displays the results of DOT's efforts to measure disadvantage, including the Final Index Score and its breakdown by five key components. ETCE allows users to easily explore the index and select census tracts for analysis, gaining insight into the distribution of individual components and burden score.

The Map Viewer feature of the dashboard offers a versatile framework with different layers including the five main components of the score and additional information. This enhances users' understanding of community level of disadvantage and reveals patterns and trends that may not be immediately noticeable. ETCE is a critical tool for USDOT, enabling it to measure disadvantage that includes dimensions of Health, Environment, Socioeconomic, Transportation, and Climate burdens.

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[2] Lee, C. (2020). A game changer in the making? Lessons from states advancing environmental justice through mapping and cumulative impact strategies. Envtl. L. Rep., 50, 10203.

Background

The Biden-Harris Administration created the Justice40 Initiative to confront and address decades of underinvestment in disadvantaged communities. The initiative will bring resources to communities most impacted by climate change, pollution, and environmental hazards.

At the USDOT, the Justice40 Initiative is an opportunity to address gaps in transportation infrastructure and public services by working toward the goal that at least 40% of the benefits from many grants, programs, and initiatives flow to disadvantaged communities.

Through the Justice40 initiative, USDOT will work to increase affordable transportation options, that connect Americans to good-paying jobs, address climate change, and improve access to resources and quality of life in communities in every state and territory in the country.

The initiative allows USDOT to identify and prioritize projects that benefit rural, suburban, tribal, and urban communities facing barriers to affordable, equitable, reliable, and safe transportation. Through Justice40, USDOT will also assess the negative impacts of transportation projects and systems on disadvantaged communities and will consider if local communities have been consulted in a meaningful way during the project's development.

Methods

Summary

USDOT's Equitable Transportation Community Explorer is an interactive web application that explores the disadvantage communities experience, resulting from underinvestment in transportation, in the areas of Transportation Insecurity, Climate and Disaster Risk Burden, Environmental Burden, Health Vulnerability, and Social Vulnerability. The index computes cumulative disadvantage by normalizing indicators associated with disadvantage, summing the percentile ranks of these indicators into components, and then summing the percentile ranks of the sums of each component to determine an overall score.

Overview of Data

The Disadvantaged Community Index, which drives the USDOT Equitable Transportation Community Explorer, is a composite measure that defines census tracts as being disadvantaged communities in the US based on several dimensions of disadvantage. The index is based on multiple publicly available government data sources that include variables such as the percent of households with no car, average commute time, walkability index, frequency of transit services per square mile, jobs within a 45-minute drive, calculated average annual cost of transportation as a percent of household income, traffic fatalities, and air quality indicators like ozone and particulate matter 2.5 ($PM_{2.5}$) levels.

The index also considers socioeconomic indicators, such as poverty level, education, employment, housing, health, language proficiency, and age demographics, as well as data on disaster risk, climate change, and land use, such as estimated annualized loss due to disasters, increase in number of hot days, change in precipitation patterns, risk of coastal flooding, and impervious surface area. The aim of the index is to define disadvantaged communities in the US using multiple dimensions of disadvantage including transportation insecurity, social vulnerability, health vulnerability, environmental burden and climate and disaster risk burden.

The compilation of the index involved integrating data from various sources, which differ in format, type, source, completeness, units of measurement, and spatial and temporal resolution. To address these challenges, USDOT has created a system for harmonizing and standardizing these datasets. The system includes careful consideration of time and space misalignment between different datasets, as well as variable normalization, to ensure that the index provides a comprehensive definition of disadvantaged communities in the US.

Census Tract Adjustments

The updated index was constructed using the latest available data, including 2015-2020 American Community Survey (ACS) 5-year estimates and Census Tracts drawn after the 2020 Census. The 2020 Census increased the total number of tracts by more than 12,000 (an increase of more than 15%) and redrew many others. For datasets not yet available in 2020 Tracts, for example the Centers for Disease Control and Prevention (CDC) Population Level Analysis and Community Estimates (PLACES), the team scaled data from 2010 to 2020 tracts using a relationship file provided by the U.S. Census Bureau that showed which 2010 tract(s) corresponded to which 2020 tract(s). In cases where Census Tracts were combined, the percentage of the area from 2010 to 2020 was used to calculate a weighted average of the values at 2010 tract level to the 2020 tract. For example, if two tracts in 2010 make up one in 2020, but one makes up 99.8% of the area in 2020, each raw data point in the 2010 dataset was averaged but weighted according to the percent per tract. In the more common case where a 2010 tract was split into multiple tracts in 2020, the raw data values per variable were assigned to each corresponding 2020 tract.

The data used in this index comes from the raw Topologically Integrated Geographic Encoding and Referencing (TIGER)/Line with Selected Demographic and Economic Data Census Tract boundaries from 2020.[3] However, the dashboard displays the view of the 1:500,000 *scaled* version. This was done to enhance usability and reduce load times. These tracts are substantially similar to standard Census Tracts; however, are simplified and so may have small differences than standard tracts when viewed at a local level.

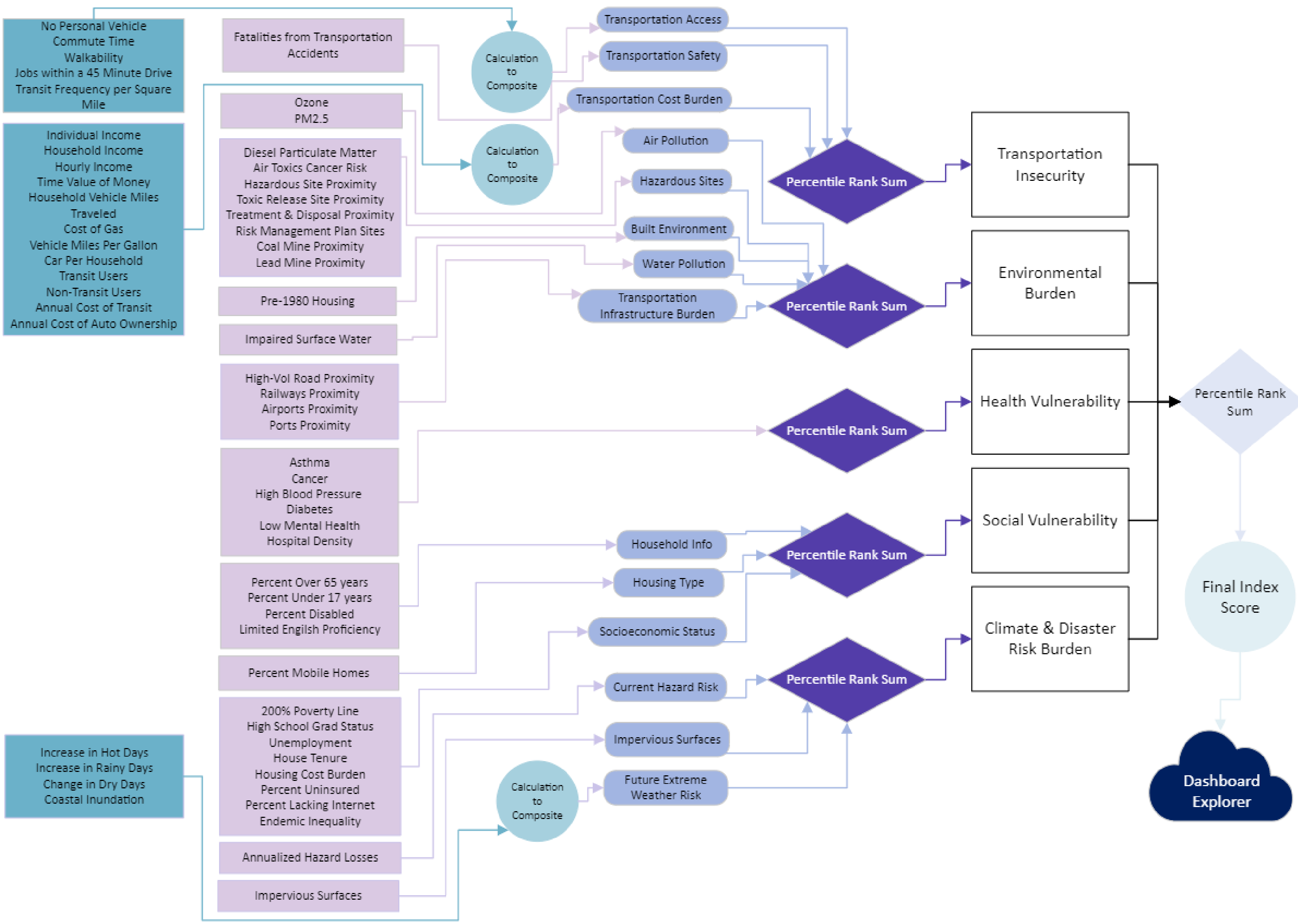
Model

The model used to create the overall score is displayed in *Figure 1*. The model takes all the individual indicators and creates subcomponent indicators to clarify the main variables key to understanding disadvantage. In components with composite indicators, the variables of interest are normalized and summed to create a composite, which is used the same as a category or subcomponent indicator. The subcomponents are added, and normalized, to create the component score. The components are then percentile ranked, and each census tract receives a score for each component. The component scores are then added together, and percentile ranked to create the final disadvantage score for each tract. The final score is displayed in the index and dashboard as a percentile rank, for easy visualization.

For example, "No Personal Vehicle" is an indicator within a composite score. The raw data is taken and min-max normalized, and then summed with the other min-max normalized variables within the composite. The composite is percentile ranked, then added to the other sub-components within Transportation Insecurity. That sum is percentile ranked once more to assign census tracts a component score for Transportation Insecurity. The component score is added to the other component scores, and the sum is percentile ranked once more, giving the tract a final index score, which is displayed in the dashboard. For variables not included in a composite, like "Asthma", the raw data is min-max normalized, added to the other health components, and the sum is percentile ranked to create the Health Vulnerability component score, where the method proceeds as described above.

[3] https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-data.html

Figure 1. Graphical Representation of Model



Scoring

USDOT employs a comprehensive approach to defining disadvantage, which involves standardizing the data through normalization. The chosen normalization method is min-max scaling, transforming data into a standard range, 0 to 1, to enable a comparison and eliminate the effect of different units of measurement. The five components — Transportation Insecurity, Health Vulnerability, Environmental Burden, Social Vulnerability, and Climate and Disaster Risk Burden — are comprised by summing the ranked normalized variables for each component. The result is a composite score that succinctly summarizes the data for each component.

USDOT then leverages percentile ranking to determine each Component Score. This statistical approach assigns a ranking, expressed as a percentile with 0 percentile as the lowest and 100th percentile as the highest value, to each data point in a dataset based on its relative position compared to other data points. This ranking allows USDOT to gauge the relative performance of each component's composite score with respect to other components at the tract level. Summing up the ranked Component Scores results in the final composite score, which summarizes the overall data across all components. And finally, USDOT calculates the Final Index Score via percentile ranking on the final composite score, thus determining how the overall score of a given census tract compares to that of the other census tract and overall. This methodology enables USDOT to define disadvantage on multiple dimensions.

This methodologyoffers a deeper insight into the interactions between different factors that contribute to disadvantage. By combining min-max scaling and percentile ranking, USDOT is able to standardize the data and assign a relative position to each location for each component. Census tracts are defined as “burdened" or “disadvantaged” in communities with a Final Index Score greater than 0.65 (65th percentile). We also define communities as “burdened" in a component if their component-specific percentile score is greater than 0.65 (65th percentile) in that area.

Selection

Variables were selected for inclusion in the Index based on several criteria: 1) they had data that was regularly updated and available across all or most of the country, 2) they were part of the CDC Environmental Justice Index (EJI), or another widely used federal data source (e.g., the National Risk Index), 3) they represented a phenomenon critical to assessing transportation insecurity (e.g., transit frequency, transportation safety, or transportation cost burden), and/or 4) the variable enhanced our understanding of disadvantage (e.g., climate change estimates).

