CRESP
Consortium For Risk Evaluation with Stakeholder Participation

Consortium Universities: **Vanderbilt University**, Georgia Tech, Howard University, New York University, Oregon State University, Rutgers University, University of Wisconsin, Texas Tech University

Environmental and Social Justice for DOE EM Site-Regions:

A Geographical Analysis

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Acknowledgment and Disclaimer

This report was developed and authored by Michael R. Greenberg[1], Ph.D., Henry J. Mayer[2], Ph.D., and David S. Kosson[3], Ph.D. and is based on work supported by the U. S. Department of Energy, under Cooperative Agreement Number DE-FC01-06EW07053 entitled 'The Consortium for Risk Evaluation with Stakeholder Participation III awarded to Vanderbilt University. The opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily represent the views of the Department of Energy, Vanderbilt University, and the author's CRESP colleagues.

The first author recognizes the increased significance of social and environmental justice issues. To be as transparent as possible, the author has expressed views and demonstrated approaches to the issue beginning in 1984 and this interest continues exemplified by recent publications (See references below). He also acknowledges that he was part of the team that worked on *Toxic Waste and Race* (1987), working with Charles Lee and Benjamin Goldman, the main authors of that study for the United Church of Christ. The author served on a US EPA environmental justice committee.

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Study Objective

The objective of this CRESP study was to measure and compare the economic and social status of the communities located around seventeen active DOE-EM sites. In comparison to each site's host state and the U.S. as whole, which areas around EM sites appear to be the most underserved, overburdened and vulnerable communities that DOE might be able to assist through improved environmental justice[4] programs? Geographical studies such as this have contributed to raising the visibility of environmental and social justice and planning approaches to impactful assistance.

This study does not advocate for action at a particular set of sites; it is not meant to be prescriptive. It does provide a perspective across demographic, environment, public health and local attractiveness indicators that can be considered when developing specific EM programs. Indeed, to the best of our knowledge it is the most complete effort to combine environmental and social justice, public health and environmental data sets produced by the U.S. EPA, Centers for Disease Control and Prevention, and the 500 cities project and apply them to multiple geographical scales.

Background

Billions of dollars invested by the federal government in nuclear weapons research, testing, and production began in the mid-1940s and a half-century later has been augmented by cleanup and restoration missions to close the circle on the spitting of the atom. These investments have created cycles of economic distress and wealth in host regions. On the one hand, tens of thousands of jobs were created in erstwhile rural regions and brought urban wealth and services to the current Savannah River, Oak Ridge, Washington Tri-cities and other areas of the weapons' complex. When the U.S. American Manufacturing Belt cities of the Northeast and Midwest lost manufacturing jobs, many of these DOE site-regions maintained their local economies (Melaman, 1974; Bluestone & Harrison, 1982). Yet, the annual federal government's allocations to these mostly rural regions has varied, which at times has led to unstable economies

Approach

Poverty and race/ethnicity are key element of environmental justice. However, there is wide variation in the United States in regard to the presence of poverty, lack of educational achievement, race/ethnicity, and different age groups. Accordingly, while these characteristics usually are associated, they are not strongly associated in every place and yet there can be evidence of environmental justice challenges.

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[4] Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations and policies. Fair treatment means no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental and commercial operations or policies. (USEPA)

The reader will see that some places have populations with four or more of the standard environmental justice metrics, while others have only one or two.

The main text offers a basic presentation of the results and Appendix B provides the county-by-county results for some of the metrics evaluated. CRESP created two data sets. The primary data set is an 81-county-state-national data set constructed around 17-DOE-EM cleanup sites (See Table 1). Thirty-four variables (Table 2) were chosen to measure demographics (8), public health (8), environment (11), and local attractiveness (7).

The second data set, more limited, was built for higher resolution geographic analysis at Paducah, Portsmouth, and Oak Ridge regions using circles with radii of 1, 1.5, 2, 3, 5 and 10 miles. As a demonstration, census tract data about health of Yakima City's population was used to demonstrate the potential value of having health data at the census tract level. Only data for Yakima City and Kennewick are available at this time.

The study primarily drew on data published in the U.S.EPA (2019) EJScreen data base and the Population Health Institute's (2021) *County Health Rankings and Roadmaps*. These two data bases, in turn, obtained data from a wide variety of government data bases, most notably the Centers for Disease Control and Prevention (CDC). These data bases have only been available for a few years, and hence, the analyses in this paper containing this wide variety of metrics were not feasible to do until the last few years.

A guiding principle during this study is that statistical findings should not rest on a single method or on a limited number of metrics. Hence, combinations of metrics with several statistical methods were tested. Given the consistency of the results, a good deal of the statistical results is provided in appendices. Appendices A through D present different statistical approaches to analyzing the data and associated results. Appendices E, F, and G present information for the higher resolution Paducah, Portsmouth, and Yakima case studies, respectively.

Results

CRESP developed a summary metric called the demographics of environmental justice (DEJ) using EPA data and averaging the EPA metrics of low income, people of color, linguistic isolation, and less than a high school education. Each of the four metrics was scaled of 0 to 100. The metrics are compared to the host state. For example, a county with an index score of 80 in regard to low income means that the county is the upper 20% in proportion of the population that is low income compared to its host state. The overall DEJ index is the average of all four metrics. If a county had index values of 50, 60, 70 and 80, then its overall DEJ index score would be 65 (260/4). An index average score of 75 or more means that the county in question presents relatively strong evidence of environmental justice issues, whereas counties with an average of 30 or less present low evidence. Average values of 47 to 53 are close to the average of 50. Results indicated that high DEJ values were associated with poorer health outcomes, a lower food index score, a lack of adult insurance, lower home values, and many other indicators used in the analyses.

The three most important results are highlighted here:

1. County scale associations among demographics of environmental justice, environmental exposure, health outcomes, and local attractions:

As expected from the literature, we found strong correlations among many of the demographic, environmental exposure, health, and local attractions metrics. Briefly, 10 of 81 counties provided the most evidence of environmental and social justice challenges. With 100 indicating the highest possible DEJ score and noting that the scores below have been rounded off to the nearest whole number, the counties neighboring DOE-EM sites with the highest scores are:

> Savannah River: Allendale (81), Barnwell (71), Bamberg (73), Hampton (75), and Orangeburg (70)
>
> Hanford: Franklin (87), Grant (83), Yakima (87)
>
> Moab: San Juan (89)
>
> Idaho NL: Bingham (73)

The highest scores, indicating relatively high vulnerability across the set of 81 counties, were concentrated in the Hanford and Savannah River site regions, as noted above. The county-scale geographical analysis points to these two very large cleanup sites as strong candidates for special DOE-EM environmental and social justice attention.

The lowest scores were found in the counties surrounding the Los Alamos, WIPP and Nevada Test Sites. For example, the Los Alamos region counties, with the exception of Mora (65), had values between 18 and 54, the counties surrounding the Nevada site had values from 21 to 50, and those around WIPP ranged from 44 to 64 (See Appendix B for details).

In order to examine the relationships among the measures of environmental justice, several multivariate tools were used that show how and where the socioeconomic, race/ethnicity, and age metrics intersect and do not intersect. For example, to show where they intersect and are associated with health outcomes, environmental contaminants, and local assets, a multiple regression was carried out based on EPA's Demographic Index that combines low income and people of color (Appendix C). Yet the divergence of socioeconomic status and race/ethnic across the DOE sites shows that race/ethnicity and poverty are not strongly associated in every location, and nevertheless there can be environmental justice challenges. In short, each DOE site has its unique challenges in regard to environmental justice, and these analyses summarize the patterns across the complex. These results are briefly discussed in the main text, but presented in far more detail in Appendix D.

2. Variations Among the Host and Adjacent Counties in Environmental Justice:

Based on the county data, using average value for each demographic environmental justice measure and the 25th, 50th, and 75th percentiles, each county was compared to its host state and the U.S. as a whole. Seven metrics were obtained from EPA's EJScreen data base (USEPA, 2019). The metrics include low income, people of color, linguistic isolation, limited educational achievement, children and senior citizens. The EPA created a demographic index, which is the average of low income and people of color as a seventh indicator. Areas with a disproportionate number of people with these characteristics are expected to have disproportionate vulnerability to contaminants that fall under the EPA's mandate. The scores for the seven metrics were standardized by the EPA to their states and the U.S. on a scale from 0 to 100 as described above. With 50 as the central tendency, an average of 47 through 53 means that the DOE-EM-site-region county is representative of their host state and/or the nation.

Across the 81 counties, the average scores were statistically significantly higher (P<.05) than their host state and the United States for: (1) population > 64 years old, (2) linguistic isolation, (3) less than a high school education, and (4) low income. None of the indicator averages were significantly lower than their states and the United States. In other words, as a whole the site regions present evidence of EJ challenges for some of the EPA metrics.

Perhaps the most interesting comparison of means was among 18 counties that hosted EM sites with annual cleanup budgets of at least $100 million, their 28 adjacent counties, and 35 counties that are in regions with a cleanup budget less than $100 million. For example, Aiken, Allendale and Barnwell counties are Savannah River's host counties with large cleanup budgets. Bamberg, Edgefield, Hampton, Lexington, and Orangeburg are adjacent counties in the Savannah River region. In contrast, Lawrence Livermore's counties are in a region with a relatively low cleanup budget.

We found that the 18 host counties with the highest site cleanup budgets were in the middle of almost every comparison (See Table 4). An interesting interpretation that follows is that DOE's investments have reduced the host state's demographic patterns of inequity in these DOE-EM-region counties, albeit the differences are small. For example, the low-income average in the 18 host counties was 58. In comparison, the value for the 28 adjacent counties was 62 and was 54 for the 35 non-major counties (See Table 4 for all these comparisons). Differences of 1 or 2 points clearly can occur by chance. Yet, the fact that the major host sites had the middle score for all 7 metrics is improbable, which we suspect will be of interest in follow-up environmental justice evaluations and initiatives. Unfortunately, the data base is not historical, which would have allowed the Department to measure changes during its long history at many of these sites.

3. High Resolution Case Studies of Oak Ridge, Paducah and Portsmouth:

County-scale analysis is appropriate for the DOE sites as a whole because many of the sites are so large that they include multiple counties that have been impacted by the DOE site. However, when a site is small and/or has a centroid that can be used to study how impacts change with distance or direction from the site, a high resolution, more granular data base is appropriate. To demonstrate what such resolution could yield, we designed a data base for Oak Ridge, Paducah, and Portsmouth. Measurements were made from the centroid of Paducah and Portsmouth, and centroid of Y-12 was used as the center for Oak Ridge. Instead of using a politically defined area, circles with various radii were drawn from the center of the sites, and then data from EPA's data base was collected for these circular areas. The environmental justice indicators show challenges at Oak Ridge and Portsmouth. However, these cannot be followed into health impacts because the health outcomes and behaviors data are only available at the county scale and for 500 large U.S. Cities, which includes only Yakima City and Kennewick.

Suggestions

During the course of this study, the authors encountered information–related gaps related to environmental justice. We view them as ideas to consider, perhaps in collaboration with site advisory boards, elected officials, and regulators. Some may be high priorities, and each offers the opportunity for DOE to track its investments in disadvantaged communities and to build communication channels with advisory boards, local elected officials and communities.