In the data selection process for the index, a comprehensive approach was taken to ensure the validity and significance of each indicator. The multi-step process for identifying problematic variables in a spatial Multi-Criteria Decision Analysis (MCDA) began by examining the variables based on various factors such as skew, variance, missingness, and modality. Skew was assessed to understand the representation of high or low values in the variable and determine if it was unbalanced. Variance was evaluated to determine the distribution of the variable and if it was centered around one value. Missingness was considered to understand the number of census tracts with missing values for the variable. Modality was evaluated to determine the number of peaks in the variable.

The next step involved comparisons of variables based on correlation and Principal Component Analysis/Factor Analysis. Collinearity was checked to remove variables that displayed it, as it violates the main assumption of a standard "good" model. Correlation was used to understand the relationship between the variables and determine if they measure similar things. Principal Component Analysis and Factor Analysis were used to determine the contribution of some variables to the final score.

Finally, maps were created to understand spatial variation and regional patterns. Clustering and hotspots were used to determine if the variable logically congregated around certain regions. Rural vs. urban patterns were used to understand if the variable followed patterns of urban sprawl. State-level patterns were used to determine if the variable had decent variation for each state. This process helped identify problematic variables and a qualitative discussion by experts was then held to determine if these variables should be included or excluded from the MCDA.

Data

The following sections provide an in-depth examination of the five components that make up the index. The aim is to give a comprehensive overview of the data used to create the index. The sections are organized by component and further categorized into groups of variables. The categories serve to illustrate the thought process behind the index, and within each category, the reasoning for each indicator's inclusion is explained. The index contains raw data for each indicator, unless stated as a "calculation" indicator, which is a composite score derived from the indicators within. The categories are provided for easier reading and to highlight the types of disadvantages captured by the index and displayed in the dashboard. The component breakdown, including data sources and years, as well as the geography of the raw data and analysis done for each indicator are displayed in the tables found in Appendix 1.

Transportation Insecurity

The Transportation Insecurity component of the index is comprised of three measures, two composite measures, Transportation Cost Burden and Transportation Access, and one standard measure of Transportation Safety. USDOT utilizes data from multiple sources such as the Census Bureau, the DOT, the Environmental Protection Agency (EPA), and the Bureau of Labor Statistics, to measure transportation access in disadvantaged communities.

The Transportation Cost Burden and Transportation Access Burden are calculated by combining multiple factors that provide a representation of the transportation situation. The data is analyzed and transformed into a composite score for each indicator. In the final index, each indicator is presented as a single, distinct measure. For more information about the specific indicators used to measure Transportation Insecurity, please refer to *Table 3*.

Transportation Insecurity – Transportation Access

The Transportation Access composite variable, incorporates automobile prevalence, average commute time, walkability, and access to jobs, services, and transit, measures the level of access that communities have to transportation options. This indicator is calculated by combining data from the Census Bureau (on commute time and vehicle ownership), U.S. EPA Smart Location Database (on walkability, jobs within a 45-minute drive, and transit frequency per square mile), and provides a view of transportation challenges faced by communities and their impact on well-being and opportunities. Long commute times and limited access to personal vehicles can create significant barriers to employment, while high walkability and frequent public transit options can provide greater access to employment and resources.

Indicator: No Personal Vehicle

This indicator measures the percent of households that do not have access to a personal vehicle. The lack of access to personal transportation can restrict access to employment, healthcare, education, and other essential activities, negatively impacting the overall quality of life. This is particularly true in rural areas, where public transportation may be limited or unavailable.

Indicator: Average Commute Time to Work This indicator quantifies how long people spend on average traveling to work. The longer the commute, the greater the financial burden on workers. Longer commutes can result in higher transportation costs, a lower quality of life, and less time for leisure, family, and personal pursuits. This has the potential to exacerbate economic disparities in low-income households and communities. Longer commutes have been linked to higher levels of stress and health concerns, according to research.[4]

Indicator: Walkability

This indicator measures transportation insecurity, reflecting the degree to which an area is pedestrian-friendly and accessible by foot. According to the U.S. CDC, a community's walkability has grown to be a crucial consideration in research on how the built environment affects health.[5] The term "walkability" refers to the security and appeal of walking routes. Walkability indicators, also included in the EPA's National Walkability Index, such as street connectivity, transit stop density, and land use mix, have a positive impact on accessibility for older adults and people with disabilities. Furthermore, researchers have also found that increased walkability can reduce automobile dependence and improve overall health and well-being.[6] This measure is taken as the inverse of walkability, to trigger disadvantage where census tracts are less walkable.

Indicator: Peak Transit Frequency per Square Mile

This variable measures the number of transit options available in a specific area during peak transit times, quantified by the frequency of transit services offered per square mile (sourced from the EPA Smart Location Database, General Transit Feed Specification). The availability of transit options can greatly impact the quality of life for residents in a specific area. A well-developed transit system can provide access to jobs and can also improve mobility. On the other hand, a lack of transit options can lead to limited access to opportunities and exacerbate transportation insecurity. The frequency of transit services per square mile is therefore an important metric to consider when evaluating the overall transportation landscape of a specific area and identifying areas that may need improvement. This measure is taken as the inverse of peak transit frequency, to trigger disadvantage where census tracts have less frequent transit available.

Indicator: Jobs Within a 45-Minute Drive

This variable measures the availability of job opportunities within a 45-minute drive from a given location. This measure of time to jobs is considered a crucial factor in determining accessibility to employment and overall economic well-being of a community.[7] The number of jobs within a 45-minute drive is an indicator of the ease of access to employment, which can influence career opportunities, income, and overall quality of life. This measure is taken as the inverse of the data, to trigger disadvantage where census tracts have less jobs within a 45-minute drive.

Indicator: Transportation Access – Calculation

The Transportation Access Indicator evaluates transportation options such as personal vehicle, transit, and active mobility. It measures the following indicators: absence of personal vehicle, average commute time to

[4] McMillan, G., & Hwang, S. (2015). The health effects of commuting: A systematic review of the literature. Social Science & Medicine, 125, 1-14. https://doi.org/10.1016/j.socscimed.2014.07.054

[5] US Centers for Disease Control and Prevention. (n.d.). Walkability and community design. Retrieved from https://www.cdc.gov/physicalactivity/walking/walkable-communities/index.html

[6] Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., & Conway, T. L. (2010). The development of a walkability index: Application to the neighborhood quality of life study. Social Science & Medicine, 70(11), 1703-1710. https://doi.org/10.1016/j.socscimed.2010.02.015

[7] Krieger, J., Zabel, J., & Kaza, N. (2012). Automobility, urban form, and health inequities: A critical review. Journal of Planning Literature, 27(2), 121-138. https://doi.org/10.1177/0885412211432410

work, walkability, transit frequency per square mile, and job access within a 45-minute drive. These indicators are normalized, summed, and percentile ranked to create a sub-component score for Transportation Access Burden. Higher scores (closer to 1) indicate greater transportation access burden, while lower scores (closer to 0) indicate lower transportation access burden.

Transportation Insecurity – Transportation Cost

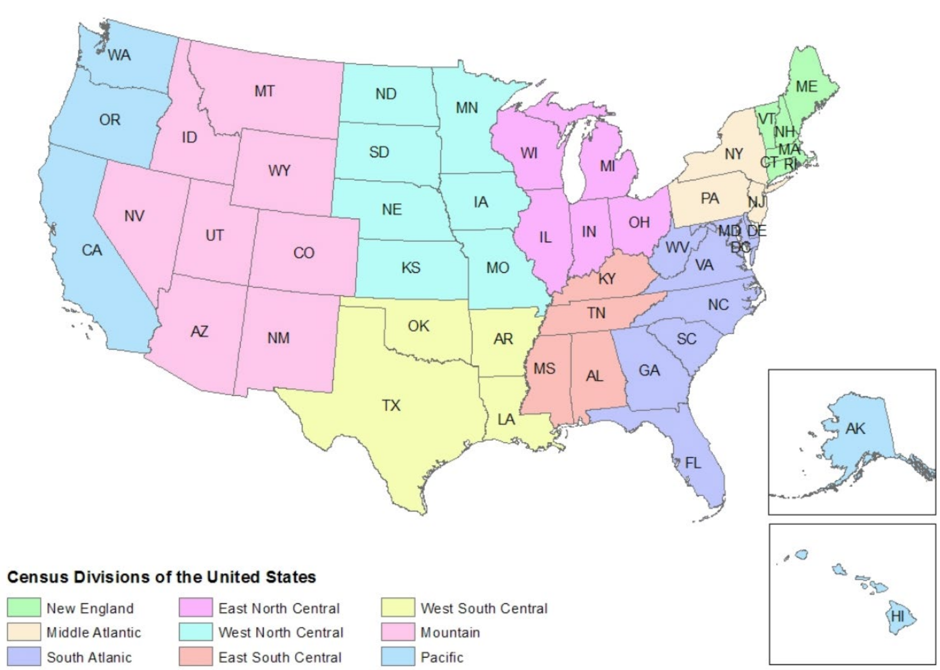
Transportation Cost Burden measures the cost of transportation relative to the respective options and median area income. This variable is included in the index measuring disadvantage as it is an indicator of transportation insecurity. It reflects the cost of transportation as a percentage of household income.

Indicator: Transportation Cost Burden – Calculation

A component of Justice 40 Disadvantaged Communities Index is identifying communities with a high transportation cost burden. This means communities whose transportation costs are high relative to their median income. The transportation costs are derived by calculating the primary costs associated with a household means of transportation: auto costs, transit cost, and commuting time costs. The methods used for calculating these costs are explained in the following sections.

The costs of owning and operating an auto can differ in areas around the country. Basic overhead, or fixed costs, for vehicles such as insurance, maintenance, financing, and the price of new or used vehicles can vary across the country. To capture these differences, the fixed auto costs are taken from the annual Consumer Expenditure Survey (CES).[8] This survey provides specific costs that are attributable to auto ownership and operations. This data is collected at the Census Division geographic level, shown in Figure 1. Census Divisions, and reflects the differences in pricing that may be caused by local regulations, logistics issues, and other supply and demand considerations.

Figure 2. Census Divisions



[8] The Consumer Expenditure Survey data can be found here: https://www.bls.gov/cex/tables/geographic/mean/cu-division-2-year-average-2021.pdf

The CES quantifies the average annual expenditure of "consumer units" for various vehicle related costs. The survey's methodology defines a "consumer unit" as:

- *All members of a particular household who are related by blood, marriage, adoption, or other legal arrangements;*
- *A person living alone or sharing a household with others or living as a roomer in a private home or lodging house or in permanent living quarters in a hotel or motel, but who is financially independent; or,*
- *two or more persons living together who use their income to make joint expenditure decisions.*

For the purposes of calculating the auto costs, it is assumed that a "Consumer Unit" is equal to a Census household. Therefore, auto costs represented in the CES are assumed to be per household averages for the various auto related costs. The costs are broken down into three main groups, vehicle costs, gas and fuel costs, and other vehicle costs. *Table 1* shows the captured transportation costs in the CES.

Table 1. CES Transportation Costs

Total Transportation Cost		
	Vehicle Purchases (net outlay)	
		New Cars and Trucks
		Used Cars and Trucks
		Other Vehicles
	Other Vehicle Expenses	
		Vehicle Finance Charges
		Maintenance and repairs
		Vehicle Rental, leases licenses, and other charges
		Vehicle Insurance
	Public and other transportation[9]	

Based on these categories, the summation of vehicle purchases, and other vehicle expenses are used as representative costs per household for auto ownership "fixed costs."

The variable cost, gasoline and fuel, are calculated using the average state gasoline prices, average miles per gallon, and average household vehicle miles traveled. The total cost of autos is displayed in *Equation 1*.