Air quality data bases depend on air quality monitoring stations, and too few stations can lead to misleading air quality estimates. We cannot judge the distribution of monitoring stations near DOE sites. EM, we believe, would be able to assist in figuring out the needed density of monitoring stations for measuring the outdoor environment. DOE has ecological data for its sites. Again, in cooperation with its surrounding communities there may be opportunities to help government and communities figure out how to build a data base that can be used by other government agencies and publics centered around ecological resources.

Another glaring data gap is the absence of drinking water quality and local water quality data. We are not saying that these data do not exist. What we are saying is that there is no national published data set that allows comparison of drinking water quality across U.S. counties. We suspect that DOE has some of these data for its regions and the assets to place them in a data base in cooperation with state regulators, EPA and local communities.

In regard to human health outcomes and behaviors, it would be helpful to have the outcome and behaviors data for DOE site regions. We do not know the cost of building such a data base but suspect that local communities would want to see it and that state government epidemiologists would be a good partner in such an effort.

Also, this study shows a wide range of data about the built environment assets near DOE sites. Local communities may be interested in building data bases that they can use to attract investments and people to their communities.

DOE and its community advisory panels understand the growing importance of social media in listening to and sending information to communities. We think that some sites would want to have a data base that would allow them to more effectively communicate with stakeholders and discuss the kinds of data that they believe to be most important to them. In this study, the only information available is broadband access by county. Notably, the disadvantaged communities typically had lower access rates.

We offer a hypothetical example of how this might work at a site. Suppose for example DOE wanted to build environmental and social justice programs in the set of counties near Savannah River identified above as marked by environmental and social justice challenges. The average DEJ index we created for Allendale, Bamberg, Barnwell, Hampton, and Orangeburg was 74, higher than any other set of counties in the study. The study found that the five-county premature death rate for these counties was 48%

higher than the state as whole, their self-declarations of poor or fair health were 47% higher, their flu vaccination rate was only 60% of the state's, and children's insurance rate was 20% lower. In addition, in regard to assets, home values averaged only about 40% of the state's, broadband access was 20% less, and unemployment rates were over 80% higher. In counties that are approximately 60% African American, we cannot say what the community's priorities are. Will they want to focus on jobs? Health services? Communications? Education? What studies such as this one can do is compare this set of counties to others near DOE facilities and provide context about the interconnected set of challenges that these communities face.

While these suggestions entirely focus on data-related issues found during this empirical study, we are confident that these will overlap ideas that relate to education, job training, small business programs and establishing social media connections and others that would follow from site case studies based on interviews with key stakeholders and document review.

Introduction

During the 1970s and early 1980s, the Clean Air Act, Safe Drinking Water Act and more than a dozen other Federal laws and regulations made it clear that environmental protection had become a national issue. Indeed, Dunlap and Mertig (1991) considered these actions to constitute the third environmental movement in U.S. history. In 1982, the PCB hazardous waste case in Warren County, North Carolina tied environmental justice to the federal environmental mandate. President Clinton's 1994 Environmental Justice Executive Order (12898) formalized this link.

Geographical studies have contributed to raising the visibility of environmental justice. *Toxic Waste and Race* (United Church of Christ, 1987) demonstrated the association of the location of major hazardous waste sites with poverty and minority status, and the value of using geographical data to better understand the on-the-ground properties of social and environmental justice. Other geographical studies found similar results, but some did not (Bullard et al. 2007; U.S. GAO, 1983; Baden, Coursey 2002; Zimmerman, 1993; Anderton et al., 1994).

Over 25 years after Executive Order 12898 was signed, the Biden Administration's Executive Order 14008 on Climate Change includes provisions for environmental justice actions by the federal government, a new White House Interagency Council, and a White House Environmental Justice Advisory Council Justice40 Initiative, Climate and Environmental Justice Screening Tool, and revisions to Executive Order 12898.

Arguably, the EPA has been the major government EJ operative because of the breadth of its responsibilities. Yet, DOE EM has a special responsibility because it has managed nuclear weapons and waste materials at more than 100 sites across the United States. Furthermore, when the Atomic Energy Commission was developing nuclear weapons, private land was confiscated, and people were forced to move. The environmental legacy and land use actions have left an ongoing challenge that former Secretary Hazel O'Leary called "closing the circle on the spitting of the atom." (OEM 1995, 1996, see also Bebbington, 1980; Gerber, 1992; Kyne and Bolin, 2016; Kiernan, 2013).

Another issue that draws EM to social and environmental justice is the argument that the DOE has created cycles of economic distress and wealth in its host regions. On the one hand, tens of thousands of jobs were created in erstwhile rural regions and brought urban wealth and services to the current Savannah River, Oak Ridge, Tri-cities and other areas of the weapons complex. Markusen et al. (1991) called them "state anchored regions." (see also Greenberg et al., 2002, 2003). Hence, when the U.S. American Manufacturing Belt cities of the Northeast and Midwest lost manufacturing jobs, these DOE site-regions maintained their local economies (Melaman, 1974; Bluestone & Harrison, 1982). Yet, the federal government's allocations to these mostly rural regions has varied, which has led to unstable economies. For example, Brauer (1995, 1997) argued that DOE-occupied areas have had higher unemployment rates than areas that the DOE did not choose for sites. Mitchell et al. (1989) asserted that the DOE-supported areas may be stigmatized and not attract private investment. Economist Milton Russell (1999) recognized the debt owed to the residents off these DOE regions, calling for separate budgets for cleanup and economic redevelopment, while the U.S. GAO (1999) called for targeted economic redevelopment programs. Even if these ideas are well over three decades old and arguably out of date, they provide the historical basis for ongoing expected support from the DOE.

The DOE's present position impacting its site-regions is summarized in an official release called "promoting energy justice" (USDOE, 2021). DOE's Office of Economic Impact and Diversity will lead this effort:

> "For far too long, communities of color and low-income communities have borne the brunt of pollution to the air, water, and soil they rely on to live and raise their families. The clean energy revolution must lift up these communities that have been left behind, and make sure those who have suffered the most are the first to benefit.
>
> DOE's Office of Economic Impact and Diversity will lead this effort through a new role committed to implementing President Biden's Justice40 Initiative —a plan to deliver 40% of the overall benefits of climate investments to disadvantaged communities and inform equitable research, development, and deployment within the DOE."

DOE Secretary, Jennifer Granholm (2021) put inclusion at the center of the DOE's agenda in her March 9, 2021, speech:

> "Our work is about more than just restoring the land. It is really about keeping our promises to the American people. It is our responsibility to lift this burden from communities that have shouldered the burden of our safety and help them achieve a more vibrant and sustainable future. Local residents may or may not have had some idea of what was going on in their backyard during the early years at our sites, but they certainly weren't at the decision-making table."

The massive size of some of DOE's sites makes it challenging to determine who are local stakeholders. While many of its sites are the size of large brownfields and industrial/waste management Superfund sites, others such as Hanford, Idaho National Laboratory, Nevada National Security, Savannah River and Oak Ridge comprise massive land holdings in multiple counties and municipalities, which means multiple environmental and social justice communities with different perceptions, values and preferences.

Given the complexity of EM's challenges, the authors conducted an analysis of demographic and other information to help better understand the communities living near DOE's major cleanup sites. The analysis focused on traditional demographic attributes associated with social and environmental justice and vulnerability, most notably low-income populations, concentrations of Afro-, Latino/Hispanic, and Native-American populations; limited educational achievement, linguistic isolation, and concentration of the youngest and oldest populations (U.S.EPA, 2019). Given the history of the United States, the authors expected to find that geographically concentrated EJ communities would be associated with relatively poor health outcomes, more environmental vulnerability, and less assets to attract people and investors.

The specific goals of this study were:

1. Examine demographic characteristics of residents of DOE-EM-site-regions by comparing the host areas to their host states, the United States, and each other;
2. Measure the health, environment, and economic correlates of the demographic attributes looking for patterns that would assist DOE-EM with its environmental justice programs.

These objectives required working with data from pre-defined areas, specifically, census tracts, local governments, counties, as well as host states. These objectives also required gathering data for user-defined areas, in this case building circular study areas with radii of 1.5, 2, 3, 5 and 10 miles around a single point (e.g., EM site centered).

The paper is presented in four parts: (1) data and methods; (2) results for 81 counties (3) results for high resolution studies, focusing on Oak Ridge; and (4) multiple appendices, including most of the multivariate analyses and case studies of Paducah, Portsmouth, and Yakima.

Data and Methods

The diversity of places, populations and the data sets included in this study requires highlighting what this study could and could not do as discussed in the following sections.

Choosing Site-Regions

The DOE geographical legacy includes more than 100 sites across the United States, sometimes referred to as the “nuclear factory” (OEM, 1995). One possibility was choosing all sites. While valuable as part of a DOE history project, this definition was too broad a net to cast given the need to address active sites and those close to closure. At the other extreme, only the major cleanup sites with billions more to spent during future decades could have been selected. Hanford, Savannah River, Oak Ridge, Idaho, Paducah, Portsmouth, and the WIPP sites account for 94% of the $5.8 billion requested in the FY2021 budget (OEM, 2021). The difficulty with a limited geographical definition is that it omits several sites where active cleanup is occurring, is drawing to a close, or has just closed. There is no perfect set of sites. As a compromise, 17 sites were selected that the Office of Environmental Management (OEM) lists as “cleanup sites” (Table 1).

The definition of host areas within the selected 17 site locations is not straightforward. Previous studies focusing on economic impacts and planning at DOE EM sites ranged from including any county within 50 miles of a DOE facility to a few counties (Greenberg et al., 2002, 2003; Lowrie and Greenberg, 1997, 2001). For this study, DOE’s designations of surrounding cleanup areas include counties, municipalities, and tribal nations. Yet, experience with DOE-EM-sites and other studies suggests that impacts extend beyond official area designations. Hence, almost all the counties adjacent to those indicated by OEM as the host counties were included. Those counties that barely shared a boundary with the EM-designated county were not included.

The county is an appropriate unit for starting because a great deal of data is available for counties. Only limited amounts of data are available for towns, census tracts and blocks. Hence, the county is the basic unit for the first part of the analysis. However, ideally the analyses also should be conducted with census tracts, circles and other polygons (Greenberg 2021a, b, c). Unfortunately, currently, only EJScreen data was searchable for every area at these granular levels. EJScreen (U.S.EPA, 2019) is a new data base that allows users to identify a city, county, census tract or block and access data about each unit. The biggest data gap is the absence of health outcomes and behavior data. Recognizing this limitation, a higher resolution study was carried out for the Paducah, Portsmouth, and Oak Ridge sites, as well as exploring Yakima city to demonstrate what can be done with the current data and with new data and software that is expected to become available in the not-too-distant future.

Another decision was to compare each host area to other areas, a choice that reflects experience at presenting these kinds of data to public audiences. Many of the measurable indicators mean little to audiences. What does an ozone level of 42 ppb mean? It means more if there is a national standard, which there is, and even more if it is compared to other areas, especially the state and other nearby areas. Having experimented with comparisons to the United States as a whole and the host state, the host state is the most relevant. For example, the first author has presented health outcomes data to public audiences. Telling an audience that the life expectancy in their county is 80 will normally bring smiles to audiences, but not if the state average is 84 years. They will ask why is their rate four years less? This normally leads to a discussion of premature deaths due to firearms and other violent causes of death, drug-related deaths, and in 2020 and 2021 to a discussion of COVID-19 related deaths. While the first part of this paper focuses on county to state comparisons, several comparisons are made with the nation as a whole for additional context. A county to nation comparison is also appropriate but, in our experience, resonates less with community groups.

Current data limitations mean that high resolution studies for small cities, towns, and census tracts are constrained. Nevertheless, Paducah, Portsmouth, and Oak Ridge were examined with current existing data for circular areas around the sites with inner circles with a 3-mile radius, which is then compared to a 10-mile radius circle, as well as the local county and state. For example, in the case of Paducah, the county is McCracken, and the state is Kentucky. Figuratively, these demonstration projects are the equivalent of cutting open an onion and comparing the core to layers closer to the surface.

Overall, choosing counties currently listed as cleanup sites has the disadvantage of leaving out historical sites such as Fernald, Mound, the former plutonium plant near Denver, and others. Another disadvantage is that some counties are quite large and arguably are not impacted or only slightly impacted by the DOE site. An advantage of focusing on 17 sites is the study was able to concentrate on a smaller number of site-regions and built a good data set. The high-resolution analysis of three sites allows analysis of the EPA EJScreen data for the area immediately around the site and compare it to adjacent areas. The disadvantage is that a good deal of the desirable data is not available. Table 1 provides summary data about the 17 site-regions. The DOE not only works with counties (identified in Table 1), but also selected cities and tribal nations.

Table 1. Seventeen EM Cleanup Sites

Site (n=number of counties)	Location**	Fy2021 budget request*
1- Brookhaven, NY (n=2)	Host county: Suffolk Adjacent county: Nassau	0
2- Energy Technology Engineering Center (ETEC), CA (n=4)	Host counties: Ventura Adjacent counties: Kern, Los Angeles, Santa Barbara,	$11 million
3- Hanford Office of River Protection, WA	North of City of Richland, WA Areas same as number 4 below.	$1.258 billion
4- Hanford Operations Office, WA (n=5)	Host counties: Benton, Franklin Adjacent counties: Grant, Walla Walla, Yakima	$655 million
5- Idaho National Laboratory, ID (n=4)	Host county: Bonneville Adjacent counties: Bingham, Jefferson, Madison	$271 million
6- Lawrence Livermore, CA (n=5)	Host county: Alameda Adjacent counties: Contra Costa, San Joaquin, San Mateo, Santa Clara	$1.764 million
7- Los Alamos National Laboratory, NM (n=8)	Host counties: Los Alamos, Rio Arriba, Santa Fe, Taos Adjacent counties: Colfax, Mora, Sandoval, Torrance	$120 million
8- Moab, UT (n=4)	Host county: Grand Adjacent counties: Emery, San Juan, Uintah	$48 million
9- Nevada National Security Site, NV (n=4)	Host county: Nye Adjacent counties: Esmerelda, Eureka, San Juan	$61 million
10-Oak Ridge, TN (n=6)	Host counties: Anderson, Roane Adjacent counties: Cumberland, Knox, McMinn, Morgan	$432 million
11- Paducah KY (n=4)	Host county: McCracken Adjacent counties: Ballard, Graves, Marshall	$282 million
12-Portsmouth, OH (n=7)	Host counties: Jackson, Pike, Ross, Scioto Adjacent counties: Gallia, Highland, Pickaway	$491 million
13- Sandia National Laboratory, NM (n=5)	Host county: Bernalillo Adjacent counties: Cibola, Sandoval, Torrance, Valencia	$4.86 million
14-Savannah River, SC (n=8)	Host counties: Aiken, Allendale, Barnwell Adjacent counties: Bamberg, Edgefield, Hampton, Lexington, Orangeburg	$1.703 billion
15-Separtions Process Research Unit, NY (n=7)	Host counties: Albany, Schenectady Adjacent counties: Greene, Montgomery, Renselaer, Saratoga, Schoharie	$15 million Work should be completed in 2021
16-WIPP, NM (n=4)	Host county: Eddy Adjacent counties: Chaves, Lea, Otero	$390 million
17- West Valley, NY (n=4)	Host county: Cattaraugus	$92 million

	Adjacent counties: Allegany, Chautauqua, Erie	
Total:	17 DOE EM site regions, 81 counties, 11 states	

*Source: OEM, DOE (2021). Cleanup Sites. https://www.energy.gov/em/mission/cleanup-sites. May 22, 2021

**The location information is limited to counties. In many locations, DOE works with local governments and tribal nations.

Choosing Metrics

The author gathered 34 metrics divided into four categories (See Table 2). Seven of the 8 demographic metrics were used for state and national comparisons. Hence, there are 34 metrics that were used to create 41 variables. Table 2 explains how the 34 were used to create 41 variables.

Demographic (8 state comparisons, also used for 7 national comparisons)

Public Health (8 state comparisons)

Environment (11 state comparisons)

Local Attractiveness (7 state comparisons)

Table 2. County-Scale Metrics

Metrics	Explanation	Source
Demographic metrics (n=8) and variables (n=15		
1 & 2. Demographic index, % Compared to state & nation	Average of minority and income indicator	EPA: EJScreen
3 & 4. Minority population, % Compared to state & nation	Group tends to be more vulnerable	EPA: EJScreen
5 & 6. Low-income population, % Compared to state & nation	Group tends to be more vulnerable	EPA: EJScreen
7 & 8. Linguistically isolated population, % Compared to state & nation	Group tends to be more vulnerable	EPA: EJScreen
9 & 10. Population with less than a high school education, % Compared to state & nation	Group tends to be more vulnerable	EPA: EJScreen
11 & 12. Population under 5 years of age, % Compared to state & nation	Group tends to be more vulnerable	EPA: EJScreen

13 & 14. Population over 64 years of age, % Compared to state & nation	Group tends to be more vulnerable	EPA: EJScreen
15. Index of dissimilarity Compared to state	% of Non-Hispanic Whites that would need to move to another census tract in the county to equalize the distribution. Used in several multivariate tests.	Federal Reserve Bank of St. Louis
Public Health (n=8)		
16. Health outcome rankings Compared to state	Aggregate of multiple indicators	County Health Rankings & Roadmaps, updated 2021
17. Health behavior ranks Compared to state	Aggregate of multiple indicators	County Health Rankings & Roadmaps, updated 2021
18. Age-adjusted premature death rates. Compared to state	Pre-75-year-old death rates. NCHS mortality files	County Health Rankings & Roadmaps, 2017-2019. Missing some counties with few people
19. Adults reporting poor or fair health, age-adjusted Compared to state	CDC behavioral risk factor survey data	County Health Rankings & Roadmaps, 2018
20. Adult health insurance codverage rates Compared to state	Small area health insurance estimates	County Health Rankings & Roadmaps, 2018
21. Children health insurance Compared to state	Small area health insurance estimates	County Health Rankings & Roadmaps, 2018
22. Healthy food environment, 1=worst, 10=best Compared to state	Multiple sources, including USDOA.	County Health Rankings & Roadmaps, 2015 & 2018
23. Proportion had flu vaccination Compared to state	CDC files	County Health Rankings & Roadmaps, 2018
Environment (n=11)		
24. Particulate matter (PM 2.5 in ug/m^3) Compared to state	Annual average, 2016. A combination of monitoring data and modeling.	EPA: EJScreen

25. Ozone (ppb) Compared to state	Summer seasonal average (May-September), ozone level, 2016. Monitoring and modeling.	EPA: EJScreen
26. NATA diesel PM (ug/m^3) Compared to state	National Air Toxics Assessment program focused on 187 hazardous air pollutants. Diesel particulate matter level in air, 2014.	EPA: EJScreen
27. NATA cancer risk (lifetime risk per million) Compared to state	National Air Toxics Assessment program focused on 187 hazardous air pollutants. Lifetime cancer risk from inhalation of air toxics, 2014.	EPA: EJScreen
28. NATA respiratory hazard index Compared to state	National Air Toxics Assessment program focused on 187 hazardous air pollutants. National ratio of exposure concentration to health-based reference concentration, 2014.	EPA: EJScreen
29. Traffic proximity & volume (daily traffic count/distance to road) Compared to state	Annual average vehicle count at major roads within 500 meters of block centroid divided by distance in meters, 2017	EPA: EJScreen
30. Lead paint indicator (% pre-1960 housing) Compared to state	% of housing built pre-1960, as an indicator of potential lead exposure, 2013-2017.	EPA: EJScreen
31. Superfund proximity (site count/km distance) Compared to state	Count of proposed and listed divided by distance in km, 2019	EPA: EJScreen
32. Risk management plan sites (RMP proximity - facility count/km distance) Compared to state	Sites within 5 km or nearest one beyond 5 km divided by distance in km, 2019.	EPA: EJScreen
33. Hazardous waste proximity (facility count/km distance) Compared to state	Count of TSDFs within 5 km or nearest one beyond 5 km divided by distance in km, 2019.	EPA: EJScreen

34. Wastewater discharge indicator (toxicity-weighted concentration/ m distance) Compared to state	Toxicity-weighted concentrations in stream- segments within 500 meters divided by distance in km, 2017.	EPA: EJScreen
Local Attractiveness (n=7)		
35.. Local park access Compared to state	% live within ½ mile of a park	EJScreen CDC data file
36. Violent crimes reported per 100,000. Compared to state	Uniform crime reporting, 2014 & 2016	County health rankings & roadmaps - FBI data
37. Home value Compared to state & nation	First quarter 2021	National Association of homebuilders, 2021
38. Adult unemployment rates. Compared to state	Labor statistics, 2019	County Health Rankings & Roadmaps, BLS
39. Population change, 2010-2020	Counts and estimates	U.S. Census Bureau
40. Severe housing economic stress % households spent ≥50% of their household income on housing Compared to state	American Community Survey, 2013-2017	County Health Rankings & Roadmaps
41. Broadband access. Compared to state	American Community, 2015-2019	County Health Rankings & Roadmaps Survey

Some of these data are excellent quality, and as a whole represent a substantive contribution to our ability to understand social and environmental and social justice. Nevertheless, these data do have limitations, and these are discussed.

Demographic

Seven of the eight demographic metrics are from EPA's EJScreen data base (USEPA, 2019). They include low income, people of color, linguistic isolation, limited educational achievement, children and senior citizens. The average of low income and people of color metrics was used by EPA to create the "demographic index." Areas with a disproportionate number of people who fit into one or more of these groups are expected by EPA to have a disproportionate vulnerability to contaminants that fall under the EPA's mandate. EPA has a solid literature review in its 2019 technical document (USEPA, 2019) to support the selection of these indicators as indicative of greater vulnerability. Less clear are the impacts of multiple such characteristics. A person, for example, who is >64 years old has a higher likelihood of dying than someone 10 years younger, and that probability increases substantially after age 75. In addition, if that person is poor, not well educated, linguistically isolated, and Afro, Latino American, and

American Indian, the literature suggests that the probability is even higher. We know that counties, cities and census tracts and blocks with multiple such demographic characteristics typically have notably worse health outcomes than those places that have few, if any, of these demographic characteristics. The challenge for the analyst is avoid the ecological fallacy of attributing outcomes to individuals based on data collected about places because each person has their own set of vulnerabilities and assets based on their genetics and the way they live.