[9] See methodology for calculating transit costs.

Equation 1. Total Cost of Autos

CES Vehicle Purchases + CES Other Fixed Vehicle Expenses + (Gallon of Gas Prices X Mile per Gallon X Household VMT)

One cost that all commuters incur is the "lost" time due to traveling to and from work. Although this travel is considered a necessity, it is still a loss of valuable time that could be used doing something else. In some instances, travel time may exhibit lifestyle choice such as wealthier commuters trading longer commute times for quality-of-life issues. For this reason, this metric should not be directly comparable without context.

USDOT has assessed a standardized value of time for transportation based on trip purpose within their Benefit Cost Analysis Guidance.[10] The value of time depends on the type of purpose for traveling. For instance, leisure and business travel often have very different values. For more a more generalized use, the USDOT has assessed a standardized value of time for transportation by trip purpose. These values are displayed in *Table 2*.

Table 2. Standardized Value of Time for Transportation by Trip Purpose

Purpose	***Value of Time***
Personal	$17.00
Business	$31.90
All Purposes	$18.80
Walking, Cycling, Waiting, Standing, and Transfer Time	$34.00

To calculate the time value of commuters, the average daily commute time, which is expressed in minutes, is converted to annual hourly commute time then multiplied by the USDOT Value of time for personal travel. This is then normalized by households to estimate the travel time per household costs, as shown in *Equation 2*.

Equation 2. Time Value of Commuters

$$\frac{((Tract\ Average\ Daily\ Commute\ Time\ X\ 50\ X\ 5)/60)\ X\ USDOT\ Value\ of\ Time}{Tract\ Households}$$

This methodology does not factor in reliability or time loss due to waiting due for late, early, or slow transit. Nor does this methodology account for congestion and traffic issues for commuters who drive. However, it assumes that these issues are intrinsic to the total commute times reported in the Census.

[10] The Benefit Cost Analysis Guidance can be found here: https://www.transportation.gov/sites/dot.gov/files/2023-01/Benefit%20Cost%20Analysis%20Guidance%202023%20Update.pdf.

Unlike auto costs, national transit costs are more diverse in terms of regional availability and transit system pricing mechanisms. More locally, transit costs often rely on proximity to major destinations such as urban cores, the type of mode being used (commuter train, bus, light rail, ferry, or other), passenger frequency (monthly or weekly ticket discounts and peak and off-peak pricing), and passenger attributes (senior and student discounts).

As Table 1 shows, the CES contains an expense component that captures public transportation. However, the public transportation expenses are not exclusively provided but rather grouped with other transportation expenses. The largest of these other expenses is air transportation. For this reason, using the CES public and other transportation expenses would not provide a realistic cost for transit.

Instead, the approach utilizes the Federal Transit Administration's (FTA) National Transit Database (NTD). This database collects financial and operational data from transit providers across the country. Using this database, the passenger and operational revenues from transit agencies in designated Census Urbanized Areas (UZA) will be used. These revenues will be set against their respective UZA unlinked passenger trips (UPTs). Unlinked passenger trips are essentially boarding passengers on a bus, train, ferry, or other mode of transit. Unlinked trips are measured by counting the number of times a passenger boards a vehicle, no matter how many vehicles they use to travel from their origin to their destination. The product of the passenger and operational revenues and UPT is the average trip cost for the UZA.

Although this method yielded UPT prices that were consistent, some UZAs exhibited abnormally high or low prices. In these cases, the UPT price was constrained. The price constraint was one half of the standard deviation above or below the median UPT price. If a UPT price broke the threshold, it was assumed the revenue or UPT levels were faulty, and the national mean price was used instead.
The UZA geographies are combined with Census tracts to define areas that have access to transit systems.[11] Although all the UZAs were assigned to tracts, only UZAs that are accounted for in the NTD are used. Areas outside of the UZAs not reporting transit use a national mean.

To estimate the amount of household spending on transit, the average cost of per UPT was annualized, then doubled as most people using public transportation take two trips per day (one to a destination in the morning and one home in late afternoon or evening), as shown in *Equation 3*.[12] The annualized UPT cost was then applied to the number of transit commuters in each tract. The product was then divided by the total number of households in the tract to provide a per household transit spending estimate, as shown in *Equation 4*.

Equation 3. UZA Cost per Unlinked Passenger Trip

$$UZA\ Cost\ per\ Unlinked\ Passenger\ Trip = \frac{UZA\ Passenger\ and\ Operational\ Revenue}{UZA\ Unlinked\ Passenger\ Trips}$$

From this estimate, the tract level transit commuters were applied.

[11] This assumption also accounts for passengers who may drive to rail, bus, or other transit stations within the UZA.
[12] This assumption is derived from work done at the following: https://www.bts.dot.gov/learn-about-bts-and-our-work/statistical-methods-and-policies/public-transit-ridership/

Equation 4. Transit Spending per Household

$$Transit\ Spending\ per\ Household = \frac{UZA\ Cost\ per\ Unlinked\ Passenger\ Trip\ X\ Tract\ Transit\ Commuter}{Tract\ Households}$$

This approach assumes that transit use is present in tracts that have transit users. It also assumes a uniformity in transit pricing and use across the UZA area. As data on all transit users in a tract is not collected, transit commuters were used as a proxy to measure transit use in a tract, as the most consistent data is gathered on them.

Therefore, the total transportation cost burden is reflected in Equation 5.

Equation 5. Transportation Cost Burden

$$Transportation\ Cost\ Burden = \frac{Auto\ Cost\ Per\ Household + Travel\ Time\ Per\ Household + Transit\ Spending\ per\ Household}{Average\ Household\ Income}$$

Transportation Insecurity – Transportation Safety:

Measuring transportation safety is crucial in understanding access It highlights areas that are disadvantaged due to unsafe conditions and identifies regions with high crash rates, which can be improved through additional or improved infrastructure and safety measures.

Indicator: Transportation-Related Fatalities

This indicator measures the number of fatalities per capita (per 100,000 persons) that occur in transportation-related crashes as recorded by the Fatality Analysis Reporting System (FARS), within the National Highway Traffic Safety Administration (NHTSA). The number of traffic fatalities were acquired at the county level and divided by ACS county population to derive traffic fatality rates per 100,000 persons. This indicator provides valuable insight into the level of traffic safety in each community and can be used to identify areas with higher rates of transportation-related fatalities.

Environmental Burden

The Environmental Burden component of the index includes variables measuring factors such as the built environment, pollution, and hazardous facility exposure to define disadvantaged communities. This is accomplished through the measurement of aspects of transportation infrastructure burden and other relevant factors. These environmental burdens can have far-reaching consequences such as health disparities, negative educational outcomes, and economic hardship. The Environmental Burden indicators are calculated using data from EPA’s Environmental Justice Screening Tool (EJScreen) 2022. More detail on the indicators can be found in *Table 4*.

Environmental Burden – Air Pollution

Air pollution is a common factor in communities facing environmental inequities, and it has been linked to multiple health disparities. People living in areas with high air pollution levels are more likely to suffer from asthma, cancer, and other diseases, which can adversely affect their quality of life.[13] Furthermore, air pollution is often linked to poverty and other social disadvantages, as those in lower socio-economic classes are more likely to live in areas with poor air quality.[14]

Indicator: Ozone Level

The Ozone Level Indicator measures the concentration of ozone in the air. Exposure to high levels of ozone can lead to negative health outcomes, including increased risk of respiratory and cardiovascular disease.[15] Both short-term and long-term exposure can contribute to air pollution-related illnesses and death.[16] Ozone is generated from human activities such as the burning of fossil fuels and chemical reactions in the atmosphere. Transportation activities contribute to this factor by releasing compounds that interact to create ozone.[17]

Indicator: PM 2.5 Level

The PM 2.5 Level indicator quantifies the presence of fine PM having a diameter of 2.5 micrometers or less in the air. Exposure to high levels of PM 2.5 may cause irritation of the eyes, nose, throat, and lungs, as well as an increased risk of acute cardiovascular events. Long-term exposure has been associated to increased death rates from a variety of diseases, including cancer and cardiovascular disease.[18] Among the causes of exposure to PM 2.5 are vehicle emissions and industrial activities, meaning areas with high levels of PM 2.5 may also be experiencing other types of disadvantages.

Environmental Burden – Hazardous Sites

This category of variables considers the number of hazardous sites near communities that may negatively impact human health. These variables are included in the index measuring disadvantage as they are indicators of environmental burden, potentially posing a risk to the health and well-being of residents.

Point data was retrieved for non-abandoned coal mines and non-abandoned lead mines locations from the Mine Safety Administration. A 1-mile buffer was created around each site, following the EJI methodology.[19] Census tracts were intersected with the buffered area and the intersecting area was calculated, in square miles. The table of calculated areas was joined with Census tracts by Gravity for Earth, Ocean, and Ice Dynamics (GEOID) and the percent of tract, calculated as the intersection area divided by census tract area multiplied by 100, was appended to the table.

Point data was also retrieved for Hazardous Sites, Toxics Release Sites, Treatment, Storage and Disposal sites, and Risk Management Plan Sites from the EPA FRS (Facility Registry Service). The process of creating buffers, finding intersections with Census tracts, and calculating the percent of area for each site was followed.

The team used a 1-mile buffer for all hazardous site indicators, including: Hazardous Sites, Toxics Release Sites, Risk Management Program Sites, Treatment and Disposal Facilities Sites, Coal Mines, Lead Mines. The 1-mile

[13] Anderson, G. B., Bell, M. L., Matsumura, L., Smith, K. R., & Wheeler, A. J. (2017). Exposure to fine particulate air pollution and mortality: An analysis of 20 years of data from the Nurses' Health Study. Environmental Health Perspectives, 125(2), 126-133. https://doi.org/10.1289/ehp.1408508

[14] Rauh, V.A., Landrigan, P.J. and Claudio, L., 2008. Housing and health: intersection of poverty and environmental exposures. Annals of the New York Academy of Sciences, 1136(1), pp.276-288.

[15] Devlin, R.B., Duncan, K.E., Jardim, M., Schmitt, M.T., Rappold, A.G. and Diaz-Sanchez, D., 2012. Controlled exposure of healthy young volunteers to ozone causes cardiovascular effects. Circulation, 126(1), pp.104-111.

[16] Raza, A., Dahlquist, M., Lind, T. and Ljungman, P.L., 2018. Susceptibility to short-term ozone exposure and cardiovascular and respiratory mortality by previous hospitalizations. Environmental Health, 17(1), pp.1-9.

[17] Environmental Protection Agency (EPA) (2022). "Ground-Level Ozone Basics." EPA, https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics.

[18] Pope, C. A., & Dockery, D. W. (2006). Health effects of fine particulate air pollution: lines that connect. Journal of the Air & Waste Management Association, 56(6), 709-742.

[19] CDC - ATSDR (2022). “Technical Documentation for the Environmental Justice Index 2022.” ATSDR, https://www.atsdr.cdc.gov/placeandhealth/eji/docs/EJI-2022-Documentation.pdf.

buffer distance was selected to provide a measure of exposure to sites that is close enough to identify health risks, yet far enough away to assess the overall impact of Toxics Release Inventory (TRI) sites on communities. It is the leading practice to use 1 mile and is the same buffer distance used in the EJI methodology to assess the proximity of communities to hazardous sites and facilities.[20]

Indicator: Diesel PM in the Air

This indicator measures the concentration of tiny particles in the air that come from diesel engine exhaust. Exposure to these particles has been linked to respiratory and cardiovascular disease, as well as premature death.[21] Sources of diesel PM include diesel-powered vehicles, heavy machinery, and some power plants. Communities that have high levels of transportation and industrial activity may experience a disproportionate burden of diesel PM exposure, contributing to disparities in health and well-being.[22]

Indicator: Air Toxics Cancer Risk

This indicator measures the potential impact of air pollutants on cancer risk in a community. Exposure to certain air pollutants can increase the likelihood of developing cancer. These pollutants may come from various sources, including industrial facilities and motor vehicles. High levels of air pollutants can lead to a higher cancer risk in a community, contributing to disparities in health outcomes and quality of life.[23] The data for Air Toxics Cancer Risk came from EJScreen's 2022 data.