The multivariate statistical analyses presented in this study found strong associations among many of these demographic measures, which, in fact was expected from the literature. Indeed, the statistical analysis found such strong associations among many of the demographic metrics that the authors created a CRESP demographic index to use in a regression analysis (see below). We also used EPA's demographic index as a metric (average of low income and people of color). Yet, these statistical associations are imperfect as shown by the canonical correlation analysis presented in the appendices that shows some decoupling of socioeconomic status from race/ethnicity in some DOE site-regions. Furthermore, we reiterate that associations among indicators at the county, city, and census tract scales do not clearly point to causal associations among individuals (Cox, 2021; Buhlmann, 2020). Cox's (2021) recent book about causality and air pollution is a powerful effort to expand the number of statistical approaches used to posit and test causality among variables. In the spirit of the important issue of causality, this book is studying associations among indicators with geographical data, it is not making statements about causes and effects.

EPA gathered the raw data to build EJScreen and then compared each unit (county, city, census tract, blocks, and user-defined combinations) to the state and nation. Assuming these data are updated, this EPA data set should be an important ongoing record about both environmental and social justice, in essence, a cornerstone for researchers.

The last of the eight demographic metric, the index of dissimilarity, is not part of the EPA data base. It measures spatial randomness with which two groups are located in geographic areas that make up a larger area. The number is interpreted as the percentage of one of the two groups that would have to move to different geographic areas in order to produce a distribution that matches that of the larger area (St. Louis Federal Reserve Bank, 2021).

For this study the index of dissimilarity refers to non-Hispanic White and Nonwhite data at the census tract scale, indicating the proportion of non-Hispanic Whites that would need to move to another census tract in the county to equalize the distribution by race/ethnicity over a 5-year period. The index uses anyone who is defined in the census as Non-Hispanic White as White and all others as Nonwhite. The census bureau also publishes a score for Black and non-Hispanic Whites. The latter is of limited use here because so many of the minority populations living near DOE sites are American Indians and Latino/Hispanics.

The index of dissimilarity used to measure segregation have limitations (Cortese, Falk, and Cohen, 1976). For example, this author used it in the mid-1960s when working on his master's thesis study of demographic attributes of the residents of portions of New York City. It is problematic when the census measurement areas are not recently adjusted to the changing distribution of the population. One solution is to compare each census unit to a much larger unit, such as the state. In this case, the authors calculated the median index by county in each state and divided the counties included in the DOE-EM-site-regions by the state median. The authors did not expect many insights from this measurement because of the diversity of people included as Nonwhite in this set of host regions and the wide variation in the measurement unit sizes. However, this is a widely used metric and it needs to be included in any statistical study that pivots on environmental or social justice. Hence, we used it in several multivariate analyses, and it was not a notable correlate.

Public Health

Funded by the Robert Wood Johnson Foundation, organized by the Population Health Institute (2021) and published since 2010, *County Health Rankings & Roadmaps* offers a marvelous, updated data set at the county scale. The focus of their data base are more than 30 metrics measure health outcomes and behaviors that influence health. An area with low health insurance rates, especially for children, suggests limited access to health care, and an association with poverty. Lack of the annual flu vaccinations for older adults is problematic. Food insecurity is a serious problem, and the index of a healthy food environment a good indicator of food security. It need not directly relate to DOE's missions. However, in many places food insecurity is a high priority issue, and we would expect environmental justice communities to raise it with government officials, including possibly the DOE.

The authors used many of these indicators and added the pre-75-year-old age death rate in this study, which reduces misleading results associated with people who have recently moved to clustered retirement facilities and may not reflect local population history. Over time this data base will continue to improve. It already is extremely valuable for county-scale research.

Environment

With regard to the 11 environmental indicators 2.5 ppm and ozone are indicators incorporated into national ambient air quality standards (Table 2). The three National Air Toxics Assessment (NATA) metrics values are based on local data and mathematical models developed by EPA. The EJScreen software package draws data from the nearest air quality monitors and calculates a value for the geographical centroid of the study area, which could be a county, city, or census tract. Hence, this data set can be used for county, as well as high resolution research in much smaller areas as demonstrated below with the Oak Ridge, Paducah, and Portsmouth case studies.

The traffic proximity, RMP (risk management plan), Superfund, hazardous waste site, and wastewater discharge indicators are linear measurements from the nearest facilities to the centroid of the study area. RMP's are not familiar to many readers. Briefly, the Risk Management Plan (RMP) Rule implements Section 112(r) of the 1990 Clean Air Act amendments, requiring facilities that use beyond a threshold amount of extremely hazardous substances that are explosive, flammable and toxic to develop a Risk Management Plan. These plans must be revised and resubmitted to EPA every five years. Please note that this is a controversial rule and EPA has been holding hearings to discuss RMP rules.

In regard to EJScreen, the EPA tool measures the distance from the nearest RMP or set of RMPs to the centroid of the census area. These calculations assume that more distance from a potential exposure source means less potential for public exposure. In other words, all other things being equal, it is better to live 5 miles from the nearest major arterial road and RMP than 0.5 miles. DOE sites become part of the calculation when they are close enough to the populated area, are a Superfund site, a site with an RMP or hazardous waste (see case studies of Paducah, Portsmouth, and Oak Ridge below). DOE sites may not contribute to highway traffic, but in some cases, they may be a major contributor through commuting patterns and shipments.

These environmental measurements are imperfect. One concern with the air quality set is the limited number of monitors. Places with few monitors may not have representative estimates, which is a special concern in areas in rural places and in settlements with hills and valleys that have local meteorological conditions, which is true of some DOE-EM-site regions. In regard to the distance-based metrics, a nearby contaminated site does not mean that anyone is exposed. A site further away that is poorly managed may be a bigger threat than a large site with good risk management. Overall, DOE sites may not contribute much to some of these environmental indicators. However, as key players in their site-regions, knowledge of the factors that contribute to the environment of their regions and potentially to the concerns of elected officials and the public is important.

An example is the EJScreen metric for lead exposure. Lead is a serious neurotoxin impacting children, The U.S. eliminated lead from automobiles engines in 1996, and lead paint was banned in 1978. However, few houses used lead paint after 1960. Hence, EJScreen used houses built before 1960 as a surrogate for lead paint exposure. In other words, the indicator is not measuring lead but housing age, which is assumed to be a surrogate for lead paint. In fact, it is not clear that this metric is a good indicator of lead contamination, however, lead is a concern in many communities and part of the environmental justice literature. Hence, it is important for DOE officials to recognize if there is an issue in their community.

A lack of published water quality data is a problem. EPA has collected drinking water quality and stream water quality data for decades. Yet, EJScreen includes no drinking water quality violation data or water quality data, which is particularly troubling in rural settings where many people depend on private groundwater supplies, which is the case with some DOE-EM-site-regions. The requirements of the Safe Drinking Water Act (SDWA) include collection of data about drinking water standard violations and communication such violations to residents. SDWA has responsibility for over 100 contaminants, including naturally occurring arsenic, and biological threats such as E. Coli.

There are some possible options. In light of the Flint, Michigan drinking water case, the Natural Resources Defense Council (NRDC) (Fedinick, 2018) examined federal government files for 2015-2018. NRDC found 13,991 violations exposing 29.7 million people to excessive copper and lead between January 1, 2015, and March 31, 2018. In the context of the DOE-EM study, the author of this report found that the 81 counties had a population of 29,950,150 people. A total of 298,929 were reported to potentially be exposed in these counties, which amounted 1.07% of the total exposed. These DOE-EM-site-region counties were responsible for 340 violations, which was 2.43% of the total 13,991 reported violations. We cannot tell from the study who was responsible for the contamination. In other words, there may be a safe drinking water issue, but such a conclusion would be premature. Safe drinking water and water quality data are the biggest data gap in the county-scale analysis.

With additional time, we would contact all the state agencies and use the proportion of persons on private wells as a surrogate. Clearly, however, the key is to be able to find direct exposure pathways and indirect ones through eating contaminated fish. It would be interesting to see how important this issue is to local communities compared to water quality issues that are related to DOE but do not impact local drinking water. This, of course, would require a survey or focus groups.

Local Attractiveness

Seven variables were used to assess local attractiveness. These and similar data are consulted when people search for a new place to live or a place for vacation. Their objective is to find positive attributes and few negative ones. People look for places close to parks, for example, EJScreen's CDC file that estimates how many people live within 0.5 miles of a public park. They look for places with growing wealth for investments, indicated by high home sales values (National Association of Home Realtors, 2021), and population growth. They also, seek places that are ahead of others in securing new technology, which the author measured with broadband access. On the other hand, crime, difficulty paying for housing, and high unemployment are considered bad signs. Crime and physical blight are not well tolerated by investors and residents (Greenberg, 1999).

DOE is not directly responsible for these local attractiveness conditions. However, the literature, as noted earlier, identifies DOE's sites with environmental conditions that discourage people and investments Hence, we added these metrics to assess the picture across the DOE sites.

Results

Demographic Comparisons Among the DOE-EM-Site-Region-Counties, their Host States and the United States

Table 3 compares the set of 81 counties to their host states and to the nation. The values are scaled 0 to 100. An average of 50 means that the DOE-EM-site-region counties have the average value of their host state and/or the nation. An average above 50 is evidence of a population with above average population vulnerability based on their demographic characteristics. Note, as indicated above, the 7 EJScreen demographic metrics were used to build 14 variables (7 state and 7 national comparisons). Table 3 focuses on the average values, but also presents the median, 25th and 75th percentile numbers for the state comparisons because these help interpret the results for people of color.

Also please note that the EPA number for each county is compared to all the others in the same state. So, a score of 20 means that it is the 20th percentile in the state.

Twelve of the 14 metric averages are above 50. In other words, income, education, younger and older age groups, linguistic isolation, and the EPA's demographic index have central tendencies higher than their host states and the U.S as a whole. Nine of the 14 average metric values are significantly above the state and/or national market value of 50.

Only the averages of the two people of color indicators are below 50, which is notable. The 25th percentile number for people of color is 29, much lower than the 25th percentile for any other metric. What this means is a large number of counties have relatively few people of color whereas a smaller number have quite a large proportion. In the DOE-site-regions this is further complicated by the fact that people of color in some counties are primarily Afro-Americans, but in other counties the people of color population is largely American Indians and/or Latino/Hispanics. The reader will find that the geographical distribution of people of color figures heavily in the analyses and interpretations that follow, especially as in its association with socioeconomic status.

How do these findings compare to other applications of the same data? Greenberg (2021a) used the same EJScreen metrics to compare the 50 largest cargo tonnage ports in the United States to their states. Ten-mile circular zones around the centroids of 50 largest U.S. ports averaged 55-67 for the minority, low income and education metrics. The closer to the port centroid, the higher the demographic values. The two-mile circular areas around the 50 ports had the highest averages. For example, the demographic index for the 10-mile radius zone was 59, for the 5-mile-radius-area it was 67, and the 2-mile-area had an average of 72. In other words, areas surrounding the nation's largest ports clearly have higher levels of demographic-based vulnerability than do these DOE-EM-site-region counties as a whole, which had an average demographic index of 51.8.

A second comparison was between the outer city areas of New York City, Philadelphia, Chicago, Detroit and Los Angeles and their adjacent suburbs (Greenberg, 2021c). Over the eight-mile distance from the outer city to the inner suburbs the indices markedly dropped. For example, the average demographic index centered on a circle four miles from the city-suburban border was 75, this average dropped to 70 at two miles from the border, and in the suburbs it dropped to 55 and 49. In other words, over a relatively short distance the demographic index dropped an average of 26 points. In Detroit and Philadelphia, two cities with a history of demographic segregation the index declined more than 30 points. Overall, at this county-scale, these DOE-EM-site region counties exhibited less evidence of pronounced demographic-related measures of vulnerability than their counterparts surrounding ports and five large cities, several with a long history of segregation.

These papers used the same EJScreen data base and same approach as the higher resolution studies for the Paducah, Portsmouth, and Oak Ridge case studies (see below), which was circles with variable width radii.

Another result from Table 3 is that the county-nation comparisons are similar to the county-state ones. Differences from the 50-midpoint increased for the following metrics: demographic index, low income, less than a high school education, and population less than 5 years old; and they decreased toward 50 for population of color, linguistic isolation, and population $\geq$65 years old. The Pearson R correlations between the county-state and county-United States indices were quite high (the median correlation between the scores average R=.828). Given that the importance of the state as a measuring stick, the remaining analyses in the county-scale-study are based on the county-state comparisons.

Table 3. Initial Comparisons of Counties, Host states and the United Sates

Metric	Counties compared to states Mean & (standard deviation) 25* 50* 75*					Counties compared to U.S. Mean & (standard deviation)	
	Mean	(standard deviation)	25*	50*	75*	Mean	(standard deviation)
Demographic index (n=80)^	51.83	(18.11)	40	49	60	54.23*	(18.91)
Low income (n=81)	57.68**	(16.41)	45.5	59	71.5	61.58**	(47.62)
Population of color (n=80)^	45.35	(21.38)	29	43	55.5	47.62	(24.78)
Linguistic isolation, (n=81)	60.44**	(13.54)	50.5	62	68	59.83**	(13.38)
Less than high school graduation (n=81)	58.85**	(16.35)	47	57	71.5	62.51**	(13.98)
Population < 5 years old (n=81)	50.41	(12.48)	43	50	58.5	51.16	(13.51)
Population > 64 years old (n=81)	62.38**	(14.61)	54.5	63	70	61.99**	(15.89)

Test-value =50 for the host states and the U.S. as a whole

*25 is 25th percentile, 50 is the median and 75 is the 75th percentile

**P <.01; *P<.05

^Missing Rio Arriba County

As noted earlier, the author chose counties adjacent to the host counties because he assumed there would be site-related impacts, even if these were less than those of the host counties. It is important to compare the demographic metrics of the host and adjacent counties. Appendix Table A shows that the host versus adjacent county distinction makes little difference. None of the means are significantly different from each other (see appendix table A), which was a surprise.

The surprise is probably due to the classification of the 17 sites and their counties. Perhaps the most interesting comparison of means was among 18 counties that hosted EM sites with annual cleanup budgets of at least $100 million, their 28 adjacent counties, and 35 counties that are in regions with a cleanup budget less than $100 million. For example, Aiken, Allendale and Barnwell counties are host counties with large cleanup budgets at the Savannah River site. Bamberg, Edgefield, Hampton, Lexington, and Orangeburg are adjacent counties in the Savannah River region. In contrast, Lawrence Livermore's counties are in a region with a relatively low cleanup budget.

We found that the 18 host counties with the highest site cleanup budgets were in the middle of every comparison (See Table 4). An interesting interpretation that follows is that DOE's investments have reduced the host state's demographic patterns of inequity in these DOE-EM-region counties, albeit the differences are small. For example, the low-income indicator for the major host county average (18 counties) for this index was 58. In comparison, the value for the 28 adjacent counties was 62, and the 35 non-major counties had an average of 54 (See Table 4 for all these comparisons). Differences of 1 or 2 points clearly can occur by chance. Yet, the fact that the major host sites had the middle score for all of the metrics is improbable suggesting that the EM sites have had an affect that on the host counties, which is likely to be of interest in follow-up environmental justice considerations.

More specifically, since the metrics are controlled for state values, the implication of this observation is that there has been a systematic positive impact of the DOE sites on host county demographics at the Idaho, Kentucky, Ohio, South Carolina, Tennessee, one of the New Mexico, and Washington site-regions. This impact is not consistent because only the demographic index, minority and linguistic isolation metrics had a statistically significant difference in the comparisons. However, these results undermine the argument that the DOE sites have negatively impacted their nearby sites in the early 21st century.

Table 4. Comparison of the Current Major Cleanup Cost Regions and Other Site-Regions

(highest number is bolded)

Metric	Major host counties, adjacent counties, and non-major counties (n=number of counties)	Site regions hosts Mean**
Demographic index	Major host (n=17) Adjacent to major host (n=28) Non-major (n=35)*	55.47 **58.21** 44.94
Low income	Major host (n=18) Major adjacent (n=28) Non-major (n=35)	57.88 **62.04** 54.09
Population of color	Major host (n=17) Major adjacent (n=28) Non-major (n=35)*	50.33 **50.71** 38.48
Linguistic isolation	Major host (n=18) Major adjacent (n=28) Non-major (n=35)*	64.83 **68.32** 51.89
Less than high school graduation	Major host (n=18) Major adjacent (n=28) Non-major (n=35)	61.22 **63.32** 54.06
Population < 5 years old (n=81)	Major host (n=18) Major adjacent (n=28) Non-major (n=35)	53.06 **53.07** 46.91
Population > 64 years old (n=81)	Major host (n=18) Major adjacent (n=28) Non-major (n=35)	61.06 59.96 **65.00**

*P<.05 that others are lower than the major host and major adjacent groupings.

** Numbers are not rounded off to nearest whole number.

Major sites are Hanford Office of River Protection and Operations Office, Idaho National Laboratory, Oak Ridge, Paducah, Portsmouth, Savannah River, and WIPP.

Multivariate Analyses

Early studies of environmental justice, as noted above, focused on specific types of sites, such as hazardous waste sites across the United States. The effort is now much more widespread and includes a more holistic view connecting social justice, environmental exposures, health outcomes and behaviors, and community assets. In other words, it is necessary but insufficient to view the spatial distribution of poverty, people of color, and other demographic measures. The data should include additional metrics. Twenty-six of the 34 metrics in this study are about environmental exposures, health outcomes, and community assets. Multivariate methods are used to find associations among these sets. Briefly, there are many multivariate tools, and it is important to make sure that the results are not driven by any one specific method or one specific metric of environmental justice. In these analysis, we used linear regression, and canonical analysis. Only one of those is presented in this section because the results do not markedly differ between the simplest and most complex. The one presented in this section shows clear relationships among the metrics and lists counties that exemplify the results. The raw data for that linear regression and the statistical results are presented in Appendix B. A second application of linear multiple regression using EPA's demographic index is in Appendix C, and Canonical Analysis, the most complex tool applied here is in Appendix D. A key point is that the results vary slightly among the applications and readers can review them. Yet, the essence of the multivariate results is in the next several paragraphs.

Beginning with the simple regression, after preliminary tests, CREP developed a summary demographic metric from the EPA EJ data, which averaged the low income, people of color, linguistic isolation, and less than a high school education as a demographic aggregate metric. Is this a statistically legitimate metric? To answer that question, we used the Cronbach's Alpha statistic, which essentially is the correlation among the set of indicators. Users of Cronbach's Alpha suggest that a value of $\geq$0.7 implies an acceptable index. The four we used produced a value of 0.79, which is above the 0.7 standard expected for a metric.

The zero-order correlations of this CRESP-derived demographic metric with four of the more than 20 indicators were poor/fair health outcomes (R=.842), food environment (R=-.208), home value (R=.-.306); and lack of adult health insurance (R=.731). The adjusted multiple R^2 of the demographic metric with the four correlates was R^2 =.802 (P<.001), a strong result for so few variables. The regression is found in Appendix B.

Appendix B also provides the county-by-county results for these metrics. The 10 counties with the most evidence of an environmental and social justice issue are as follows:

Savannah River: Allendale (81), Barnwell (71), Bamberg (73), Hampton (75),
and Orangeburg (70)

Hanford: Franklin (87), Grant (83), Yakima (87)

Moab: San Juan (89)

Idaho NL: Bingham (73)

In contrast, the lowest scores were found in the counties surrounding the Los Alamos, WIPP and Nevada Test Sites. For example, the Los Alamos counties, as noted in Appendix B, with the exception of Mora (65) had values between 18 and 54, the counties surrounding the Nevada site had values from 21 to 50, and those around WIPP ranged from 45 to 64 (See Appendix B for details). Notably, the results of this simple regression were confirmed by a regression with EPA's demographic index as the major correlate (Appendix C), and by a canonical analysis that used all the metrics we gathered (Appendix D).

Please note, however, that the higher resolution analysis shown below identifies the area around the Oak Ridge and Portsmouth sites as other places with environmental and social justice challenges. Please note that aggregate data can obscure issues that exist at more granular geographical levels.

A Higher Resolution Scale of Analysis: Oak Ridge, Paducah, and Portsmouth

Ideally, we would like to get to a more granular level of analysis that takes us down to census tracts and distance or other zones that fit user needs, such as along rivers and valleys. What is available is the EJScreen data, which offers the same seven demographic indicators used at the county level (not the index of dissimilarity), 11 environmental metrics, and a very limited number of metrics about employment and housing. It is especially unfortunate that health outcome and behavior data are not systematically available for fine scale studies. The exception is from a project funded by the Robert Wood Johnson Foundation and carried out by the CDC (2021) to make data available at the census tract level. The 500 cities study allowed users to collect many of the same indicators used here for the county analysis for the 500 most populated cities in the United States. The data set has been used to study the relationship between demographics, environmental indicators, and health outcomes and behaviors at the census tract scale long America's so-called "grand avenues." (Greenberg, 2021b) The data were vital in painting a portrait of who lives along these famous boulevards in New York City, Philadelphia, Chicago, Los Angeles, Detroit, Richmond, New Orleans, Kansas City, New York City, and Washington, DC. Nardone et al (2021) used the 500 cities data to evaluate the health implications of redlining on public health in major U.S. cities with extensive redlining. Being able to scale down to small census tracts and blocks is advantageous to see details in relationships among metrics.

In the context of the DOE-EM-site-regions, the 500 cities project includes areas near DOE sites, such as Las Vegas, Knoxville, Santa Fe, Albuquerque, Schenectady, and Los Angeles. Yet, the only cities that are really close to DOE-EM's sites that published health data are Kennewick and Yakima in Washington state. Both of these are in the Hanford site-region.

CRESP proceeded with a study of the Paducah, Portsmouth, and Oak Ridge sites to demonstrate what can be done at this time, recognizing that the CDC will eventually allow computation of health data for granular geographical studies, as it has for Yakima City.

In order to make the study replicable, the authors followed the same process in each case. A point was placed on the centroid of the site, except in the case of Oak Ridge, where the center point was the centroid of the Y-12 plant. The numbers in the first data column are the actual values. All the other numbers compare the first set of numbers with a potential range from 0 to 100, with 50 the same as the area of comparison. All numbers exceeding 75 are bolded. We suggest viewing the site areas as an onion. The first place to look is the center of the onion and then move away from the center to larger areas. If the site has had a major impact, it should manifest more evidence of poor, minorities, less education, and more potential exposure in the innermost ring. In this case, we explored distances with a radius of 1.5 miles, 2 miles, 3, 5 and 10 miles. To simplify the tables, only the 3- and 10-mile data are displayed along with the county, state and national data. This decision does not mean that 3 and 10 miles are necessarily the best options. We suggest that local site staff and communities should suggest options.