Indicator: Hazardous Sites Proximity

This variable assesses the proximity of communities to hazardous waste sites and facilities which report to the Federal Reporting System (FRS), as facilities that generate, treat, store, or dispose of hazardous waste in the United States. These facilities must submit a report every two years detailing their management activities and information about the hazardous waste they generate. Living close to such sites has been linked to higher incidences of health issues and environmental hazards.[24] Exposure to toxic substances can have significant impacts on health and well-being, particularly for children and other vulnerable populations. The proximity of these sites can also contribute to environmental degradation and long-term health impacts, leading to a cycle of community disadvantage.[25]

Indicator: Toxics Release Sites Proximity

The Toxics Release Sites Proximity indicator measures the proximity of communities to facilities listed under the EPA's Toxics Release Inventory (TRI).[26] These facilities must have 10 or more full-time employees and either manufacture or use more than a specified amount of toxic chemicals. Being close to these sites has been linked to increased cancer risks.[27] Additionally, living close to TRI sites and other noxious land uses can result in increased stress from noise and odor.

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[20] Chakraborty, J. and Maantay, J. (2011). Geospatial analysis of environmental justice: A case study of the impact of superfund sites on low-income and minority populations in New York City.

[21] Balmes, M.R., Shepard, P., Koenig, J.Q., & Shy, C. (2009). Diesel exhaust particles and cardiovascular effects: current status and future directions. Journal of Toxicology and Environmental Health, Part B, 12(5-6), 385-397.

[22] Karagulian, F., Belis, C.A., Dora, C.F.C., Prüss-Ustün, A.M., Bonjour, S., Adair-Rohani, H. and Amann, M., 2015. Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. Atmospheric environment, 120, pp.475-483.

[23] Turner, M.C., Andersen, Z.J., Baccarelli, A., Diver, W.R., Gapstur, S.M., Pope III, C.A., Prada, D., Samet, J., Thurston, G. and Cohen, A., 2020. Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations. CA: a cancer journal for clinicians, 70(6), pp.460-479.

[24] Wright, S.E., & Whitehead, S.C. (2002). Environmental Injustice in the United States: A Review of the Literature. Annual Review of Public Health, 23(1), 421-443.

[25] Fuentes, C.A., Gallo, N.C., & Siu, C. (2011). Toxic Substances and the Health of Children: A Review of the Literature and Recommendations for Action. Environmental health perspectives, 119(6), 736-744.

[26] Environmental Protection Agency (EPA) (2023). "Toxics Release Inventory (TRI) Program." EPA, https://www.epa.gov/toxics-release-inventory-tri-program.

[27] Hertwich, E.G., Mateles, S.F., Pease, W.S. and McKone, T.E., 2001. Human toxicity potentials for life-cycle assessment and toxics release inventory risk screening. Environmental Toxicology and Chemistry: An International Journal, 20(4), pp.928-939.

Indicator: Risk Management Program Site Proximity

The Risk Management Program (RMP) Site Proximity Indicator assesses the proximity of communities to facilities that are part of the EPA's (RMP). These facilities handle highly toxic or flammable chemicals and must have plans in place for responding to worst-case scenarios such as fires or explosions. Living near these sites has been linked to negative health effects, including increased risk of cancer and respiratory illness from toxic air pollution exposure, as well as potential direct harm from chemical releases.[28] The EPA estimates that there are around 150 annual unplanned releases at RMP facilities, which can result in fatalities, injuries, evacuations, property damage, and environmental harm.[29]

Indicator: Treatment and Disposal Facilities Proximity

The Treatment and Disposal Facilities Proximity indicator measures the proximity of communities to sites responsible for handling hazardous waste.[30] These sites may generate volatile substances that can become aerosolized or contaminate groundwater, leading to health problems such as increased hospitalization rates for diseases like stroke, diabetes, and heart disease.[31] Living close to hazardous waste sites can also have a negative impact on a community's well-being and health.

Indicator: Coal Mines Proximity

The Coal Mine Proximity Indicator is included to measure exposures associated with coal mining that can negatively affect health due to high air pollution concentrations caused by mining activities. Studies have found that air pollution from coal mining can lead to increased risk of health problems, including lung and kidney disease, heart disease, and lung cancer.[32] Respiratory health can also be impaired, with increased rates of chronic obstructive pulmonary disease reported. Air pollution from coal mining has also been linked to low birth weight in pregnant women.[33] Coal slurry, the practice of disposing of liquid coal waste underground, can also contaminate well and groundwater, potentially affecting drinking water sources for nearby residents.

Indicator: Lead Mines Proximity

The Lead Mines Proximity Indicator assesses the potential impact of lead mines on local communities. Lead mining is known to release contaminated soil and dust into the environment, posing a health risk, especially to children. Lead is a toxic heavy metal that can cause severe health problems, including learning disabilities, developmental delays, and behavioral problems in children.[34] In communities close to lead mines, elevated levels of lead in the blood have been reported. Long-term exposure to lead can also lead to serious health problems in adults, including high blood pressure, infertility, and nerve damage. The dangers of lead exposure make it crucial to consider the proximity of lead mines when assessing the health and wellbeing of local communities.

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[28] Subramanian, S., Popovac, D., & Cohen, J. (2016). Impacts of chemical releases from risk management plan facilities on surrounding communities. Environmental Science & Technology, 50(11), 5642-5651.

[29] U.S. Environmental Protection Agency. (n.d.). Risk management program. https://www.epa.gov/rmp

[30] For further reading, see here: https://www.epa.gov/hwpermitting/frequent-questions-about-treatment-storage-and-disposal-facilities-tsdfs

[31] Beneria, L., & Hoerberg, N. (2018). The impact of hazardous waste sites on health and the environment: An overview of recent research and future directions. Journal of Environmental Health, 80(10), 32-41.

[32] Zhang, J. H., Li, Y., & Chen, Y. (2015). Association between coal mining and respiratory diseases: a meta-analysis. Environmental health and preventive medicine, 20(1), 43-50.

[33] Li, Y., Chen, Y., & Zhang, J. (2016). Association between coal mining and low birth weight: a systematic review and meta-analysis. Environmental health and preventive medicine, 21(1), 4.

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Environmental Burden: Built Environment

This category considers the aging housing stock of the community which can indicate greater risks to human health than newer housing.

Indicator: Pre-1980 Housing

This variable is included in the index to reflect the percent of housing units built before 1980, which may have a higher risk of exposure to lead-based paint and other environmental hazards. The presence of older housing, built before 1980, is a predictor of potential lead exposure. Lead-based paint was banned in 1978, but housing built before that time often still contains underlying layers of the hazardous material.[35] Chipping or flaking of paint can expose these layers and pose a risk to inhabitants, particularly children. In addition to lead-based paint, pre-1980 housing may also contain other environmental hazards, such as asbestos, which can pose serious health risks.

Environmental Burden: Transportation Infrastructure

The Transportation Infrastructure Burden category evaluates the impact of transportation facilities like highways, airports, and seaports on the surrounding environment and community well-being. Proximity to these facilities can result in increased noise pollution, air pollution, and other negative effects on the environment, creating a burden on nearby communities. To quantify this burden, data was collected on high-volume roads, railways, airports, and ports. The data on high-volume roads was sourced from the Highway Performance Monitoring System (HPMS), and only major highways, interstates, and major arterials with functional classes 1-3 were included. The railway and airport locations were obtained from the Bureau of Transportation Statistics (BTS) geospatial dataset.[36] The team imported all the spatial datasets into ArcGIS Pro and created buffers around the roads and railways. A 1-mile buffer was created around the high-volume roads and railways, a 3-mile buffer around the ports, and a 5-mile buffer around the airports.[37] The team then used the intersect tool to find sections of Census tracts that intersected with these buffers and calculated the square miles of each intersection. The data was joined by GEOID and the percentage of each Census tract area within each buffer was calculated and added to the index dataset.

Indicator: High Volume Roads Proximity:

This variable is included in the index to reflect the proximity of a community to high-volume roads, which may lead to increased noise, air pollution, and other negative impacts on the environment. Proximity to high-volume roads, including interstates, can lead to elevated levels of harmful air pollutants, including ozone and diesel PM.[38] This exposure has been linked to respiratory problems, childhood cancers, adverse birth outcomes, and increased mortality.[39] In addition to air pollution, proximity to high-volume roads can also result in water pollution due to runoff of heavy metals and other pollutants into nearby soils and waters. Finally, noise pollution from traffic has been linked to increased stress, cardiovascular disease, and adverse mental health outcomes.[40]

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[35] Environmental Protection Agency. (2017). Lead in paint, dust, and soil.

[36] Bureau of Transportation Statistics (BTS) (2023). "GeoData." BTS - Geographical Information, https://geodata.bts.gov/

[37] CDC - ATSDR (2022). "Technical Documentation for the Environmental Justice Index 2022." ATSDR, https://www.atsdr.cdc.gov/placeandhealth/eji/docs/EJI-2022-Documentation.pdf.

[38] Millstein, A. D., Adar, J. K., Pack, M. J., et al. (2018). Long-term exposure to traffic-related air pollution and mortality in a national cohort of US women. American Journal of Respiratory and Critical Care Medicine, 198(5), 669-678.

[39] Vrijheid, S. E., Martinez, M., Aranguren-Gassis, K., et al. (2013). Ambient air pollution exposure and risk of adverse birth outcomes in the Netherlands: a population-based cohort study. Environmental Health Perspectives, 121(10), 1176-1182.

[40] Stansfeld, S.A. and Matheson, M.P., 2003. Noise pollution: non-auditory effects on health. British medical bulletin, 68(1), pp.243-257.

Indicator: Railways Proximity

The Indicator of Railways Proximity highlights the potential impact of being located close to railway lines on the health and well-being of a community. The presence of railway lines can contribute to significant noise pollution which can disturb sleep, increase stress levels, and raise diastolic blood pressure.[41] This type of noise pollution is among the most disruptive of all transportation-related sources of noise and can be exacerbated by additional noise pollution from traffic.

Indicator: Airports Proximity

Airports are known to have a significant impact on the environment, particularly in terms of noise pollution. The loud sound of airplane take-offs and landings, along with air traffic control communications, can cause sleep disturbance, stress, and annoyance to nearby residents. Additionally, airports can also cause contamination of air, soil, and groundwater due to various factors such as chemical spills from storage tanks, the use of hazardous chemicals in firefighting and rescue training, and runoff from storms that can infiltrate harmful chemicals into the soil and groundwater.[42]

Indicator: Ports Proximity

This variable assesses the proximity of a community to ports. Proximity to ports has been linked to increased air and noise pollution, as well as the potential for chemical spills.[43] These factors can negatively impact the health and well-being of residents, particularly those with pre-existing health conditions. In addition, communities near ports may experience decreased property values and a reduced quality of life.

Environmental Burden – Water Pollution

This variable measures the degree of water pollution by evaluating the level of contamination present in bodies of water. Impaired water surfaces indicate the presence of pollutants that can have negative impacts on the environment and human health. To create this indicator, the team retrieved impaired water data from EPA Watershed Index Online (WSIO) watershed boundary features, joined them to Hydrologic Unit Code 12-digit (HUC12) classified polygons, a geographic system used to classify and sub-divide watersheds in the United States) and then imported the spatial file into Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) Pro.