Oak Ridge's results clearly demonstrate the most evidence of environmental justice issues. Those for Paducah and Portsmouth are presented in Appendices E and F, respectively. Also, Appendix G presents data for Yakima City because it was one of only two DOE EM city that had health data available at the city and census tract scale. We picked three census tracts to illustrate the relationship of environmental justice, health and other indicators and the results show the classical set of relationships found at the county scales.

Oak Ridge Site (TN)

DOE's Oak Ridge facilities cover approximately 55 square miles and are located about 300 miles from Paducah and 250 miles from Portsmouth. Oak Ridge was established in 1942 at a key period of World War II when the U.S.'s Manhattan project was developing nuclear weapons. The Oak Ridge National Laboratory (then called X-10) was created to develop and test for producing and separating plutonium. Y-12, S-50, and K-25 were built to enrich uranium. For purposes of this project, Y-12 is the most critical facility because it was close to the community of Scarboro, which was created by state law as a place where Black Americans who worked at the site lived in a segregated community, east of the site. (See Figure 1 below which shows the 3-mile radius circle around Y-12 and the approximate location of the Scarboro community to the east).

Given the location of Y-12 and Scarboro, the results of applying EJScreen were predictable. The innermost 1.5- mile radius circle had 1,336 people and the 2-mile circle population estimate was 4,238. The population in these circular zones were estimated at 33% people of color and half of the population meets the criteria for low income. In the 3-mile radius zone, these numbers dropped to 27% for people of color and 47% for low-income people, respectively, and they dropped in the 5-mile and 10-mile areas. The initial organization of the area led to concentration of African Americans in the Scarboro area that has persisted, and a concentration of some of the lowest socioeconomic status people.

Table 5 offers geographical-based snapshots of who lives near the Oak Ridge site and some metrics about standard environmental contaminants. Much more detail on contaminants has been gathered by the DOE and the Agency for Toxic Substances and Disease Registry (ATSDR). Over two decades ago, the DOE and ATSDR agreed to jointly work on human-health issues related to the DOE's sites. Its reviews at Oak Ridge have been extensive and ongoing since its first site visit in 1992 focused on mercury contamination of East Fork Poplar Creek, issues related to public concerns about the quality of water in the Lower Watts Barr Reservoir, and technical assistance. The ATSDR (2004, 2013) has reviewed evidence for Y-12's impact on a Scarboro community estimated at about 300 people and located on the other side of Pine Ridge from Y-12. Air dispersion models suggest that there has not been an impact from current emissions. Emissions prior to 1963 could not be evaluated, but more recent emissions are too low, they find, to cause an impact. Water quality samples also suggest no current impact.

Figure 1 shows the 3-mile radius map from the center of Y-12 as an illustration of what was done for Paducah and Portsmouth. A great deal more could be done with high resolution analyses at selected DOE sites. But health data needs to be added, and other data sets need to be updated. Also, given the hill and valley structure of this area, it would be good to study the data in a wind rose, that is, include not only distance but also direction from the centroid.

Given the considerable amount of data in Table 5, we interpret it for the reader, noting that the same explanation holds for the Paducah and Portsmouth examples in the appendices. The population row is the estimated population of the area studied. Hence, 14,952 was the estimated population of the 3-mile circular radius area around Y-12 during the years 2014-2018. The Oak Ridge 10-mile area and the county had estimated populations of 132,170 and 75,775 during those years, respectively.

The 16 metrics under demographic and environment are keyed to the 3-mile zone (inner area surrounding the site). We use the demographic index to illustrate. The people of color proportion in the inner 3-mile area was 27% and the low-income proportion was 47%. The demographic index is the average of the two: 37%. Working backwards from the outer surface, the U.S. demographic index was 36%. In other words, the inner 3 miles are similar to the U.S. as a whole, but higher, and in fact, 37% places them at the 60th percentile in the U.S. The demographic index for the state was 31%, which translates to the inner 3-mile area in the 71st percentile in Tennessee. Closer to the site the demographic indices continue to decline: 23% for Anderson County, and 18% for the 10-mile area surrounding the site. Accordingly, the inner 3-mile zone demographic indices increased to 80% and 95%, respectively. Overall, in regard to the demographic index the numbers are relatively high close to the site, drop as they move away from the site and remain high, albeit close to the U.S. as whole.

A score of 50 means the value is the same as the comparison area. Those ≥75 are bolded, which means relatively high vulnerability in the 3-mile zone compared to other areas.

Table 5. Oak Ridge, Distance-Based Results

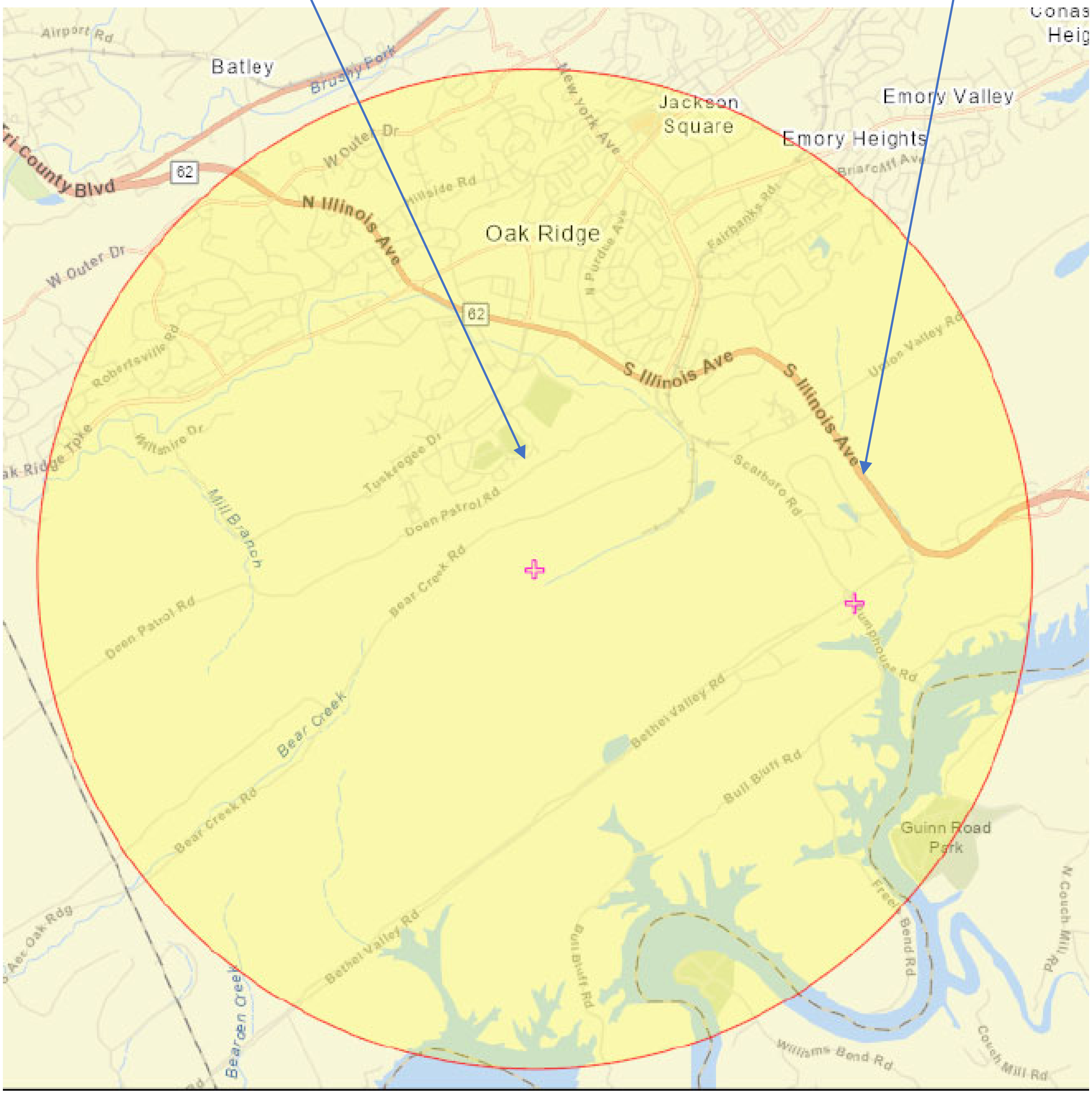
Indicators	Oak Ridge 3-mile, actual values	Oak Ridge 10-mile	Anderson County	State	U.S.
Population	14,952	132,170	75,775	--	--
Demographic					
Demographic index	37	**95**	**80**	71	60
People of color	27	**96**	**96**	67	46
Low-income population	47	**95**	65	70	**76**
Population with less than high school education	11	**79**	43	45	55
Population under 5 years of age	7	58	36	63	61
Population over 64 years old	17	47	45	61	66
Environment					
pm 2.5 in ug/m^3	8.33	49	49	40	41
Ozone, ppb	42.3	49	50	33	45

NATA diesel pm (ug/m^3)	0.333	33	57	48	<50
NATA cancer risk	36	46	50	57	60-70
NATA respiratory hazard index	0.49	45	52	53	60-70
Traffic proximity and volume	220	**79**	69	74	50
Lead paint indicator	0.51	**94**	**77**	**91**	**78**
Superfund proximity (DOE site is Superfund site)	0.067	56	71	**75**	52
RMP proximity	0.96	**86**	**94**	**83**	**75**
Hazardous waste proximity	1.3	**84**	**87**	**85**	55

Scarboro and Y-12 are in Anderson County.

Figure 1. Map of Oak Ridge Three-Mile Radius Zone Drawn around Centroid of Y-12 Site

(The centroid of Y-12 is marked by + in the center of the circle with a three-mile radius. Scarboro lies to the east.)



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Appendices

Appendix A. Comparison of Host and Adjacent County Demographic Indicators

This first appendix table shows difference-of-means t-tests between host and adjacent counties across the DOE EM sites. The values in column three were not rounded off in order for the readers to assess the ordering.

Table 6. Comparison of Host and Adjacent County Demographic Indicators

Metric	Host & adjacent (n=number of counties)	Site regions hosts* Mean
Demographic index	Host=26 Adjacent=54	51.88 51.80
Low income	Host=27 Adjacent=54	55.69 58.63
Population of color	Host=26 Adjacent=54	46.93 44.56
Linguistic isolation	Host=27 Adjacent=54	59.93 60.70
Less than high school graduation	Host=27 Adjacent=54	58.11 59.22
Population < 5 years old	Host=27 Adjacent=54	50.56 50.33
Population > 64 years old	Host=27 Adjacent=54	62.56 62.30

*None of the means are statistically significantly different at $P<.05$ from each other.

Appendix B. Sample of Five Key Variables

The abbreviations in the table below are as follows:

place = county name

sitestate = DOE site and state (see Table 1)

demoagg = average of low income, people of color, linguistic isolation, and less than high school education (CRESP created indicator).

poorhealth = poor and fair health declaration

homevalue = home value sales

adultins = Lack of adult health insurance

foodenv = healthy food environment

The table includes over 400 numbers. We highlight what you can see in the table with two examples. Suffolk County, NY hosted the Brookhaven National Laboratory and Yakima County WA is in the Hanford region. They are located near the top of the table and therefore easy to find.