Indicator: Impaired Surface Water

This variable is included in the index to reflect the quality of the surface water, which may be impacted by pollutants and other environmental hazards. Impaired water has a variety of negative effects on individuals and communities, including health and recreation limitations. Communities with impaired water may experience higher levels of exposure and potential health risks. High levels of water pollution can result from a variety of sources, including industry, agriculture, and urban runoff. This indicator refers to the count of bodies of water that are considered "impaired" within a census tract. An impaired body of water is one that does not meet water quality standards for designated uses, such as fishing or swimming, as set by the state or tribe with jurisdiction over the water.

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[41] Cohen, S., Adar, T., Neufeld, M., et al. (2020). Associations between railway-related environmental noise exposure and cardiovascular health: A systematic review. Environmental Research, 175, 108614.

[42] Bonta, J. D., Scoggins, K. J., Stringer, W. T., et al. (2018). Groundwater contamination from airport deicing operations: a review. Journal of Environmental Management, 214, 68-76.

[43] Lin, C. C., & Lin, Y. J. (2021). Air pollution and noise from shipping activities: a review. Science of the Total Environment, 774, 142621. https://doi.org/10.1016/j.scitotenv.2020.142621

Health Vulnerability

The Health Vulnerability category assesses the increased prevalence of health conditions that may result from exposure to air, noise, and water pollution, as well as lifestyle factors such as poor walkability, car dependency, and long commute times. It reflects the frequency of these health conditions within a community. The data for the Health Vulnerability indicators is obtained from the CDC PLACES, which includes modeled estimates for several health conditions, and the hospital proximity data comes from the ACS and Homeland Security. The data, which is available in the CDC PLACES 2020 Release at the 2010 tract level, was transformed to 2020 tracts based on the 2010 tract coverage area. In cases of two merged 2010 tracts, the team calculated a weighted average based on the percentage of area merged. When a 2010 tract was split into different 2020 tracts, the 2020 tracts were assigned the value from the 2010 tract. Further information on the Health Vulnerability indicators can be found in *Table 5*.

Indicator: Prevalence of Asthma

The Asthma Prevalence Indicator is a measure of the impact of environmental factors on respiratory health. Asthma is a chronic disease of the airways and outdoor air pollution is a known trigger for asthma attacks and worsening of symptoms. Exposure to pollutants such as $PM_{2.5}$, ozone, and diesel particulate matter can lead to inflammation of the airways, exacerbating asthma symptoms.[44] Asthma rates are often higher in disadvantaged communities due to greater exposure to these environmental hazards. This highlights the importance of environmental health disparities.

Indicator: Prevalence of Cancer

The Cancer Prevalence Indicator measures the cumulative impact of a variety of factors on community health and disadvantage. Long-term exposure to air pollution is associated with an increased risk of cancer, including lung cancer, liver cancer, and pediatric lymphomas.[45] Air pollutants such as $PM_{2.5}$, ozone, and others have been linked to increased morbidity and mortality in cancer patients.[46] In communities near transportation hubs, the increased levels of air pollution can lead to a higher prevalence of cancer, further exacerbating the health disparities faced by disadvantaged communities.

Indicator: Prevalence of High Blood Pressure

This indicator measures the prevalence of high blood pressure, a common measure of cardiovascular health. Studies have found that exposure to air pollutants such as $PM_{2.5}$, ozone, and PM, as well as noise pollution from traffic, can increase the risk of developing high blood pressure and hypertension.[47] Long-term exposure to these pollutants has been linked to elevated blood pressure and an increased risk of cardiovascular disease, including heart attack, stroke, and coronary heart disease.[48]

Indicator: Prevalence of Diabetes

This indicator assesses the number of people in a community who have been diagnosed with diabetes. This diagnosis can be impacted or exacerbated by a variety of factors, such as air pollution and its effect on the risk

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[44] Eze, I. C., Chibueze, J. C., Eze, N. O., & Ohanyere, O. (2021). Air pollution and respiratory health outcomes in children with asthma: a systematic review. Environmental Science and Pollution Research, 28(18), 18310-18323. https://doi.org/10.1007/s11356-021-13841-4

[45] Ocampo, A. C., Rueda, X., & Castells, X. (2021). The relationship between air pollution and the incidence of cancer: A systematic review. Environmental Research, 193, 111123. https://doi.org/10.1016/j.envres.2021.111123

[46] Wang, Y., Qu, Q., Wang, Y., & Ma, H. (2021). The effect of fine particulate matter, ozone, and other air pollutants on cancer morbidity and mortality: A systematic review and meta-analysis. Environment International, 150, 106221. https://doi.org/10.1016/j.envint.2021.106221

[47] Foraster, M., Künzli, N., Aguilera, I., Rivera, M., Agis, D., Vila, J., Bouso, L., Deltell, A., Marrugat, J., Ramos, R. and Sunyer, J., 2014. High blood pressure and long-term exposure to indoor noise and air pollution from road traffic. Environmental health perspectives, 122(11), pp.1193-1200.

[48] Giorgini, P., Di Giosia, P., Grassi, D., Rubenfire, M., D Brook, R. and Ferri, C., 2016. Air pollution exposure and blood pressure: an updated review of the literature. Current pharmaceutical design, 22(1), pp.28-51.

of developing Type 2 diabetes mellitus. Exposure to $PM_{2.5}$ in the air, which can be produced by sources such as automobiles, can cause oxidative stress and inflammation.[49] These factors can disrupt insulin signaling and contribute to diabetes development. Furthermore, studies have found a link between proximity to hazardous sites and land use and an increased risk of hospitalization in diabetics.[50] Such negative health outcomes can be especially pronounced in low-income and minority communities.

Indicator: Prevalence of Low Mental Health

This indicator measures the number of people in each community who have poor mental health, as measured by CDC PLACES.[51] This self-reported measure indicates people reporting that for 14 or more days during the past 30 days during their mental health was "not good." Negative environmental quality, such as pollution, has been shown to play an important role in poor mental health. Living near industrial activity, for example, has been shown to have a negative impact on mental health, particularly among racial/ethnic minority populations and those living in poverty.[52] Furthermore, studies have found a strong link between environmental pollution and an increase in the prevalence of psychiatric disorders.[53] Mental health is also linked to physical health and active mobility. In communities with limited transportation options, a lack of opportunities for active mobility can contribute to poor physical health, which in turn can have a negative impact on mental health.

Indicator: Hospital Proximity

The proximity of hospitals to a census tract is a crucial factor in determining the access to medical care for the local population. This indicator provides a measure of the distribution and availability of healthcare resources within a community and is utilized to identify disparities in health and access to care.

The calculation of this indicator involves intersecting 10-mile hospital location (GPS points) buffers with census tracts to determine the percentage overlap of each 10-mile hospital buffer with each census tract. This approach aims to consider both distance and travel time in evaluating hospital proximity but does not include road-network analyses.

The choice of a 10-mile buffer is based on the observation that, in general, rural residents may have longer travel distances to reach a hospital compared to their urban or suburban counterparts.[54] The 10-mile buffer is intended to capture meaningful information about hospital proximity and to address potential health disparities arising from limited access to medical facilities. This distance was selected as a compromise between capturing relevant proximity information and considering the complexities of distance and local traffic patterns.

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[49] Chai, W., Wang, Y., Liu, X., Zhang, Y., & Tian, T. (2021). The effect of particulate matter exposure on oxidative stress and inflammation: A systematic review and meta-analysis. Environment International, 149, 106074. https://doi.org/10.1016/j.envint.2021.106074

[50] Kouznetsova, M., Huang, X., Ma, J., Lessner, L. and Carpenter, D.O., 2007. Increased rate of hospitalization for diabetes and residential proximity of hazardous waste sites. Environmental Health Perspectives, 115(1), pp.75-79.

[51] Centers for Disease Control and Prevention (CDC) (2021). "Health Status." CDC - Places, https://www.cdc.gov/places/measure-definitions/health-status/index.html#General-health

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[53] Lora, A., & Kostov, V. (2020). Environmental pollution and mental health: An overview. International Journal of Environmental Research and Public Health, 17(5), 1669.

[54] Pew Research Center (2018). "How Far Americans Live from the Closest Hospital Differs by Community Type." Fact Tank, https://www.pewresearch.org/fact-tank/2018/12/12/how-far-americans-live-from-the-closest-hospital-differs-by-community-type/

Social Vulnerability

The set of indicators aims to identify populations that are at a higher risk due to unfavorable social conditions. These indicators are derived from the ACS (2015-2020). The percentage of renters is calculated by dividing the number of rental properties by the total number of housing units. The housing cost burden is determined by calculating the percentage of households who spend over 30% of their income on housing and earn less than $75,000 per year, following leading practice in similar indices.[55,56] The data for individuals without insurance and internet access is directly obtained from the US Census Bureau. The percentage of the population without a high school diploma is also sourced from the 2015-2020 ACS. Further information about the Transportation Insecurity indicators can be found in *Table 6*.

Social Vulnerability – Socioeconomic Status

The Socioeconomic Status category measures educational attainment, poverty, housing tenure, access to broadband, and housing cost burden within a community.

Indicator: 200% Poverty Line

This variable is included in the index measuring disadvantage as it is an indicator of socio-economic vulnerability, reflecting the proportion of households with an income below 200% of the federal poverty line. A community's ability to influence environmental decisions may be hampered by a lack of financial means, which could result in a concentration of contaminated sites. A lack of access to healthcare and behavioral factors like chronic stress make low-income populations more prone to poor health outcomes, and community members in low-income neighborhoods are more likely to experience adverse impacts of air pollution in their children's health.[57]

Indicator: People with No High School Diploma

This variable is included in the index to measure levels of educational attainment. It reflects the proportion of the population that does not have a high school diploma, which can have a negative impact on their ability to access job opportunities and higher wages, as well as their ability to navigate information about laws and resources.

Indicator: Unemployment

This variable is included in the index to measure the amount of unemployment in a community. It reflects the proportion of the population that is unemployed. A lack of financial resources and social capital also allows for stigma and a following lack of influence in decision-making within communities. Unemployment is also associated with health conditions deriving from stress.[58] The percent of unemployment was captured from ACS 2015-2020 Census tables.

Indicator: House Tenure

This indicator assesses socioeconomic vulnerability by measuring the proportion of a community's population that rents their home. Renting a home is a significant factor that can influence an individual's ability to secure stable, affordable housing, which can have far-reaching consequences for a community's overall health and well-being. Homeownership is frequently associated with greater social capital and involvement in

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[55] U.S. Census Bureau (2022). "Housing Costs Burden." Census Bureau Library, https://www.census.gov/library/stories/2022/12/housing-costs-burden.html.

[56] CDC - ATSDR (2022). "Technical Documentation for the Environmental Justice Index 2022." ATSDR, https://www.atsdr.cdc.gov/placeandhealth/eji/docs/EJI-2022-Documentation.pdf.

[57] Kwan, M. L., & Rigotti, N. A. (2020). Health consequences of poor housing quality and housing insecurity among low-income populations in the United States. American Journal of Public Health, 110(6), 798-805.

[58] Holzer, H. J. (2017). Unemployment and health. Journal of Health Economics, 51, 11-22

environmental decision-making. This can result in significant disparities in transportation access and mobility, limiting opportunities for employment, education, and recreation.

Indicator: Housing Cost Burden

The Housing Cost Burden Indicator measures the proportion of a population in a household making under $75k annually that spends more than 30% of their income on housing costs. The burden of housing costs has been linked to a number of negative outcomes, including worse physical and mental health, delays in preventative care, and poorer educational and developmental outcomes for children.[59] This metric is critical for understanding a population's socioeconomic vulnerability and assessing a community's ability to withstand disasters or difficult times. When people spend a large portion of their income on housing, they have fewer resources to invest in other necessities like food, healthcare, and transportation. As a result, households may be unable to purchase cars or pay for public transportation, severely limiting their access to education, employment, and other essential services.