Table 7. Data for Multiple regression presented in text

place	sitestate	demoagg	rankadultins	poorhealth	homevalue	foodenv
suffolk	brookny	44.75	75	88	126	102
yakima	hanfordwa	87.25	244	173	50	96

The CRESP aggregate index is (demoagg) and is almost twice as high in Yakima County as in Suffolk. The index is scaled 1 to 100, so these two represent near polar opposites. Suffolk is among a set of urban metropolitan counties with relatively few poor people and low to medium numbers of people of color. The population has a high proportion with college educations and few are linguistically isolated. In contrast, Yakima county is much more rural and about half of its population is considered poor and minority.

The other four metrics in the table show a strong contrast. These comparisons were created by dividing the county number by the state one. For example, the home value number for Suffolk is 126 and it 50 for Yakima. This means that Suffolk's is over one-quarter higher than New York's and Yakima's about half of Washington's. Compared to the Washington state as a whole, many residents of Yakima County lack insurance and self-rate their health as poor or fair. Also, their home values average about half of those of their state. In contrast, Suffolk County's proportions without health insurance and who self-rate their health as poor of fair are lower the State of New York's. Their home values are not surprisingly higher. Only in the case of the food environment metric are they similar to their host state numbers.

place	sitestate	demoagg	rankadultins	poorhealth	homevalue	foodenv
suffolk	**brookny**	**44.75**	**75**	**88**	**126**	**102**
nassau	brookny	46.00	75	81	164	108
ventura	ETECca	46.75	140	100	107	101
Losangeles	ETECca	64.00	130	117	110	95
santabarbara	ETECca	53.75	140	106	101	99
kern	ETECca	63.75	120	150	42	85
franklin	hanfordwa	87.00	189	160	59	98
benton	hanfordwa	62.50	133	113	65	100
grant	hanfordwa	83.00	189	153	59	94
yakima	**hanfordwa**	**87.25**	**244**	**173**	**50**	**96**
wallawalla	hanfordwa	65.75	122	120	54	99
bonneville	inlid	57.50	94	113	74	106
jefferson	inlid	59.75	119	113	72	114
madison	inlid	54.00	88	133	75	99
bingham	inlid	72.25	119	127	75	105
alameda	livermoreca	50.00	60	83	55	101
santaclara	livermoreca	49.00	60	78	182	106
contracosta	livermoreca	43.00	70	83	100	101
sanmateo	livermoreca	44.00	60	72	179	107
sanjoaquin	livermoreca	59.00	100	122	68	90
Losalamos	LANM	18.25	21	45	140	210

santafe	LANM	45.00	114	90	150	183
rioarriba	LANM	.	100	130	79	155
taos	LANM	53.75	43	105	113	143
sandoval	LANM	44.50	93	90	106	174
torrance	LANM	47.25	86	120	56	136
mora	LANM	64.50	64	135	53	152
colfax	LANM	49.75	79	110	49	117
grand	moabut	67.50	125	107	69	93
uintah	moanut	66.25	142	133	55	95
emery	moabut	51.00	83	113	39	99
sanjuan	moabut	88.50	167	167	36	50
nye	nevnev	43.50	93	111	54	76
esmerelda	nevnev	50.00	100	132	22	49
eureka	nevnev	21.50	47	89	40	82
lincoln	nevnev	37.75	87	95	47	72
anderson	ortn	54.00	93	100	85	116
roane	ortn	49.25	87	100	80	118
knox	ortn	53.25	80	90	107	121
cumberland	ortn	52.25	100	105	81	118
morgan	ortn	61.00	107	133	54	111
mccinn	ortn	59.25	107	114	71	119
mccraken	paducahky	58.25	88	100	100	104
ballard	paducahky	56.50	100	123	68	103

graves	paducahky	64.25	113	114	70	110
marshall	paducahky	47.00	88	91	87	119
jackson	portsmoh	60.75	111	136	74	94
pike	portsmoh	63.50	111	133	75	97
ross	portsmoh	63.50	100	122	82	104
scioto	portsmoh	64.25	111	133	74	94
pickaway	portsmoh	56.75	89	106	105	121
highland	portsmoh	60.75	122	122	75	107
gallia	portsmoh	63.75	122	128.	71	100
bernalillo	sandianm	49.00	93	95	102	181
cibola	sandianm	67.75	107	145	39	119
valencia	sandianm	59.00	107	120	56	142
sandoval	sandianm	44.50	93	90	106	174
torrance	sandianm	47.25	86	120	56	136
aiken	srssc	59.75	100	106	79	121
barnwell	srssc	70.75	94	139	42.	110
allendale	srssc	80.75	81	172	25	93
edgefield	srssc	63.75	100	122	66	122
bamberg	srssc	72.50	100	139	39	94
orangeburg	srssc	70.25	100	133	45	107
hampton	srssc	74.75	94	150	37	113
lexington	srssc	50.50	88	89	85	125
schnectady	sprny	45.00	75	100	55	92

albany	sprny	44.25	63	81	71	93
greene	sprny	46.25	75	106	54	90
schoharie	sprny	38.50	75	100	44	89
rensalear	sprny	40.75	63	94	61	93
montgomery	sprny	54.50	76	125	32	82
saratoga	sprny	29.75	63	81	82	100
eddy	wippnm	44.50	79	105	73	155
otero	wippnm	51.50	79	110	56	150
chaves	wippnm	63.75	100	125	46	162
lea	wippnm	61.00	114	115	69	193
cattaraugus	westny	45.00	100	125	29	90
chautauqua	westny	47.50	75	113	29	86
erie	westny	46.25	63	106	51.	90
allegany	westny	41.75	88	113	23	89
81	81	80	81	81	81	81

Table 8. Pearson Correlations of Five Variables

Correlations

		demoagg	adultins	poorhealth	foodenv	homevalue
demoagg	Pearson Correlation	1	.731**	.842**	-.217	-.472**
	Sig. (2-tailed)		<.001	<.001	.053	<.001
	N	80	80	80	80	80
adultins	Pearson Correlation	.731**	1	.655**	-.086	-.226*

	Sig. (2-tailed)	<.001		<.001	.446	.043
	N	80	81	81	81	81
poorhealth	Pearson Correlation	.842**	.655**	1	-.474**	-.703**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001
	N	80	81	81	81	81
foodenv	Pearson Correlation	-.217	-.086	-.474**	1	.681**
	Sig. (2-tailed)	.053	.446	<.001		<.001
	N	80	81	81	81	81
home value	Pearson Correlation	-.472**	-.226*	-.703**	.681**	1
	Sig. (2-tailed)	<.001	.043	<.001	<.001	
	N	80	81	81	81	81

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix C. The Demographic Index as an Overall Metric from EPA: A Multiple Linear Regression

The demographic index reflects the essence of the message about income and race/ethnicity in Presidential Executive Order 12898. Indeed, it is the average of the low income and people of color metrics. The problem is that it equally weights low income and people of color, which is not necessarily the case in the field. That is, the reader will see that some sites (e.g., Savannah River) present a strong association between race/ethnicity and poverty. That is not the case, for example, at Portsmouth. The demographic index does not include linguistic isolation and education, which are metrics of note. Hence, as noted above, we computed a separate index, the demographic environmental justice (DEJ) based on four indicators, of which people of color is one, and linguistic isolation is a second, and in the context of DOE sites is associated with the presence of Hispanic/Latino Americans. Poverty and less than a high school education completes the four metrics.

Nevertheless, we believe it would be inappropriate to ignore EPA's environmental justice index, as it may be referred to in conversations with communities and certainly is useful as a single poverty/race/ethnicity indicator. Hence, we computed a linear regression between the demographic index values assuming counties with high demographic index scores would have unfavorable health outcomes and related health behaviors, more potential exposure to contaminants, and have fewer attractive assets.

Preliminary analyses led to choosing 11 of the metrics for a stepwise regression. The statistical model process adds one variable at a time or eliminates one already added only when it adds significantly to the statistical results at $P<.05$. A variable marking the 17 major host counties in order was also added to see if a major host designation makes a difference. (It did not.) The variable selection process excluded variables that were clearly intercorrelated and would lead to potentially confusing results caused by collinearity among the indicators.

Table 9. Stepwise regression of demographic index and selected public health, environment and community attribute indicators

Indicator (n=79)	Standardized beta coefficients	Partial correlation	Zero-order correlation
Adults reporting poor or fair health, age-adjusted	.917**	.838	.816
Children health insurance.	-.160**	-.351	-.273
Traffic proximity and volume (daily traffic count/distance to road)	.205**	.311	.105
Home value	-.217**	-.314	-.293
Violent crime	.147**	.298	.352
Broadband access	-.122*	-.193	-.488
Host county	- .034	-.085	.132

**Variable statistically significant at P.<.01; *variable statistically significant at P.<.05.

The simple linear statistical model produced a Multiple-R value of 0.926 and an adjusted multiple-R-squared value of 0.843, which is a strong statistical outcome. The indicators are in the order selected by the stepwise process. The partial correlations are the correlation of the variable controlling for the others in the selected set of variables, and these are the most important to review because they indicate the contribution of the variable controlling for the others.

The strongest finding is that a self-declared indication of poor or fair quality personal health is by far the strongest correlate of the demographic index across these 81 counties. The second strongest correlate is lower chances of having health insurance for children. Among the set of environment indicators, the strongest was proximity to a high automobile traffic artery. Three of the county attractiveness attributes were included. Counties with high demographic indices had relatively low home values (even after controlling for state differences) and were among the least likely to have access to broadband connections. Reported violent crime was higher in these higher in these high demographic index counties.

Summarizing, this table is consistent with the image that poor and racial/ethnic minorities are more likely than others to live with poor health outcomes and less protective health behaviors, with high crime and traffic, and they lack the high property values and access to new technology that attract people and investments, observations consistent with development of the United States as a whole.

While the demographic index confirms the perceptions of many Americans, it is too simple a metric across DOE's EM sites. To see the on-the-ground complexity of DOE's sites, we next turn to canonical analysis that allows an analyst to compare sets of environmental justice and indicators of contamination, health and local assets.

Appendix D. Digging Even Deeper: Canonical Analysis of County Data

The author took the county data one step deeper with a canonical analysis, a tool used to assess relationships among two sets of data. In the DOE case, the interesting challenge is to see the overlap between the environmental justice metrics with the health, environment, and attractiveness metrics, and what role the DOE can play in assessing community and state concerns about these relationships. The method creates seven new dimensions (one for each of the smaller set of variables). It clusters together indicators that are correlated in a way that optimizes the relationship of both sets of indicators. In this case, a set of seven demographic indicators is statistically mapped against 26 health, environment, and county attractiveness ones.

Note, that this analysis does not imply causality. These 33 metrics are associated directly, indirectly, and in some cases, there is no reason to expect an association. The statistical strength of the dimensions created by canonical correlation are measured by the canonical correlation and statistical significance of each dimension (Table D1). The strongest dimension has the highest correlation and the strongest statistical significance. The original variables are expressed as correlations with the statistically created dimensions.

The first dimension captures the strongest relationships and the second and third more subtle ones (Table D1). The first two underscore the complex relationships in the data even at the county scale, and hence these two are reported in Table E1. What is interesting and important is that the environmental justice indicators split into two dimensions.