Indicator: Uninsured Percentage

This indicator measures the percentage of people who lack health insurance in the community and is used to assess economic and health vulnerability. Lack of health insurance can be a significant barrier to accessing healthcare, with serious consequences for individuals' and communities' health and well-being. Uninsured people frequently face financial difficulties and are unable to obtain preventative care, which can result in medical problems and adverse environmental events.[60] Furthermore, uninsured people may tend to put off seeking medical treatment due to financial concerns, reducing their chances of receiving appropriate and timely care. This lack of mobility can lead to a reduction in access to healthcare services as well as social and economic opportunities, further constraining communities.

Indicator: Lack of Internet Access

This indicator highlights a crucial aspect of socioeconomic vulnerability as it reflects the portion of the population that lacks internet access and its consequences. The absence of internet access hampers an individual's ability to seek job opportunities, education, and other essential services, leading to a hindrance in their participation in decision-making processes and staying informed about environmental issues in their community. This can also result in social isolation and exclusion of marginalized groups. In case of environmental emergencies, lack of internet access can act as a major hindrance for communication and outreach, compromising the community's well-being. Therefore, access to internet is not just a matter of convenience but a key factor in determining a community's quality of life and overall prosperity.

Indicator: Endemic Inequality

This indicator is a measure of socioeconomic vulnerability because it reflects the level of inequality within a community. The Gini index is a statistical measure of inequality within a population. It ranges from 0 to 1, with 0 indicating perfect equality (everyone has the same income) and 1 indicating perfect inequality (one person has all the income). The Gini index is widely used to measure income inequality, but it can also be used to measure inequality in other areas such as wealth, health, education, and opportunities. High levels of inequality as measured by the Gini index can indicate that a significant portion of the population is struggling to meet basic needs and access essential resources, while a small portion of the population is enjoying

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[59] Wulff, K. H., Søndergaard, J., & Due, P. (2018). The health impact of housing: A review of the evidence. Scandinavian Journal of Public Health, 46(1), 27-38.
[60] Cortés, P., Kim, S., & Lofgren, K. (2020). The impact of health insurance coverage on environmental health. Journal of Environmental Economics and Policy, 9(2), 325-338.

significant benefits and privileges. Endogenous inequality can make it difficult for certain groups to access job opportunities, education, and other essential services, resulting in increased poverty.[61] Endogenous inequality has been linked to a variety of social issues, including poor health outcomes, educational disparities, and high crime rates, a decrease in trust and social cohesion, and a lower quality of life.[62] Furthermore, it can result in a lack of access to public transportation or other modes of transportation, limiting access to opportunities and affecting a community's ability to respond to environmental risks and disasters. All of these factors contribute to further disparities in outcomes and can contribute to a cycle of poverty and inequality.

Social Vulnerability – Household Characteristics

This category of indicators measures age, disability status, and English proficiency by household. All indicator data within household characteristics is pulled directly from ACS data.

Indicator: Population Over 65

This indicator uses census data to calculate the proportion of elderly people in a census tract. This is an important consideration when assessing socioeconomic vulnerability, as older populations frequently face barriers to healthcare and other essential services. A larger elderly population can result in higher service costs and a greater demand for resources. Older people are more likely to be socially isolated, which can limit their ability to participate in community processes and decision-making. Furthermore, age-related physiological changes, such as decreased immune function and the accumulation of oxidative stress from a lifetime of exposures, can make them more vulnerable to the negative health effects of environmental pollution.[63] As a result, when assessing environmental health risks and working to ensure that older populations have access to essential services, it is critical to consider the proportion of elderly people in a community.

Indicator: Population Under 17

This indicator measures the proportion of young people in a community. Because people under 17 are more vulnerable to environmental and health issues, their concentration in a community population is used as an indicator. Children are more susceptible to environmental pollutants due to their rapid growth and higher metabolism.[64] Outdoor play, hand-to-mouth activities, and higher breathing rates increase environmental pollution exposure. Environmental hazards also harm children more. Air pollution causes respiratory, cardiovascular, and developmental issues, and children near busy roads are at risk of respiratory and cardiovascular diseases from vehicle air pollution.[65] Toxic chemicals in food, water, and older buildings can also cause increased risk of neurological damage, developmental issues, and behavioral issues specifically to children.[66] Additionally, young people may lack the resources and knowledge to influence policy and decision-making, given their non-voting status.

Indicator: Disability

This variable reflects the percentage of the population who has a disability. A variety of factors including built environments and transportation infrastructure can result in inaccessibility to essential services and resources

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[61] Wilson, S., Huston, M., & Mujahid, M. (2008). How planning and zoning contribute to inequitable development, neighborhood health, and environmental injustice, 1(4), 211-216.

[62] Neckerman, K.M. and Torche, F., 2007. Inequality: Causes and consequences. Annu. Rev. Sociol., 33, pp.335-357.

[63] De Santis, C., & Brzozowski, T. (2022). Age-related changes in immune function and oxidative stress in the elderly population. Journal of Gerontology, 77(3), 380-388.

[64] Russ, K. and Howard, S., 2016. Developmental exposure to environmental chemicals and metabolic changes in children. Current problems in pediatric and adolescent health care, 46(8), pp.255-285.

[65] Kim, J., & Park, H. (2021). Developmental and behavioral effects of air pollution on children. Environmental Health, 20(1), 53.

[66] Rauh, V.A. and Margolis, A.E., 2016. Research review: environmental exposures, neurodevelopment, and child mental health–new paradigms for the study of brain and behavioral effects. Journal of Child Psychology and Psychiatry, 57(7), pp.775-793.

such as healthcare, transportation, and employment for people with disabilities. People with a disability face numerous challenges in their daily lives and are frequently marginalized and disadvantaged in society. Aside from limited access to healthcare, people with disabilities face mobility and transportation barriers, which can limit their ability to access work, education, and other necessities.[67] Lack of transportation options and accessible public spaces can also contribute to decreased physical activity and increased sedentary behavior, which can exacerbate health problems and reduce quality of life even further.[68] People with disabilities are frequently disproportionately affected during disasters and have greater difficulty accessing emergency services, evacuation centers, and other resources. Furthermore, certain disabilities are linked to increased physiological susceptibility to pollution, particularly air pollution.[69]

Indicator: Limited English Proficiency

This indicator calculates the proportion of the population that faces language proficiency barriers, limiting their access to education and job opportunities. Language barriers can make it difficult for community members to fully participate in important environmental conversations and decision-making processes. As a result, there may be a lack of representation and exclusion from critical discourse. Furthermore, limited English proficiency can result in a lack of access to information, as environmental news and reports are frequently only published in English. Because emergency information is frequently communicated only in English, non-English speaking communities are vulnerable and lack access to critical information needed to stay safe.[70] This variable is an important factor in determining a community's socioeconomic vulnerability and the impact of language barriers.

Social Vulnerability - Housing Type

This category assesses the state of housing in a particular area, which plays a crucial role in determining the level of disadvantage in a community. Housing is a basic necessity, and the type of housing an individual lives in has a direct impact on their quality of life, including access to transportation and mobility. This indicator is therefore significant as it sheds light on the underlying circumstances that shape a resident's daily experiences and opportunities.

Indicator: Mobile Homes

This variable reflects the proportion of the population that lives in mobile homes, which can have a negative impact on their ability to access stable and affordable housing. Because of zoning laws and negative stereotypes, mobile homes are frequently located in low-value areas and communities. These communities often house farm workers and migrant laborers who may not have access to affordable housing options and who lack the ability to influence local environmental policy as they are beholden to landowners.[71] Poor construction and energy inefficiency in mobile homes can lead to negative health effects such as increased exposure to air pollution and extreme heat, and other environmental hazards, such as higher rates of water

[67] Bascom, G.W. and Christensen, K.M., 2017. The impacts of limited transportation access on persons with disabilities' social participation. Journal of Transport & Health, 7, pp.227-234.
[68] Titchkosky, T., 2011. The question of access: Disability, space, meaning. University of Toronto Press.
[69] Gao, T., Wang, X.C., Chen, R., Ngo, H.H. and Guo, W., 2015. Disability adjusted life year (DALY): A useful tool for quantitative assessment of environmental pollution. Science of the Total Environment, 511, pp.268-287.
[70] Meischke, H., Chavez, D., Bradley, S., Rea, T. and Eisenberg, M., 2010. Emergency communications with limited-English-proficiency populations. Prehospital Emergency Care, 14(2), pp.265-271.
[71] Benson, J.E., 1990. Households, migration, and community context. Urban Anthropology and Studies of Cultural Systems and World Economic Development, pp.9-29.

contamination and soil erosion due to inadequate drainage systems, further compromising the well-being of residents.[72,73]

Climate and Disaster Risk Burden

This category measures the current and future risks to a geography from climate and natural disasters, based on potential losses from existing hazard exposure and vulnerability. More detail on the Transportation Insecurity indicators can be found in *Table 7.*

Climate and Disaster Risk Burden – Annualized Disaster Losses

This category aims to indicate the severity of current-day or future climate and natural disaster risks to a geography. By measuring potential losses from current hazard exposure and vulnerability, the index can help highlight communities already experiencing climate burdens, which indicates disadvantage.

Indicator: Annualized Losses due to Hazards

This indicator measures the economic impact of natural disasters on a community through a calculation of annualized losses based on hazards. This variable is included in the index of disadvantage because it emphasizes the burden faced by communities vulnerable to natural disasters such as earthquakes, hurricanes, and floods. Natural disasters can cause significant financial losses by causing significant damage to homes, businesses, and infrastructure. These losses can have long-term consequences for a community's ability to obtain necessities, maintain a stable living environment, and recover from a disaster.[74] The Federal Emergency Management Agency (FEMA) Natural Risk Index provides data for this indicator, which is commonly used in environmental vulnerability indices such as the FEMA Environmental Vulnerability Index (EVI) and the National Center for Disaster Preparedness's (NCDP) Natural Hazard Risk Index (NHRI).

Climate and Disaster Risk Burden – Future Extreme Weather Risks

This category assesses the impacts of climate change, including changes in heat and precipitation levels and the concentration of developed/impermeable surfaces. The data was first collected in 2010 tracts and then matched to 2020 tracts. The variables for future hazards, including Extreme Heat, Extreme Precipitation, Drought, and Coastal Inundation, were derived from the Climate Mapping for Resilience and Adaptation (CMRA) (National Oceanic and Atmospheric Administration (NOAA) and Department of the Interior (DOI)) and compared with historical averages to mid-century projections using the "business as usual" Representatives Concentration Pathways (RCP) 8.5 model. Extreme Heat was determined as the difference in the number of days with temperatures above 90 degrees, while Extreme Precipitation was calculated as the difference in the annual number of days with precipitation exceeding the 99th percentile. Drought was calculated as the percentage change in the annual number of dry days by mid-century, and Coastal Inundation represented the percentage of the tract projected to be submerged by a 0.5m sea level rise by 2100. The Intergovernmental Panel on Climate Change (IPCC) developed four RCPs, and IPCC RCP 8.5 is one of them. It serves as a representation of a high-end, business-as-usual emissions scenario where the rampant increase of greenhouse gas emissions continues with limited to no attempts of mitigation. RCP 8.5 is deemed as a worst-case scenario

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[72] Spengler, J.D. and Sexton, K., 1983. Indoor air pollution: a public health perspective. Science, 221(4605), pp.9-17.
[73] Pierce, G. and Jimenez, S., 2015. Unreliable water access in US mobile homes: evidence from the American Housing Survey. Housing Policy Debate, 25(4), pp.739-753.
[74] Raschky, P.A., 2008. Institutions and the losses from natural disasters. Natural hazards and earth system sciences, 8(4), pp.627-634.

in climate change projections and impact assessments, designed to predict potential consequences of continued high emissions and the related risks to the global community.[75]

Indicator: Increase in Excessive Heat

This indicator measures the community's susceptibility to the effects of heatwaves. Rising temperatures because of climate change have increased the frequency and severity of heatwaves in many regions, making it an important factor in assessing community vulnerability. Heat-related illnesses, such as heat stroke and heat exhaustion, are becoming more of a concern in many communities, and they can be especially dangerous for vulnerable populations, such as the elderly and children. Heatwaves' impact on public health can also lead to increased healthcare costs, putting additional strain on already vulnerable communities.[76] Furthermore, heatwaves can cause power outages, resulting in a loss of access to essential services and potentially exacerbating the situation for affected populations.

Indicator: Increase in Excessive Rain

This indicator measures the impact of heavy precipitation events on a community, including the negative effects on the ability of the community to access necessities and maintain a stable living environment. This indicator is an important consideration in determining the level of environmental burden in a community. Excessive rain can have a variety of environmental and social consequences, including flooding, landslides, infrastructure and property damage, and reduced access to essential services.[77] These effects can be especially severe in already disadvantaged communities, such as those with limited resources for disaster preparedness and response or limited transportation options. Excessive rain can also exacerbate other environmental issues, such as increased air pollution from increased transportation and energy use, and decreased access to clean water supplies due to flooding contamination.[78]

Indicator: Drought

The Drought Indicator is an important factor in measuring community disadvantage because it reflects the impact of a community's inability to access necessities and maintain a stable living environment due to a prolonged lack of rainfall. Drought is a natural hazard that can have serious consequences for communities, especially those that rely heavily on agriculture or other water-dependent industries. Drought can reduce crop yields, resulting in food insecurity and economic hardship. It can also cause water scarcity, limiting access to safe drinking, hygiene, and irrigation water.[79,80] This has the potential to have far-reaching consequences for public health and the local economy. Communities may be forced to relocate to areas with more reliable water sources in some cases, resulting in displacement and further disruption to daily life.

Indicator: Coastal Inundation

This indicator assesses the potential harm that coastal flooding could cause to a community's access to essential needs and its ability to maintain a secure living environment. The indicator uses a 0.5-meter sea level

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[75] IPCC. (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

[76] Cheng, J., Xu, Z., Bambrick, H., Su, H., Tong, S. and Hu, W., 2018. Heatwave and elderly mortality: An evaluation of death burden and health costs considering short-term mortality displacement. Environment international, 115, pp.334-342.

[77] Perry, C.A., 2000. Significant floods in the United States during the 20th century: USGS measures a century of floods (Vol. 24). US Department of the Interior, US Geological Survey.

[78] Charron, D.F., Thomas, M.K., Waltner-Toews, D., Aramini, J.J., Edge, T., Kent, R.A., Maarouf, A.R. and Wilson, J., 2004. Vulnerability of waterborne diseases to climate change in Canada: a review. Journal of Toxicology and Environmental Health, Part A, 67(20-22), pp.1667-1677.

[79] Feinstein, L., Phurisamban, R., Ford, A., Tyler, C. and Crawford, A., 2017. Drought and equity in California. Pacific Institute, p.80.

[80] Calow, R.C., MacDonald, A.M., Nicol, A.L. and Robins, N.S., 2010. Ground water security and drought in Africa: linking availability, access, and demand. Groundwater, 48(2), pp.246-256.

rise by 2100 as the benchmark for this indicator, as sea level rise is expected to increase the frequency and severity of coastal flooding. The 0.5-meter rise in sea level by 2100 is based on the IPCC's RCP 8.5 scenario as mentioned above, emphasizing the potential impact of rising sea levels on coastal communities. The indicator provides insight into areas that are susceptible to coastal flooding and their level of vulnerability. It gives a comprehensive understanding of how a rising sea level could impact transportation and mobility, public health, and public infrastructure in a community.

Climate and Disaster Risk Burden – Impervious Surfaces (from Land Cover)

This indicator measures the environmental burden on a particular community to help analyze community disadvantage in the context of climate change, transportation, mobility, and health. Impervious surfaces, such as roads and parking lots, can have a variety of negative consequences, especially in communities that are already disproportionately exposed to environmental burdens. These surfaces generate and amplify heat islands, resulting in poor air quality and an increased risk of heat-related illnesses and death.[81] This indicator is derived from the United States Geological Survey (USGS) Multi-Resolution Land Characteristics (MRLC) Consortium's National Land Cover Database (NLCD) 2019 product and aids in understanding how communities are exposed to heat islands and lack access to transportation options.

Indicator: Impervious Surfaces

This variable is included in the index measuring disadvantage as it is an indicator of increased climate burden. It reflects the impact of heat islands on a community and can have a negative impact on public health and increase the risk of heat-related illnesses. The data for this indicator comes from the USGS MRLC Consortium, within the NLCD 2019 Impervious Products.

Indicator: Impervious Surfaces – Calculation

This indicator calculates the 2019 impervious surface by U.S. Census tract in 2020, based on the NLCD. The census shapefile was then reduced to only the tract codes and geometry, to reduce the size of the file. The code then proceeded to run a zonal statistic, mean calculation, on the overlaid data.

[81] Laaidi, K., Zeghnoun, A., Dousset, B., Bretin, P., Vandentorren, S., Giraudet, E. and Beaudeau, P., 2012. The impact of heat islands on mortality in Paris during the August 2003 heat wave. Environmental health perspectives, 120(2), pp.254-259.

Limitations and Considerations

USDOT's methodology measures neighborhood disadvantage. The ArcGIS dashboard facilitates stakeholder communication and data comparison, while component selection, normalization, and percentile ranking allow decision makers to factor in relative level of disadvantage where appropriate. The data, methodologies, and visualization tool have both strengths and limitations, discussed below.

Data

The Department of Transportation's (USDOT) methodology for measuring community disadvantage utilizes several components to determine a community's overall score. The components used include Transportation Insecurity, Health Vulnerability, Environmental Burden, Social Vulnerability, and Climate and Disaster Risk Burden. Each component is designed to capture various aspects of disadvantage and contribute to the overall score, allowing USDOT to understand the relative position of each community in terms of multiple layers of disadvantage.

The selection of these components provides a comprehensive approach to the complex interplay of various factors. An advantage to this approach is the ability to look at multiple factors, allowing communities to dive into the areas they deem as priorities. However, it should be noted that this method may not fully capture the multifaceted nature of disadvantage as it related to transportation. Some limitations of the data utilized in USDOT's methodology include the unknown missing data and metrics that cannot be easily measured. This impacts the accuracy of the results, as these factors may have a significant impact on the overall score.

In order to deal with missing data USDOT has taken specific measures. Alaska and Hawaii are calculated separately from the rest of the nation for their index scores, particularly due to the significant missing data in the Environmental Burden component for those states. This approach enhances the accuracy of the outcome by avoiding any distortion caused by missing data.

Where missing data is present (all data, except Alaska and Hawaii, have less than 5% missingness), the contiguous-mean interpolation method is employed by census tract. This method assigns the mean value of contiguous tracts to the missing data in a census tract, thereby providing a robust estimation of the missing data, while minimizing errors. This method is well-established in geographical data analysis and has demonstrated success in similar applications. In cases where a census tract with missing data does not have any neighboring tracts with complete data, the missing data will remain missing. It should be noted that this interpolation method may also fill in missing data for areas where it is logically unlikely to have any data, such as predominantly park areas. Thus, it is crucial to consider the underlying geographies when interpreting the resulting national index score.

However, there may still be concerns over the missing data in the current version of the data affecting local understanding. This limitation of the model is expected to improve with the availability of better and more complete data. To ensure transparency, Table 8 provides missingness analyses and descriptions for identification purposes.

By taking these steps, USDOT aims to bolster the accuracy and credibility of the results and to better comprehend community disadvantage and the relative position of each community in terms of multiple layers of disadvantage. The results of the contiguous-mean interpolation, as well as the separate calculation for Alaska and Hawaii, are available within the index files for further review.

Scale – Temporal and Spatial Misalignment

In this index and tool, we include census tract-level data, point-level data, county-level data, state-level data, etc. In other words, the data sources used are not always aligned in space. This means we may be generalizing the term "disadvantage" across populations that are in fact experiencing differing levels or impacts of disadvantage. We also include data that is not aligned in time, and therefore may be including metrics that describe disadvantage snapshots at different periods in the past, present, or future that may not be currently reflective of present disadvantage. We aggregate all these data sources to census tracts, as these are that most common area where data is reported, as well as being a statistical boundary where many policy decisions are made. For this reason, the results reported and displayed in the ETCE tool are not generalizable to individuals and are meant to be high-level descriptions of community-level cumulative disadvantage only.

This is important because while the tool allows for better-informed community-level decision making, it may not be generalizable to all use cases or populations where the data may smooth levels of disadvantage. In other words, populations and individuals living in disadvantaged census tracts, may in fact not be cumulatively disadvantaged, and vice versa – those not living in disadvantaged tracts may be in fact disadvantaged in regard to many of the indicators utilized.

Methods

USDOT's methodology incorporates several methods to determine the overall score, including min-max scaling and percentile ranking. Normalization is a strength of the method as it allows for data standardization and eliminates the impact of different units of measurement, leading to consistent data comparison. The percentile ranking helps USDOT to understand the relative position of each component and overall score in relation to other census tracts, allowing them to design policies and programs that effectively address the needs of the most vulnerable communities.

However, there are some limitations to USDOT's methodology, such as the use of a single threshold (the 65th percentile) to determine whether a community is disadvantaged. Using hard cutoffs, like the 65th percentile, may over-simplify disadvantage definitions and underlying local realities, which is why we include deep dive on component scores and indicator values so that more localized understanding can be achieved. However, it is important to note that this threshold may not accurately reflect the unique needs and challenges of various communities, nor will it fully capture the complexities and nuances of the relationship between communities. While the team has added in the option to view data and see different percentiles, the cutoff remains at the 65th percentile. This statistical choice may be considered a limitation that could impact the interpretation of the results. Some local variation may be hidden due to the tool's design toward comparison at the national, regional, and state level. The team has aimed to retain as much granularity as the data and methods allow, but future research could benefit from considering alternative methods for defining disadvantaged communities, such as the use of multiple thresholds or indicator weights, to better reflect the unique needs and challenges of different communities across variables.

Tool

USDOT's methodology is visualized using an ArcGIS dashboard, which provides users the ability to interact with the data, allowing for a more in-depth understanding of the results. This is a strength of the tool as it allows for effective communication and collaboration between USDOT and stakeholders, making it easier to understand disadvantage.

However, there are some limitations to the ArcGIS dashboard. The tool may be limited by the data inputs and calculations used in USDOT's methodology. Additionally, the tool may not provide the ability to analyze and compare the results with other data sources, making it difficult to determine the reliability and validity of the results. In conclusion, while the ArcGIS dashboard is a useful tool for visualizing the results of USDOT's methodology, it should be used in conjunction with a critical evaluation of the data inputs, methods, and limitations of the methodology to ensure the accuracy and credibility of the results.