The first dimension finds strong associations between socioeconomic status, indicators of health and attractiveness. Self-reported poor or fair health is the strongest correlate (R=.977), followed by adult health insurance (R=-.731), protective health behaviors (R=-.710), lack of broadband access (R=-.711), home values (R=-.655), and relatively high unemployment rate (R=.520). Canonical analysis produces standardized scores for every county. The counties that stand out with the strongest evidence of this pattern are at the Ohio Portsmouth site and Savannah River one. The fit is imperfect, that is, not all the counties show all the metrics in the table. One obvious difference is the Portsmouth site has a relatively low minority population and the Savannah region has a large minority population. What they share is relatively high values of poverty and low educational achievement.

In regard to the second canonical variable, the focus is on race/ethnicity in counties with young and growing populations. The major manifestation of this combination of attributes is in Hanford site-region and Idaho National Laboratory-site one. As noted for the first canonical variable, the fit is not perfect for every county in these two areas. However, these site-regions have many people of color (R=.538) and with linguistic isolation (R=.749), as well as many young children (R=.740), and not many older residents (R=-.578), low home value (R=-.445), high unemployment rate (R=-.495), and a relatively high population increase (R=.714). Also, most but not all of the counties in these two areas mirror this pattern.

For DOE there are two messages in this analysis. One is that there are strong relationships between environmental justice and metrics of health outcomes, environmental contaminants and local assets. The second message is that there is no single combination of associations that fits every DOE site. In some cases, race/ethnicity is a stronger correlate and socioeconomic status is less strong. The pattern is reversed at others. This surely influences the populations involved in discussions with DOE and their agendas. Health outcomes and local assets are stronger correlates in some places and environmental quality in others.

Table 10. Canonical Correlation Results

Metric	Low socioeconomic status, poor health and attractiveness	Minority, younger population, and environmental contaminants
Demographic		
Low income	.938	
Less than high school	.819	
People of color	.481	.538
Age less than 5	.454	.545
Linguistic isolation	.402	.740
Age 64		-.578
Public Health		
Self-reported poor and fair health	.977	
Health outcomes	-.739	
Adult insurance rate	-.731	.408
Health behaviors	-.710	.405
Premature death rate	.574	
Flu shot	.501	
Food environment	-.478	
Children insurance rate	-.437	

Environment		
Hazardous waste	.423	.688
Diesel particles		.440
Traffic		.604
Respiratory		.409
Cancer		.429
2.5 pm		.514
RMP		.453
Local attractiveness		
Broadband	-.711	
Home value	-.655	-.445
Unemployment rate	.520	.495
Population change, 2010-2020		.714
Canonical correlation	.989*	.942*
Wilks statistic	<.001	.001

*Canonical correlation significant at P<.01

Appendix E. Paducah Gaseous Diffusion plant (KY) Granular Scale Study

Occupying 750 acres, beginning in the early 1950s, Paducah produced enriched uranium for weapons, military reactors and for civilian nuclear power plants. Much of the surrounding area is a buffer, and part is Kentucky wildlife management land. Farms lie to the west and north. Paducah city is over ten miles away. The Ohio River flows to the east of the site. Few people live near the site. EJScreen estimated 258 residents in the 1.5-mile radius surrounding the site centroid and 571 in the 2-mile radius circle. The 3-mile radius circle population is estimated at 1,927. Table E1 estimates that 38% of these residents are low income and about 2% are people of color. Paducah's demographic values exceed the 50 mark only for low income. With regard to the environmental indicators, the values are close to the numbers for the surrounding area, county, and state with the obvious exception of proximity of a Superfund site, since Paducah is on the National Priority List. Groundwater has been an issue at the site, and this is an example of where the absence of water quality data is a notable gap, as well as water use data, as well as ecological data. Based on these limited data, there is no striking environmental justice issue near the site.

Table 11. Paducah, Distance-Based Results

(Notes: Metrics in columns 3-6 are values for the 3-mile radius zone indexed to the others with the exception of the population. A score of 50 means the value is the same as the comparison area. Values can range from 0 to 100. Those ≥75 are bolded, which means relatively high vulnerability in the 3-mile zone compared to the other areas.)

Indicators	Paducah 3-mile, actual values	Paducah 10-mile	McCracken County	State	U.S.
Population	1,927	45,503	65,284	--	--
Demographic					
Demographic index	20	44	37	38	29
People of color	2	9	6	15	3
Low-income population	38	56	51	52	64
Population with less than high school education	10	55	50	38	52
Population under 5 years of age	3	25	25	19	21
Population over 64 years old	16	40	42	55	59
Environment					
pm 2.5 in ug/m^3	9.14	49	49	**76**	69
Ozone, ppb	46	50	51	**96**	**76**
NATA diesel pm (ug/m^3)	0.263	40	36	39	<50
NATA cancer irks	29	48	47	34	<50
NATA respiratory hazard index	0.43	46	38	55	<50
Traffic proximity and volume	18	6	4	30	14
Lead paint indicator	0.17	38	32	53	49
Superfund proximity	0.21	**96**	**95**	**98**	**87**
RMP proximity	0.39	63	**92**	62	54

Hazardous waste proximity	0.22	18	10	42	27

Appendix F. Portsmouth Site (OH) Granular Scale Study

The Portsmouth, Ohio site is about 400 miles northeast of Paducah. Portsmouth and Oak Ridge further enriched uranium from Paducah. Named for the city of Portsmouth, the DOE site is about 25 miles from the city. The plant is near the intersection of the Ohio and Scioto rivers. Opened in 1956, its primary enrichment mission ended in 2001. Six decades after its opening, the site's future is unclear.

The closing of the middle school at Zahn's Corner adds to perception of an environmental issue. Population estimates were 222, 447, and 1,166 in the 1.5 mile, 2-, and 3-mile circles around the site, respectively. Like Paducah, the site has a small population of people of color living nearby and a relatively large proportion of poor and older residents. One difference between Paducah and Portsmouth is that the latter is not on the NPL, and therefore the EJScreen data base has little to say about Superfund.

The big gaps in this data is the absence of health outcomes and behavior data, as well as water quality information. All that can be said is that the host counties for Portsmouth had high rates of self-assessed poor or fair heath, as well a declining populations, high unemployment and low home values. These missing data surely would be valuable to an environmental justice assessment that appears to be grounded in low socioeconomic status and age. This site, in particular would benefit from the health metrics.

Table 12. Portsmouth, Distance-Based Results Granular Scale Study

(Notes: Metrics in columns 3-6 are values for the 3-mile radius zone indexed to the others with the exception of the population. A score of 50 means the value is the same as the comparison area. Values can range from 0 to 100. Those ≥75 are bolded, which means relatively high vulnerability in the 3-mile zone compared to the other areas.)

Indicators	Portsmouth 3-mile, actual values	Portsmouth 10-mile	Pike County	State	U.S.
Population	1,166	28,112	28,214	-	-
Demographic					
Demographic index	28	54	58	67	47
People of color	6	43	42	32	13
Low income population	51	59	59	**80**	**80**
Population with less than high school education	28	74	74	**93**	**86**
Population under 5 years of age	5	50	42	38	36
Population over 64 years old	23	64	68	**81**	**84**
Environment					
pm 2.5 in ug/m^3	8.24	50	50	1	38
Ozone, ppb	42.6	50	49	3	48
NATA diesel pm (ug/m^3)	0.193	49	49	7	<50
NATA cancer irks	26	50	50	62	<50

NATA respiratory hazard index	0.34	50	52	58	<50
Traffic proximity and volume	53	24	30	31	25
Lead paint indicator	0.32	57	62	47	64
Superfund proximity	0.02	53	63	16	17
RMP proximity	0.38	**97**	**97**	54	54
Hazardous waste proximity	0.38	**97**	**97**	25	34

Appendix G. Yakima City Illustration of Health Data at Granular Scale

The final example demonstrates the kinds of insights that might be gained if the CDC health data were available for the immediate DOE-EM-site-regions. Yakima county is the focus because of its demographic index of 89, which was the third highest among the 81 counties in the study. In comparison, Benton county's DI, which includes Kennewick, was 60. Kennewick is located closer to DOE's active facilities than Yakima, but still quite a distance south of them. Yakima County's population is estimated at 249,000 and Yakima City's as 94,000. Indexed to the state of Washington, the average demographic indicator of the city and county was 1.5% different, with the city's values lower in every case, with the exception of >64 years old. With regard to the 11 environmental indicators, the city had somewhat higher values than the county, not surprisingly especially for metrics associated with auto traffic and diesel particles since it is a city located primarily in a rural area and a main rail line runs through the area in a northeasterly direction.

The author picked three of the city's census tracts that include 22% of the city population as an illustration. One labeled "centereast" has the highest demographic values and the least favorable health outcomes and behaviors. The tract labeled "southwest" has lower demographic values and higher health outcomes and behaviors. The "northcentral" tract falls between the other two. In fact, the city appears to be divided along demographic lines by the railroad and route 12. Both move south to north along the east of the city and split in northern Yakima heading northeast and northwest.

The large Hispanic population concentrated to the east of the city is separated from the non-Hispanic White population located to the west. The American Indian population is located across the city but constitutes a small portion of the city population. The health data show that the best health outcomes and health behaviors are in the southwest census tract and worst in the centereast one, once again demonstrating the association of poverty and race/ethnicity on the one hand and health outcomes and behaviors on the other. The distance between Yakima City and DOE's active and cleanup sites at Hanford is over 60 miles, hence, these findings are not obviously useful to the DOE. However, the city is an illustration of a complex poverty and racial/ethnicity issue that involves not only the Yakima community but also the Latino/Hispanic one. The reader will note that many of the demographic values indexed to the state are above 75 (the highest quartile). The reality is that the DOE is heavily involved with the Yakima community in regard to Hanford. We feel that it would be quite interesting to have the same data base for Portsmouth, Paducah and Oak Ridge where information could be studied at a granular geographical scale as has been done for Yakima.

Table 13. Yakima, City and Census Tract Results

(Notes: All the data are actual values or indexed to the state*)

Indicator (population)	Yakima City	Census tract 53077000100 (3,170) centereast	Census tract 53077002802 (13,157) southwest	Census tract 5307700300 (4,366) centernorth
Demographic Index*	**87**	**97**	**77**	**90**
People of color*	**83**	**92**	74	**82**

Low-income population*	**84**	**98**	72	**92**
Linguistically isolated*	**84**	**95**	**81**	**77**
< High school education*	**92**	**97**	**84**	**95**
<5 years old*	73	53	**84**	**75**
>64 years*	65	13	43	33
% Hispanic	46	55	38	40
% Black	2	3	0	3
% American Indian	2	9	3	10
PM 2.5	88	89	87	89
Lead paint	79	96	71	65
Current smoking, ≥18 years old, 2014	20.2	26.6-30.2	17.4-20.2	17.4-20.2
Obesity, ≥18 years old, 2014	33.4	37.3-41.5	26.4-29.7	26.4-29.7
Current asthma, ≥18 years old, 2014	11.1	11.7-12.7	9.6-10.5	9.6-10.5
Physical health not good ≥14 days during last month	16.3	21.1-24.2	12.0-14.0	18.6-21.0
Lack of health insurance, 18-64 years old	25.6	36.4-55.6	10.3-15.0	25.2-30.5
Visit to doctor for routine checkup during last year, >18 years old	59.6	40.7-55.6	63.0-65.9	59.8-62.9