Appendix 1. Data Dictionary

The tables below represent the five main components of the ETCE Index dataset. You can find more detail on data sources and calculations at Justice40 Initiative | US Department of Transportation.[82]

Table 3. Transportation Insecurity Indicators

Component	Sub-component	Description	Units	Data Source	Geographic Granularity
Transportation Insecurity	Transportation Access (Composite)	Percent of households with no car	Percent households	ACS 2015-2020	Census Tract
		Average Commute time to work	Minutes	ACS 2015-2020	Census Tract
		Walkability Index value from EPA	Score (inverse taken)	EPA Smart Location Database 2021	Census Block Group
		Frequency of Transit Services per Sq Mi	Count/sq mi (inverse)	EPA Smart Location Database 2021	Census Block Group
		Jobs within a 45-min Drive	Count (inverse)	EPA Smart Location Database 2021	Census Block Group
	Transportation Cost Burden (Composite)	Cost of Gas	U.S. Dollar (USD)	BTS LATCH 2017	State
		Cost of Transit	USD	NTD 2017-2021	Urbanized Areas
		Time Value of Money	USD	USDOT BCA 2023[83]	National
		Time to Work	Minutes	ACS 2015-2020	Census Tract
		Median Income	USD	ACS 2015-2020	Census Tract
		Vehicle Miles Traveled	Miles	BTS LATCH 2017	Census Tract
		Vehicle Finance Charges	USD	CES 2020-2021	Census Division
		Cost of Maintenance	USD	CES 2020-2021	Census Division
		Insurance Costs	USD	CES 2020-2021	Census Division
	Transportation Safety	Traffic Fatalities per 100,000 persons	Rate	NHTSA FARS 2020	County

[82] The sources are also linked within the references section.
[83] As of 2023, in 2021 dollars.

Table 4. Environmental Burden Indicators

Component	Sub-component	Description	Units	Data Source	Geographic Granularity
Environmental Burden	Air Pollution	Ozone level in the air	Dobson Unit	EPA's EJScreen 2022	Census Tract
		PM 2.5 level in the air	Micrograms per cubic meter	EPA's EJScreen 2022	Census Tract
	Hazardous Sites	Diesel PM level in air	Micrograms per cubic meter	EPA's EJScreen 2022	Census Tract
		Air toxics cancer risk	Score	EPA's EJScreen 2022	Census Tract
		Percent of tract within 1 mile of known hazard sites	Percent of area	EPA's Facility Registry Service (FRS) 2022	Point[84]
		Percent of tract within 1 mile of known Toxics Release sites	Percent of area	EPA's Facility Registry Service (FRS) 2022	Point
		Percent of tract within 1 mile of known Treatment and Disposal Facilities	Percent of area	EPA's Facility Registry Service (FRS) 2022	Point
		Percent of tract within 1 mile of known Risk Management Plan Sites	Percent of area	EPA's Facility Registry Service (FRS) 2022	Point
		Percent of tract within 1 mile of non-abandoned Coal Mines	Percent of area	US DOL Mine Data Retrieval System 2022	Point
		Percent of tract within 1 mile of non-abandoned Lead Mines	Percent of area	US DOL Mine Data Retrieval System 2023	Point
	Built Environment	Percent of houses built before 1980	Percent of occupied houses	ACS 2015-2020	Census Tract
	Transportation Infrastructure	Percent of tract within 1 mile of high-volume roads	Percent of area	USDOT BTS 2022	Line
		Percent of tract within 1 mile of railways	Percent of area	USDOT BTS 2022	Line
		Percent of tract within 5 miles of airports	Percent of area	USDOT BTS 2022	Point
		Percent of tract within 3 miles of ports	Percent of area	USDOT BTS 2022	Point
	Water Pollution	Percent of tract that intersects with a Watershed containing impaired water(s)	Percent of area	EPA WSIO 2022	HUC 12 Polygon

[84] Point data is available as specific locations (longitude and latitude).

Table 5. Health Vulnerability Indicators

Component	Sub-component	Description	Units	Data Source	Geographic Granularity
Health Vulnerability	Health Vulnerability	Prevalence of Asthma	Crude Prevalence (% of pop)	CDC Places 2020	Census Tract
	Health Vulnerability	Prevalence of Cancer	Crude Prevalence (% of pop)	CDC Places 2020	Census Tract
	Health Vulnerability	Prevalence of High Blood Pressure	Crude Prevalence (% of pop)	CDC Places 2020	Census Tract
	Health Vulnerability	Prevalence of Diabetes	Crude Prevalence (% of pop)	CDC Places 2020	Census Tract
	Health Vulnerability	Prevalence of Poor Mental Health	Crude Prevalence (% of pop)	CDC Places 2020	Census Tract
	Health Vulnerability	Hospital Proximity – Percent of tract within 10 miles of hospital	Percent of area	Department of Homeland Security (DHS) Homeland Infrastructure Foundation-Level Data (HIFLD) 2022	Point

Table 6. Social Vulnerability Indicators

Component	Sub-component	Description	Units	Data Source	Geographic Granularity
Social Vulnerability	Socioeconomic Status	Percent of population with Income below 200% of poverty level	Percent	ACS 2015-2020	Census Tract
		Percent of people age 25+ with less than a high school diploma	Percent	ACS 2015-2020	Census Tract
		Percent of people age 16+ unemployed	Percent	ACS 2015-2020	Census Tract
		Percent of total housing units that are renter-occupied	Percent	ACS 2015-2020	Census Tract
		Percent of occupied houses that spend 30% or more of their income on housing with less than 75k income	Percent	ACS 2015-2020	Census Tract
		Percent of population uninsured	Percent	ACS 2015-2020	Census Tract
		Percent of households with no internet subscription	Percent	ACS 2015-2020	Census Tract
		GINI Index	Score	ACS 2015-2020	Census Tract
	Household Characteristics	Percent of population 65 years or older	Percent	ACS 2015-2020	Census Tract
		Percent of population 17 years or younger	Percent	ACS 2015-2020	Census Tract
		Percent of population with a disability	Percent	ACS 2015-2020	Census Tract
		Percent of population (age 5+) with limited English proficiency	Percent	ACS 2015-2020	Census Tract
	Housing Type	Percent of total housing units that are mobile homes	Percent	ACS 2015-2020	Census Tract

Table 7. Climate and Disaster Risk Burden Indicators

Component	Sub-component	Description	Units	Data Source	Geographic Granularity
Climate & Disaster Risk Burden	Annualized Climate Hazard Losses	Estimated annualized loss due to disasters	Dollars	FEMA National Risk Index (NRI) 2021	Census Tract
	Future Extreme Weather Risk (Composite)	Increase in number of days over 90 degrees by mid-century	Days	DOI/NOAA CMRA 2022	Census Tract
		Number of days exceeding 99th percentile of precipitation by mid-century	Days	DOI/NOAA CMRA 2022	Census Tract
		Percent change in number of days with less than 0.01 inches of precipitation	Percent	DOI/NOAA CMRA 2022	Census Tract
		Percent of tract inundated by 0.5 sea level increase by 2100	Percent area	DOI/NOAA CMRA 2022	Census Tract
	Impervious Surfaces	Average Percent Land classified as Impervious Surface per Tract	Percent	USGS MRLC NLCD 2019	Raster

Appendix 2. Missingness Table

The table below displays the missingness statistics of indicators included in the ETCE index. This describes the level of missingness before contiguous-mean interpolation is applied.

Table 8. Missingness Statistics

Indicator Description	# Missing Tracts (out of 85,382)	% Total Tracts with Data
Total Population	0	100.00
Percent of Households with No Car	1108	98.70
Average Commute Time to Work	1230	98.56
Walkability Index Value from EPA	0	100.00
Frequency of Transit Services per Square Mile	0	100.00
Jobs within a 45 Minute Drive	0	100.00
Transportation Cost as Percent of Household Income	2957	96.54
Traffic Fatalities per 100,000 persons	1129	98.68
Ozone Level in the Air	1229	98.56
PM 2.5 Level in the Air	1229	98.56
Diesel PM Level in the Air	579	99.32
Air Toxics Cancer Risk	579	99.32
Percent of Tract Within 1 Mile of Known Hazard Sites	0	100.00
Percent of Tract Within 1 Mile of Known Toxics Release Sites	0	100.00
Percent of Tract Within 1 Mile of Treatment and Disposal Facilities	0	100.00
Percent of Tract Within 1 Mile of Management Plan Sites	0	100.00
Percent of Tract Within 1 Mile of Non-Abandoned Coal Mines	0	100.00
Percent of Tract Within 1 Mile of Non-Abandoned Lead Mines	0	100.00
Percent of Houses Built Before 1980	1087	98.73
Percent of Tract Within 1 Mile of High-Volume Roads	0	100.00
Percent of Tract Within 1 Mile of Railways	0	100.00
Percent of Tract Within 5 Miles of Airports	0	100.00
Percent of tract Within 3 Miles of Ports	0	100.00
Percent of tract Intersecting with an Impaired Water Watershed	0	100.00
Prevalence of Asthma	2194	97.43
Prevalence of Cancer	2194	97.43
Indicator Description	**# Missing Tracts (out of 85,382)**	**% Total Tracts with Data**

Prevalence of High Blood Pressure	2194	97.43
Prevalence of Diabetes	2194	97.43
Prevalence of Poor Mental Health	2194	97.43
Hospital Proximity – Percent of tract within 10 miles of a hospital	0	100.00
Percent of Population with Income Below 200% of Poverty Level	860	98.99
Percent of People age 25+ with Less Than a High School Diploma	1806	97.88
Percent of People age 16+ Unemployed	860	98.99
Percent of Total Housing Units that are Renter-Occupied	1087	98.73
Percent of Occupied Houses that Spend 30% or More of Their Income on Housing with Less Than 75k Income	1108	98.70
Percent of Population Uninsured	1005	98.82
Percent of Households with No Internet Subscription	1108	98.70
GINI Index	1195	98.60
Percent of Population 65 years or Older	860	98.99
Percent of Population 17 years or Younger	860	98.99
Percent of Population with a Disability	1784	97.91
Percent of Population (age 5+) with Limited English Proficiency	860	98.99
Percent of Total Housing Units that are Mobile Homes	1087	98.73
Estimated Annualized Loss Due to Disasters	1480	98.27
Increase in Number of Days over 90 degrees by 2050	152	99.82
Number of Days Exceeding 99th Percentile of Precipitation by 2050	1240	98.55
Percent Change in Number of Days with Less than 0.01 inches of Precipitation	0	100.00
Percent of Tract Inundated by 0.5 Sea Level Increase by 2100	0	100.00
Average Percent Land Classified as Impervious Surface per Tract	1196	98.60

References

Datasets[85]

- U.S. Department of Commerce
    - U.S. National Oceanic and Atmospheric Administration
        - Climate Mapping for Resilience and Adaptation 2022
    - U.S. Census Bureau
        - American Community Survey (ACS) 2015-2020
        - Longitudinal Employer-Household Dynamics 2017
        - Census Tracts 2015-2020
- U.S. Department of Transportation
    - U.S. Bureau of Transportation Statistics
        - Geospatial at BTS 2022
        - Local Area Transportation Characteristics for Households Data 2017
    - Office of the Secretary
        - Benefit Cost Analysis Guidance 2023
    - National Highway Traffic Safety Administration (NHTSA)
        - Fatality Analysis Reporting System (FARS) 2020
    - Federal Transit Administration
        - US National Transit Database (NTD) 2017-2021
- U.S. Environmental Protection Agency (EPA)
        - Environmental Justice (EJ) Screen 2022
        - Watershed Index Online (WSIO) 2022
        - EPA's Facility Registry Service (FRS) 2022
        - EPA Smart Location Database 2021
- U.S. Department of Labor (DOL)
    - U.S. Bureau of Labor Statistics
        - Consumer Expenditure Survey 2020-2021
    - U.S. Mine Safety and Health Administration
        - Mine Data Retrieval System (MDRS) 2022
- U.S. Department of Health and Human Services
    - U.S. Centers for Disease Control (CDC)
        - PLACES Local Data for Better Health 2020

[85] R packages "tidycensus" and "tigris" were used to assist in data gathering for the index.

- U.S. Department of Homeland Security
    - Cybersecurity & Infrastructure Security Agency
        - Homeland Infrastructure Foundation-Level Data 2022
    - Federal Emergency Management Agency
        - National Risk Index for Natural Hazards 2021
- U.S. Department of the Interior
    - U.S. Geological Survey, Multi-Resolution Land Characteristics Consortium (MRLC)
        - National Land Cover Database (NLCD) Impervious Products 2019